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Québec

OPTONIQUE

ISEQ INDUSTRIE DES SYSTÈMES ÉLECTRONIQUES DU QUÉBEC

Technum Québec

Developing Secure Microelectronic and Photonic Value Chains in Quebec

Summary Version

YOLE Group

SIA

Authors

Myrielle Robitaille
Managing Director, Sia
Energy, Industry and Transport
myrielle.robitaille@sia-partners.com

Mathieu Demoulin
Senior Supervising Consultant, Sia
Energy, Industry and Transport
mathieu.demoulin@sia-partners.com

Catherine Kallas
Senior Consultant, Sia
Energy, Industry and Transport
catherine.kallas@sia-partners.com

Aymen Ghorbel
Senior Analyst, Yole Group
Technology and Market Analyst
aymen.ghorbel@yolegroup.com

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Executive Summary

The purpose of this study is to help **position and develop Quebec's microelectronic and photonic industries,** along with the mineral, material and component industries that lie upstream and midstream of their value and supply chains to ensure the competitiveness of strategic industries (energy, defence, aerospace, electric vehicles, life sciences, etc.). Within these sectors, the analysis revealed **several distinctive niches** in which **Quebec could establish its leadership**.

A **cross-sectional analysis was carried out involving the microelectronic and photonic ecosystem both in Quebec and abroad.** The analysis mapped over **500 stakeholders** (approximately **one hundred of which are located in Quebec and Canada**), a summary of **over 150 reports and reference studies**, along with some **twenty interviews** with industrial and institutional stakeholders.

First and foremost, the analysis focused on **the entire microelectronic/photonic supply chain,** along with **more than 85 minerals and materials** involved in these sectors. An in-depth study focused on **13 segments of interest** and **15 critical and strategic minerals (CSM)** deemed relevant to the sector's **main business and research opportunities** in Quebec.

These 13 segments underwent a comprehensive analysis along four axes at the internationally and local levels: **Technological overview, market outlook, stakeholder identification, and local outlook.** Alongside this analysis, a study involving the 15 critical and strategic minerals focused on **geopolitical aspects, export restrictions, economic vulnerabilities and local production, along with refining and recycling potential.**

Finally, the study **highlighted seven (7) major themes that could help structure future discussions and initiatives: Critical mineral resources and the recovery of mining residues** (including urban mining), **value chain integration**, **collaborative R&D**, the issues regarding **industrial upscaling**, the creation of **strategic alliances** and, finally, the development of a culture that promotes **inter-sectoral links and synergies**.

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01

Introduction and Methodology

Background | Main Project Objectives (Recap)

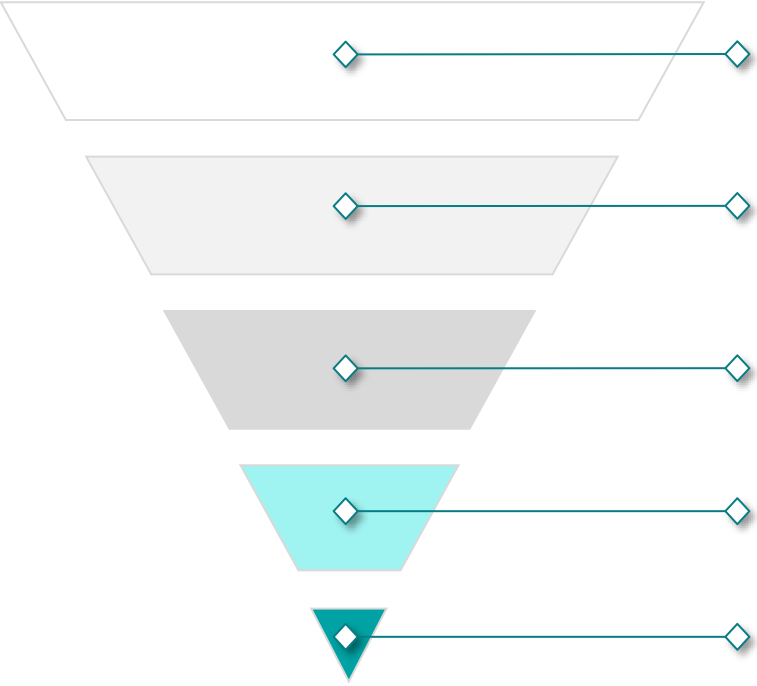
This project **seeks to further position and develop Quebec's microelectronic and photonic industries**, along with the upstream and midstream **mineral, material and component industries** within their value and supply chains. The objective is to **identify distinctive niches in which Quebec could establish its leadership**, thus benefiting its strategic industries (energy, defence, aerospace, electric vehicles, life sciences, etc.).

TO HELP MEET THIS OBJECTIVE, A NEW PARTNERSHIP WAS ESTABLISHED WITH THE FOLLOWING STAKEHOLDERS:

- **PRIMA Quebec**
- **Innovation, Science and Economic Development Canada** (ISED)
- **The ministère de l'Économie, de l'Innovation et de l'Énergie** (MEIE)
- **The ministère des Ressources naturelles et des Forêts** (MRNF)
- **The Technum Québec innovation zone**
- **The pôle d'excellence de l'industrie des systèmes électroniques du Québec** (ISEQ)
- **The pôle d'excellence Optonique**

THE SIA/YOLE GROUP CONSORTIUM WAS MANDATED TO CONDUCT THIS STUDY.

Methodology | Overview



PHASES	OBJECTIVES
1. Capitalizing existing resources and identifying of the scope *150+ cross-sectional studies*	• **To collect, assimilate and categorize** existing research; • **To define the scope** of the mandate;
2. Analyzing the international and local microelectronic/photonic ecosystem *7 interviews*	• **To outline** the dynamics and business opportunities involved; • **To position Quebec** along 13 segments: Companies, expertise, etc.;
3. Preselecting and analyzing the 13 segments of interest *100+ specialized reports, 13 interviews*	• **To develop high business intelligence** toward these 13 segments and Quebec's positioning;
4. Analyzing the materials and minerals used in microelectronics and photonics *85 elements studied*	• **To identify the available resources, strategic links** and potential levers regarding the materials used in microelectronics/photonics;
5. Drafting the analysis summary *Seven themes of interest*	• **To identify the main themes of interest** that require action.

Ecosystem Mobilization | Levers

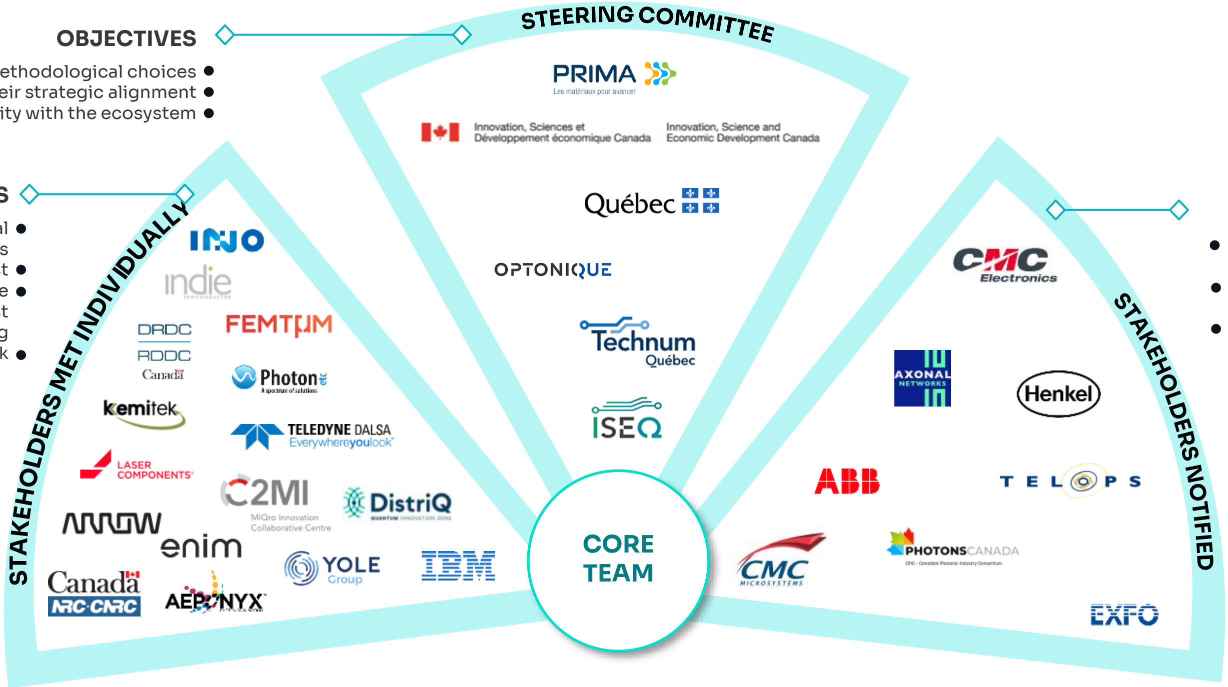
The approach was designed in collaboration with the ecosystem. Targeted interviews helped clarify certain segments while validating Quebec's contextual specificities. A **steering committee** was consulted throughout the study to help guide the methodological choices while ensuring their strategic alignment. Finally, **several stakeholders from the ecosystem were notified** of the ongoing analyses to help disseminate the findings.

OBJECTIVES

- Validate the methodological choices
- Ensure their strategic alignment
- Attract expertise and create proximity with the ecosystem

OBJECTIVES

- Identify major international, national and local trends
- Identify 13 segments of interest
- Validate the analysis regarding the 13 segments of interest
- Enhance the analyses regarding Quebec's outlook



OBJECTIVES

- Provide early access to work-related progress
- Align the work with the interim findings
- Mobilize the ecosystem around the study

02

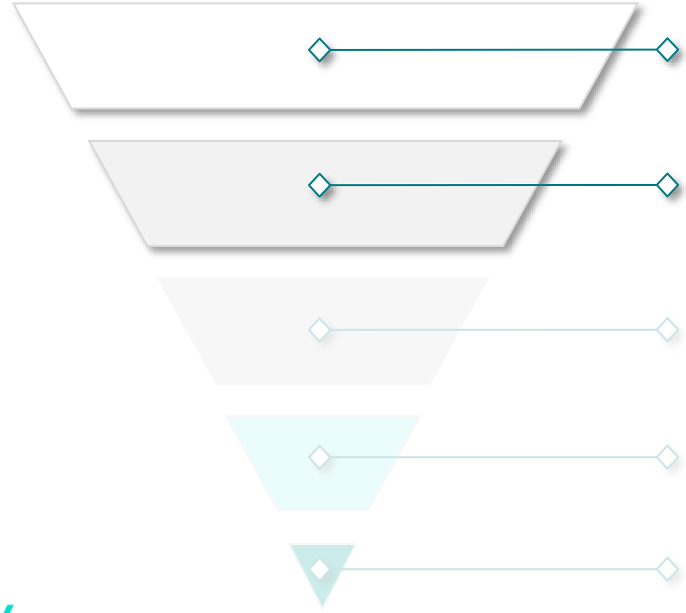
Major Trend Analysis

A. International Trends
B. Local Trends
C. Study Follow Up Impacts

Major Trend Analysis | Issues and Objectives (Recap)

The main objective is to **better understand and position Quebec within the global microelectronic/photonic ecosystem.** This requires an overall vision of the technological and industrial dynamics involved while defining the scope of the in-depth analysis and identifying 13 high-potential segments, without neglecting Quebec's expertise and industrial capabilities.

Link with the Overall Methodology



1. Capitalizing existing resources and identifying of the scope

2. Analyzing the international and local microelectronic/photonic ecosystem

3. Preselecting and analyzing the 13 segments of interest

4. Analyzing the materials and minerals

5. Drafting the analysis summary and strategic recommendations

MAIN ISSUES

- Conducting an analysis that is **sufficiently comprehensive to establish the initial priorities** while avoiding unnecessary details.
- **Anchoring the analysis in real-world conditions** by engaging directly with sectoral stakeholders.

SCOPE

- Geographical Scope - **International, Canada, Quebec.**
- Sectoral Scope - **All microelectronic and photonic value chains.**

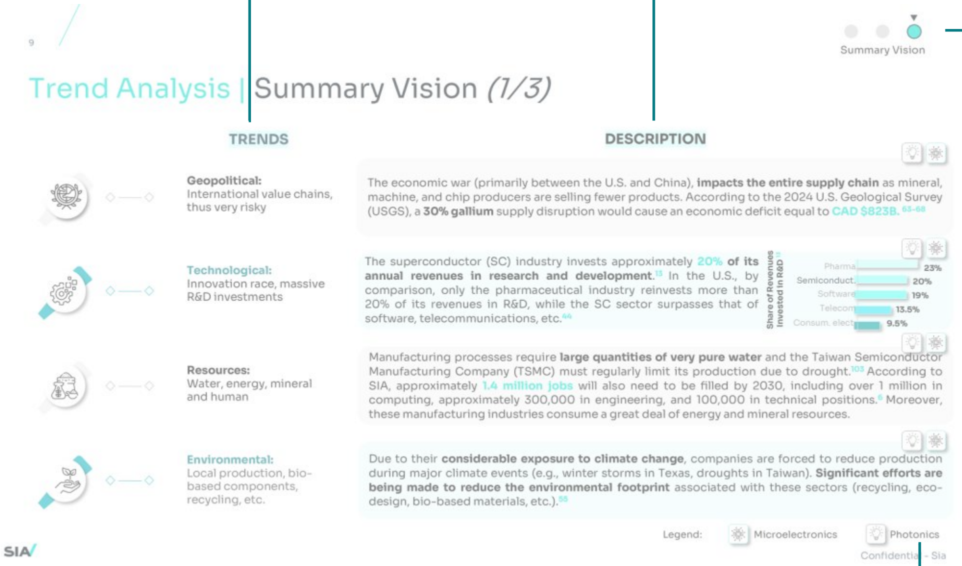
Trend Analysis | Reading Aid

A survey of the literature, including approximately one hundred reports/papers, along with the initial interviews, **helped identify 44 major trends** involving microelectronics and photonics **at the international and local levels.** The following section **summarizes 12 such trends**, each selected for their relevance and strategic contribution to the rest of the study.

Major trends/observations revealed by the literature survey and interviews

Description of the idea and analysis of several key data and ideas

Navigation aid



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Summary Vision

Trend Analysis | Summary Vision *(1/3)*

TRENDS	DESCRIPTION
Geopolitical: International value chains, thus very risky	The economic war (primarily between the U.S. and China), **impacts the entire supply chain** as mineral, machine, and chip producers are selling fewer products. According to the 2024 U.S. Geological Survey (USGS), a **30% gallium** supply disruption would cause an economic deficit equal to CAD $823B. [63-68]
Technological: Innovation race, massive R&D investments	The superconductor (SC) industry invests approximately 20% **of its annual revenues in research and development.**[13] In the U.S., by comparison, only the pharmaceutical industry reinvests more than 20% of its revenues in R&D, while the SC sector surpasses that of software, telecommunications, etc.[44]
Resources: Water, energy, mineral and human	Manufacturing processes require **large quantities of very pure water** and the Taiwan Semiconductor Manufacturing Company (TSMC) must regularly limit its production due to drought.[103] According to SIA, approximately 1.4 million jobs will also need to be filled by 2030, including over 1 million in computing, approximately 300,000 in engineering, and 100,000 in technical positions.[6] Moreover, these manufacturing industries consume a great deal of energy and mineral resources.
Environmental: Local production, bio-based components, recycling, etc.	Due to their **considerable exposure to climate change**, companies are forced to reduce production during major climate events (e.g., winter storms in Texas, droughts in Taiwan). **Significant efforts are being made to reduce the environmental footprint** associated with these sectors (recycling, eco-design, bio-based materials, etc.).[55]

Legend: Microelectronics Photonics

SIA

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Legend to identify specific microelectronic/photonic trends, or trends involving both

Trend Analysis | Summary Vision *(1/3)*

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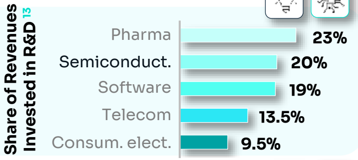


Legend: Microelectronics Photonics

Trend Analysis | Summary Vision *(2/3)*

TRENDS	**DESCRIPTION**
CSM **export restrictions**: Concrete impacts already observed	In August 2023, China imposed **export restrictions on gallium and germanium.** **98%** of refined gallium production comes from China, along with **68%** of germanium.[63-68] Five new critical minerals became subject to **export controls** from China in early 2025: **Tungsten, tellurium, bismuth, indium and molybdenum.** [72]
Quebec's CSMs are used for key products in these sectors	Quebec already mines or processes **several CSMs used in microelectronics and photonics**, such as indium (refining only), niobium, palladium, etc. Some pilot projects could help increase Quebec's potential. One example would include a gallium recovery project that is currently underway at Rio Tinto's Vaudreuil alumina plant. *These elements are detailed in Section 4, CSMs and Materials.*
Tensions are emerging in the **equipment manufacturing** sector	The United States, with support from the EU, Japan and other major stakeholders, reinforced export restrictions for advanced chip manufacturing equipment in 2023, which directly impacted Chinese companies like Huawei and SMIC. For example, Japan restricted the export of **23 types of semiconductor production machines** to China that year. [63-68]
Components used in **defence and military** applications are facing growing tensions	The International Traffic in Arms Regulations (ITAR) imposed restrictions on the export of defence-related technologies, including certain **semiconductors and manufacturing equipment.** This limits international trade with countries considered "U.S. national security risks." Exacerbated by the ITAR and its complex compliance framework, these geopolitical tensions are forcing certain countries to **develop "ITAR-free" alternatives** to reduce their dependence. [80]

Legend: Microelectronics Photonics

Trend Analysis | Summary Vision *(3/3)*

TRENDS	**DESCRIPTION**
CSMs as by-products of primary mineral mining	Most of the CSMs that are essential to the manufacturing of advanced components (gallium, germanium, indium, tantalum, tellurium, etc.) are, in fact, **by-products of the extraction and processing** of other minerals (zinc, aluminum, copper, etc.).[79] These CSM's are therefore dependent on the supply and demand of these primary minerals.
Quebec shows **tremendous mining potential**	Quebec is home to many resources, revealing a **significant potential for the production of gallium and germanium** through zinc/aluminum processing activities on its own territory.[79] However, these minerals are not consistently mined, since their **profitability has yet to be determined**. In addition, certain minerals processed in Quebec **do not stem from Quebec extraction sites, and vice versa**. This creates a loss in value.[79]
Recycling is necessary when diversifying the supply	Electronic component recycling must be scaled up, primarily with **suitable infrastructures**, which involves significant investments and a **rethinking of the value chain** to facilitate recycling from the product design stage in an effort to ease the collection, processing, and recovery activities that surround strategic materials. Furthermore, the lack of a **profitable business model** hinders its adoption.[38, 79]
Lack of a **regulatory framework to support** recycling	Despite the fact that Quebec currently considers mining by-products as mineral resources, **some production residues are still classified as "waste"**, which complicates their transport and reuse. For example, anodic sludges from copper refining contain tellurium and selenium but are classified as hazardous waste, hindering their recovery.[79]

Legend: Microelectronics Photonics

03

Detailed Segment Study

A. Preselection and Categorization of the 13 Segments

B. In-Depth Segment Analysis

Detailed Segment Study | Issues and Objectives (Recap)

The objective of this phase is to **carefully identify and study the most promising segments**. The concept is to conduct a comprehensive analysis to **better characterize the technologies involved, along with the R&D challenges, structures, market outlook and competitive environment**, among other factors, to help steer Quebec's strategic positioning choices.

Link with the Overall Methodology

1. Capitalizing existing resources and identifying of the scope

2. Analyzing the international and local microelectronic/photonic ecosystem

3. Preselecting and analyzing the 13 segments of interest

4. Analyzing the materials and minerals

5. Drafting the analysis summary and strategic recommendations

MAIN ISSUES

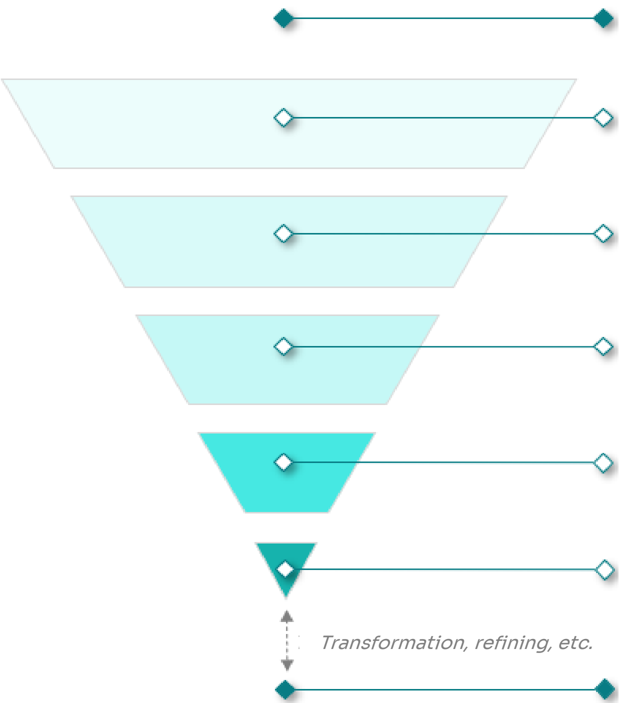
- Comprehensively exploring sectoral information, **focusing strictly on the extraction of high added-value elements.**
- **Conducting a cross-analysis of the results and the reality expressed by industry stakeholders** to consolidate and reorient the main findings.

SCOPE

- Geographical Scope – **International, Canada, Quebec**
- Sectoral Scope – **The 13 selected segments**

Selecting Segments of Interest | 13 Selected Segments

Based on the trends observed at the international and local levels, along with interviews with sectoral experts, **13 segments were selected due to their local relevance and alignment with existing capabilities**. These segments were analyzed in detail to identify business opportunities in Quebec.



DOWNSTREAM

Application sectors, sectoral structure, market, recycling, etc.

SYSTEMS

1. Laser systems
2. Imaging systems

MODULES

3. Printed circuits (rigid and flexible)

COMPONENTS

4. Semiconductor optical amplifiers
5. Semiconductor lasers
6. Photonic integrated circuits
7. Micro-electro-mechanical systems
8. Bio-based electronics
9. Compound semiconductors

TECHNOLOGICAL PLATFORMS

10. Packaging
11. Post-processing
12. Quantum

6. Photonic integrated circuits
13. Optical interconnection

MATERIALS (metals, chemicals, polymer-plastics, composites, etc.)

Section 4, CSMs and Materials

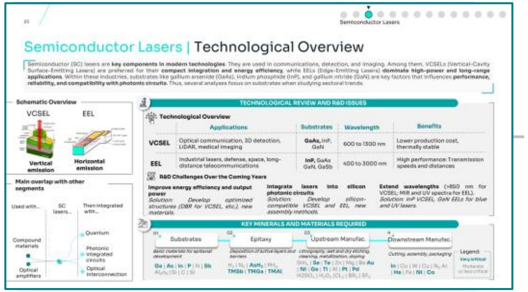
CRITICAL AND STRATEGIC MINERALS

Section 4, CSMs and Materials

Detailed Segment Analysis | Angles of Analysis

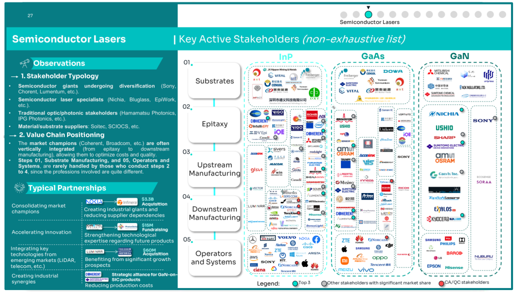
EACH SEGMENT WAS ANALYZED ALONG FOUR ANGLES OF ANALYSIS:

1. Technological Overview



Semiconductor Lasers | Technological Overview

3. Active Stakeholders

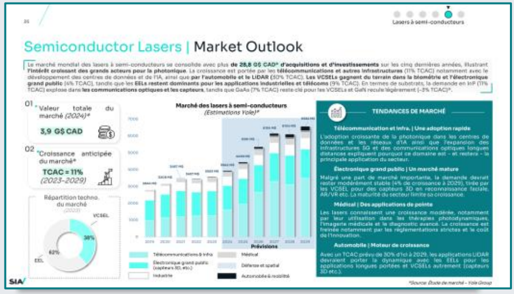


Semiconductor Lasers | Key Active Stakeholders *(non-exhaustive list)*

These elements are explained in detail for all 13 segments.

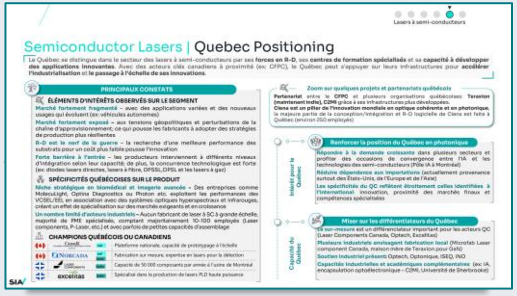
Complementary analyses regarding **Quebec's market outlook and positioning** have been grouped together at the end of the section (see below).

2. Market Outlook



Semiconductor Lasers | Market Outlook

4. Quebec Positioning

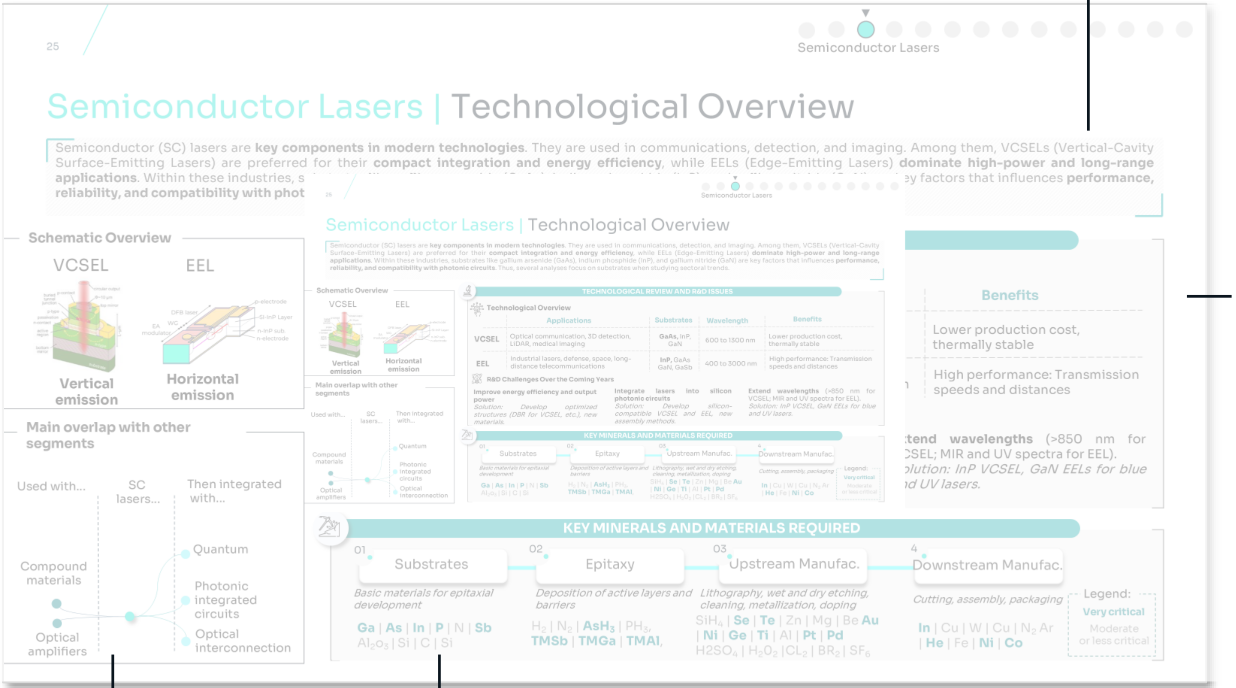


Semiconductor Lasers | Quebec Positioning

To provide a **concise summary and overview**, these analytical angles have been reworked and condensed into four slides for all segments. They conclude the section.

Segment Datasheets | Content and Reading Aid *(1/2)*

Overall description of the issues



Semiconductor Lasers | Technological Overview

Semiconductor (SC) lasers are **key components in modern technologies**. They are used in communications, detection, and imaging. Among them, VCSELs (Vertical-Cavity Surface-Emitting Lasers) are preferred for their **compact integration and energy efficiency**, while EELs (Edge-Emitting Lasers) **dominate high-power and long-range applications**. Within these industries, substrates like gallium arsenide (GaAs), indium phosphide (InP), and gallium nitride (GaN) are key factors that influences **performance, reliability, and compatibility with photonic circuits**. Thus, several analyses focus on substrates when studying sectoral trends.

Schematic Overview

Main overlap with other segments

TECHNOLOGICAL REVIEW AND R&D ISSUES

Technological Overview

	Applications	Substrates	Wavelength	Benefits
VCSEL	Optical communication, 3D detection, LiDAR, medical imaging	**GaAs,** InP, GaN	600 to 1300 nm	Lower production cost, thermally stable
EEL	Industrial lasers, defense, space, long-distance telecommunications	**InP,** GaAs GaN, GaSb	400 to 3000 nm	High performance: Transmission speeds and distances

R&D Challenges Over the Coming Years

Improve energy efficiency and output power
Solution: Develop optimized structures (DBR for VCSEL, etc.), new materials.

Integrate lasers into silicon photonic circuits
Solution: Develop silicon-compatible VCSEL and EEL, new assembly methods.

Extend wavelengths (>850 nm for VCSEL; MIR and UV spectra for EEL).
Solution: InP VCSEL, GaN EELs for blue and UV lasers.

KEY MINERALS AND MATERIALS REQUIRED

01 Substrates
Basic materials for epitaxial development
Ga | **As** | **In** | **P** | N | **Sb**
Al_2O_3 | Si | C | Si

02 Epitaxy
Deposition of active layers and barriers
H_2 | N_2 | **AsH_3** | PH_3,
TMSb | **TMGa** | **TMAl**,

03 Upstream Manufac.
Lithography, wet and dry etching, cleaning, metallization, doping
SiH_4 | **Se** | **Te** | Zn | Mg | Be **Au**
| **Ni** | **Ge** | **Ti** | Al | **Pt** | **Pd**
$H2SO_4$ | H_2O_2 | CL_2 | BR_2 | SF_6

4 Downstream Manufac.
Cutting, assembly, packaging
In | Cu | W | Cu | N_2 Ar
| **He** | Fe | **Ni** | **Co**

Legend:
Very critical
Moderate or less critical

Schematic technological overview

Technological review and related R&D issues
(maturity, benefits, etc.)

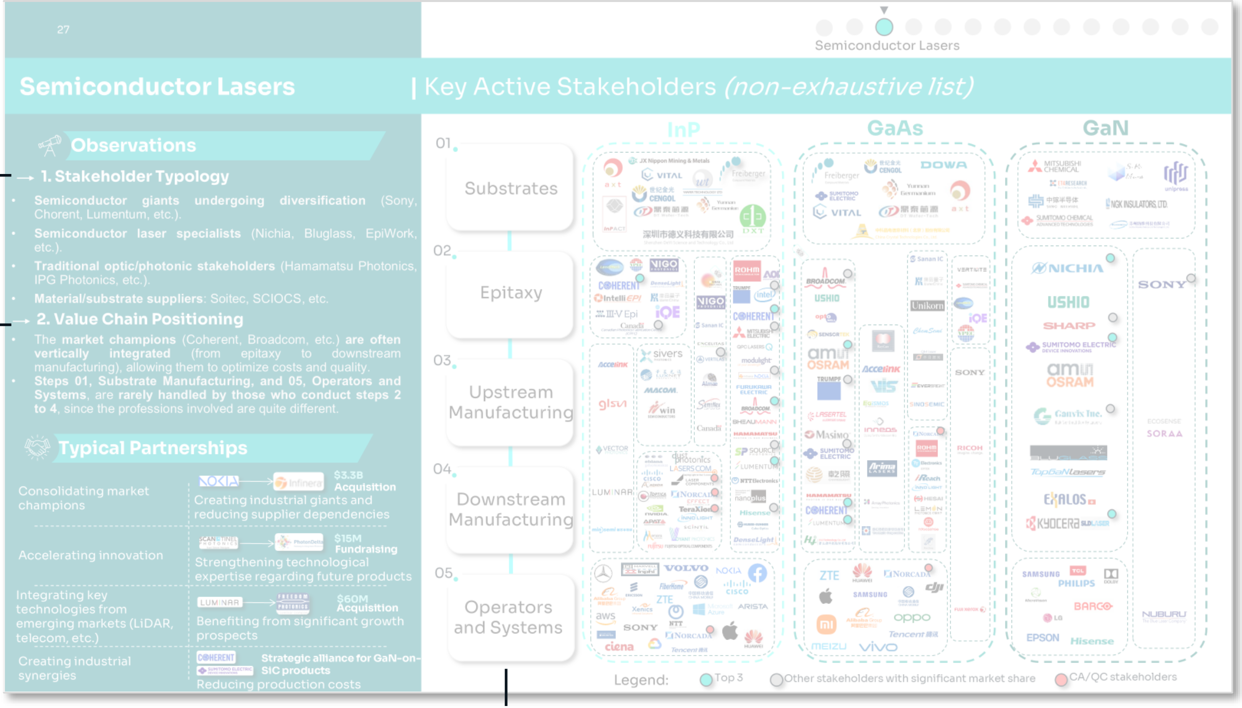
Integration and complementarity with other segments

Main critical and strategic minerals that make up the technology
A more detailed analysis appears in Section 4, CSMs and Materials

Segment Datasheets | Content and Reading Aid *(2/2)*

Active stakeholder typology
(core profession, etc.)

Value chain positioning
(vertical integration, specialization, etc.)



Semiconductor Lasers | Key Active Stakeholders *(non-exhaustive list)*

Observations

1. Stakeholder Typology

- **Semiconductor giants undergoing diversification** (Sony, Chorent, Lumentum, etc.).
- **Semiconductor laser specialists** (Nichia, Bluglass, EpiWork, etc.).
- **Traditional optic/photonic stakeholders** (Hamamatsu Photonics, IPG Photonics, etc.).
- **Material/substrate suppliers**: Soitec, SCIOCS, etc.

2. Value Chain Positioning

- The **market champions** (Coherent, Broadcom, etc.) **are often vertically integrated** (from epitaxy to downstream manufacturing), allowing them to optimize costs and quality.
- **Steps 01, Substrate Manufacturing, and 05, Operators and Systems**, are **rarely handled by those who conduct steps 2 to 4**, since the professions involved are quite different.

Typical Partnerships

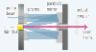
Consolidating market champions	**$3.3B Acquisition** Creating industrial giants and reducing supplier dependencies
Accelerating innovation	**$15M Fundraising** Strengthening technological expertise regarding future products
Integrating key technologies from emerging markets (LiDAR, telecom, etc.)	**$60M Acquisition** Benefiting from significant growth prospects
Creating industrial synergies	**Strategic alliance for GaN-on-SiC products** Reducing production costs

Typical partnerships
(acquisitions, industrial synergies, etc.)

Detailed description of stakeholders positioned in the supply chain
(components, systems, integration, packaging, etc.)

Laser Systems | Overview

In 2024, the global laser market reached an estimated value of **CAD $20.5B**. **Semiconductor lasers (notably VCSEL and diode) are undergoing considerable growth** driven by optical communications, AI, 3D sensors, and medical applications. Other technologies (fibre, CO_2, excimer, disk, LPSS) **remain essential for heavy industrial applications** (cutting, welding, photolithography), but **their growth has been moderate, particularly for CO_2 and excimer lasers**, as they face market maturity and technological competition.

Laser Type	Description	Illustration	Main Applications	Benefits	Disadvantage	Market Share	Evolution ($B)		CAGR
							2024	2029	*(2024-2029)*
Diode (EEL)	Current passing through a semiconductor junction, generating a beam. Very wide and dimmable.		Telecom, detection, medicine, quantum	Compact, dimmable, very wide	Heat, power limited by emitter	24%	3,6	5,5	8.7%
Fibre	Diode-pumped doped fibre producing a guided, powerful, and stable beam.		Heavy industry, medical, detection	Efficient, low maintenance, high power	Initial cost, sensitive to dirt	23%	3,5	4,3	4.2%
CO_2	Electrically excited CO_2 gas in a tube, generating a continuous or pulsed IR beam.		Cutting, welding, medical, lithography	Robust, low cost, good for non-metallic materials	Sensitive alignment, bulky	17%	2,5	3,0	3.7%
DPSSL	Diode that pumps a doped crystal emitting a coherent beam. Precise and compact		PCB, OLED, ultrafast medicine	Precision, compact, varied spectrum	Moderate cost, cooling required	12%	1,8	2,6	7.2%
Excimer	Noble-halogen gas excited by high-voltage discharge, producing powerful UV pulses.		Photolithography, screens, ophthalmology	Ultra-powerful in UV, ideal for microfabrication	Bulky, inefficient, expensive	9%	1,3	1,5	2.1%
VCSEL	Vertically emitted from a Bragg cavity integrated into the surface of a chip. Very compact and stackable.		Facial recognition, LiDAR, AR/VR, consumer electronics	Low power consumption, easy integration	Low unit power, limited spectrum	8%	1,1	2,0	11.6%
Disk	Thin doped disk pumped by diodes, reflecting light for amplification. Efficient cooling.		Self-soldering, fine cutting, LMD	Good thermal dissipation, beam quality	Complex optical system, high cost	4%	0,66	0,68	0.5%
LPSSL	Lamp that excites a doped crystal (e.g., Nd:YAG), generating a visible or IR beam. Used in aesthetics and sciences.		Dermatology, sensors, research	Simple design, high pulse energy	High maintenance, short lifespan	3%	0,43	0,56	5.2%
Other	Various technologies: Dyes, combs, QCL. Specialized sources used in spectroscopy, detection, and quantum technologies.		Gas detection, spectroscopy, metrology	Broad spectrum, scientific niches	High cost, limited market	1%	0,20	0,28	6.6%

Laser Systems | Non-Semiconductor Lasers

Non-semiconductor lasers (CO_2, fibre, excimer, disk) **are primarily used in heavy industry** (cutting, welding, marking), along with photolithography, defense, and research. **Their markets are stable and mature, with a slower growth than emerging semiconductor-based technologies**. **Quebec is well positioned in fibre lasers**, particularly in terms of research, telecommunication, material processing, and specialized stakeholders (MPB, Coractive, etc.).

Applications	Description	Fibre	CO_2	DPSSL	Excimer	Disk	LPSSL	Other
High-power material processing (kW)	Cutting and welding thick metals in the automotive and shipbuilding sectors, among others.	X	X			X		
Low-power material processing	Processing fine materials (films, plastics, ceramics), medical components (stents and implants).	X	X	X	X	X	X	X
Marking and engraving	Engraving on metal, plastic, and leather, marking on packaging, components, and luxury products.	X	X	X				
Photolithography	Etching integrated circuits in EUV/DUV microelectronic lithography processes.		X		X			
Optical pumping	Pump source for complex lasers (e.g., femtosecond and Ti:sapphire).							
Aerospace and defense	Directed-energy weapons, target designation, telemetry, and military sensors.	X		X		X	X	X
Research and development (R&D)	Fundamental and applied research (physics, chemistry, biology, nonlinear optics, X-rays, and advanced diagnostics).	X	X			X		X
Medicine and aesthetics	Dermatology (hair removal and vascular lesion treatment), ophthalmology, dentistry, and laser surgery.	X	X	X	X		X	X

A FEW QC STAKEHOLDERS

MPB Communications - **Manufactures fibre lasers** and optical amplifiers. Markets: Long-distance telecom and space. Specialized in spectral stability and robustness in critical environments.

Osela - **Designs visible laser modules** for industrial vision and metrology. Specializes in structured projection and laser alignment in manufacturing environments.

ITF Technologies - **Supplies fibre laser components** (FBG and splitters). Markets: Telecommunications and OEM integrators. Strong capability for passive and active optical customization.

Coractive - **Manufactures doped fibres and CW/pulsed fibre laser.** Markets: Materials processing and research. Vertical integration with expertise in active fibres.

Femtum - **Develops specialized fibre optic lasers for semiconductor applications** (cleaning and correction). Targets integrated photonics markets (SiN, TFLN, AI, and data centers).

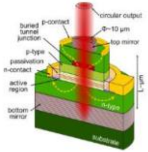
The remainder of the study will focus primarily on semiconductor lasers, which target high-growth, high-tech markets. Their industrial systems (CO_2, excimer, etc.) are less dynamic but more mature and standardized.

Semiconductor Lasers | Technological Overview

Semiconductor (SC) lasers are **key components in modern technologies**. They are used in communications, detection, and imaging. Among them, VCSELs (Vertical-Cavity Surface-Emitting Lasers) are preferred for their **compact integration and energy efficiency**, while EELs (Edge-Emitting Lasers) **dominate high-power and long-range applications**. Within these industries, substrates like gallium arsenide (GaAs), indium phosphide (InP), and gallium nitride (GaN) are key factors that influences **performance, reliability, and compatibility with photonic circuits**. Thus, several analyses focus on substrates when studying sectoral trends.

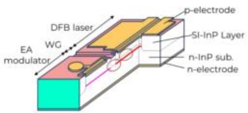
Schematic Overview

VCSEL



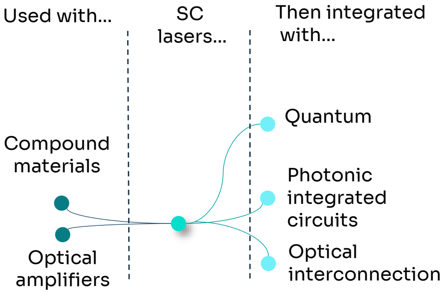
Vertical emission

EEL



Horizontal emission

Main overlap with other segments



TECHNOLOGICAL REVIEW AND R&D ISSUES

Technological Overview

	Applications	Substrates	Wavelength	Benefits
VCSEL	Optical communication, 3D detection, LiDAR, medical imaging	**GaAs,** InP, GaN	600 to 1300 nm	Lower production cost, thermally stable
EEL	Industrial lasers, defense, space, long-distance telecommunications	**InP,** GaAs GaN, GaSb	400 to 3000 nm	High performance: Transmission speeds and distances

R&D Challenges Over the Coming Years

Improve energy efficiency and output power
Solution: Develop optimized structures (DBR for VCSEL, etc.), new materials.

Integrate lasers into silicon photonic circuits
Solution: Develop silicon-compatible VCSEL and EEL, new assembly methods.

Extend wavelengths (>850 nm for VCSEL; MIR and UV spectra for EEL).
Solution: InP VCSEL, GaN EELs for blue and UV lasers.

KEY MINERALS AND MATERIALS REQUIRED

01 Substrates

Basic materials for epitaxial development

Ga | **As** | **In** | **P** | N | **Sb**
Al_2O_3 | Si | C | Si

02 Epitaxy

Deposition of active layers and barriers

H_2 | N_2 | **AsH_3** | PH_3,
TMSb | **TMGa** | **TMAl**,

03 Upstream Manufac.

Lithography, wet and dry etching, cleaning, metallization, doping

SiH_4 | **Se** | **Te** | Zn | Mg | Be
Au | **Ni** | **Ge** | **Ti** | Al | **Pt** | **Pd**
$H2SO_4$ | H_2O_2 |CL_2 | BR_2 | SF_6

4 Downstream Manufac.

Cutting, assembly, packaging

In | Cu | W | Cu | N_2
Ar | **He** | Fe | **Ni** | **Co**

Legend:
Very critical
Moderate or less critical

Semiconductor Lasers | Key Active Stakeholders *(non-exhaustive list)*

Observations

→ 1. Stakeholder Typology

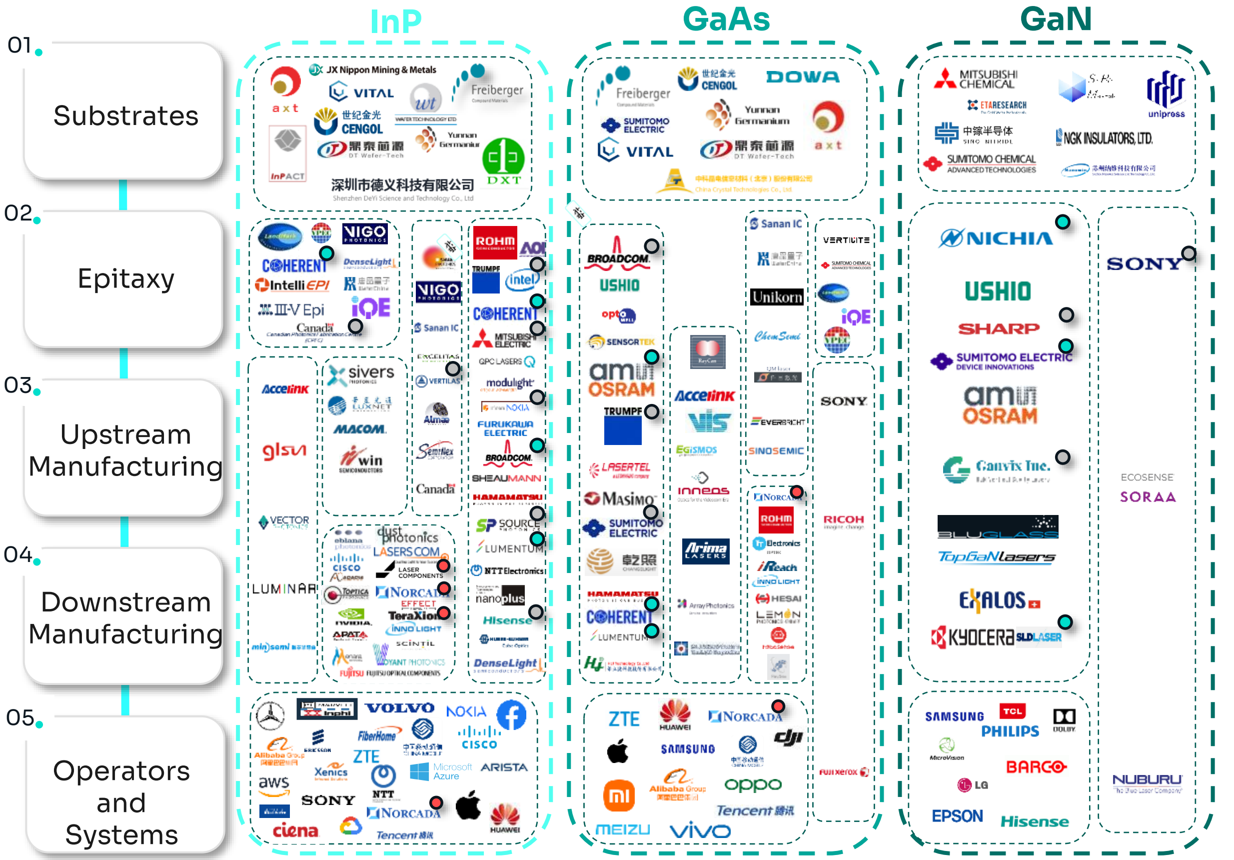
- **Semiconductor giants undergoing diversification** (Sony, Chorent, Lumentum, etc.).
- **Semiconductor laser specialists** (Nichia, Bluglass, EpiWork, etc.).
- **Traditional optic/photonic stakeholders** (Hamamatsu Photonics, IPG Photonics, etc.).
- **Material/substrate suppliers**: Soitec, SCIOCS, etc.

→ 2. Value Chain Positioning

- The **market champions** (Coherent, Broadcom, etc.) **are often vertically integrated** (from epitaxy to downstream manufacturing), allowing them to optimize costs and quality.
- **Steps 01, Substrate Manufacturing, and 05, Operators and Systems**, are **rarely handled by those who conduct steps 2 to 4**, since the professions involved are quite different.

Typical Partnerships

Consolidating market champions	NOKIA → Infinera **$3.3B Acquisition** Creating industrial giants and reducing supplier dependencies
Accelerating innovation	SCANTINEL PHOTONICS → PhotonDelta **$15M Fundraising** Strengthening technological expertise regarding future products
Integrating key technologies from emerging markets (LiDAR, telecom, etc.)	LUMINAR → FREEDOM PHOTONICS **$60M Acquisition** Benefiting from significant growth prospects
Creating industrial synergies	COHERENT, SUMITOMO ELECTRIC **Strategic alliance for GaN-on-SiC products** Reducing production costs

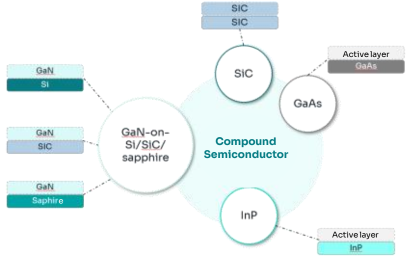


Legend: ● Top 3 ● Other stakeholders with significant market share ● CA/QC stakeholders

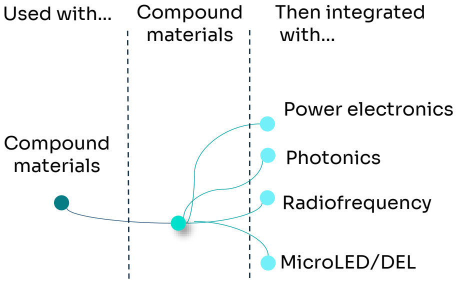
Compound Semiconductors | Technological Overview

The race for performance in the semiconductor industry **drives continuous innovation**. With regard to materials, compound semiconductors help improve component performance within various sectors that are traditionally based on silicon. **Certain compound materials, like GaAs or GaN, are not new.** GaAs has been used in the radiofrequency and photonic sectors for decades. GaN-on-sapphire has seen widespread adoption in LEDs and has also been used in radiofrequency applications for the past 20 years, primarily in the form of GaN-on-SiC, which was initially used in defense, then in telecommunications. More recently, **materials like SiC and GaN-on-silicon** have spurred significant innovations in the power sector, promising widespread adoption in the coming years.

Schematic Overview



Main Overlap with Other Segments


Used with... | Compound materials | Then integrated with...

Compound materials

- Power electronics
- Photonics
- Radiofrequency
- MicroLED/DEL

TECHNOLOGICAL REVIEW AND R&D ISSUES

	Applications	Active layer	Active layer	GaN	GaN	GaN	SIC	Active layer
		GaAs	InP	Saphir	SIC	Si	SIC	GaN
Photonics	**EEL**	[⚙]	[⚙]					[⚙]
	VCSEL	[⚙]	⚙					🔬
	LED *Screen and Light*	[⚙]	⚙	[⚙]	⚙	🔬		🔬
	RF	[⚙]	⚙		[⚙]	⚙		
	Puissance	🔬		⚙		[⚙]	[⚙]	🔬

LEGEND

⚙ In production

🔬 In development

[ ] Primary application of this material among other established compound SCs.

KEY MINERALS AND MATERIALS REQUIRED

01 Substrates

Basic materials for epitaxial development

Ga | **As** | **In** | **P** | N | **Sb**
Al_2o_3 | Si | C | Si

02 Epitaxy

Deposition of active layers and barriers

H_2 | N_2 | **AsH_3** | PH_3,
TMSb | **TMGa** | **TMAl**,

03 Upstream Manufac.

Lithography, wet and dry etching, cleaning, metallization, doping

SiH_4 | **Se** | **Te** | Zn | Mg | Be
Au | **Ni** | **Ge** | **Ti** | Al | **Pt** | **Pd**
$H2SO_4$ | H_2O_2 | CL_2 | BR_2 | SF_6

4 Downstream Manufac.

Cutting, assembly, packaging

In | Cu | W | Cu | N_2
Ar | **He** | Fe | **Ni** | **Co**

Legend:
Very critical
Moderate or less critical

Compound Semiconductors | Key Active Stakeholders *(non-exhaustive list)*

Observations

This segment includes the following **four stakeholder typologies**:

- **Vertically integrated stakeholders** (Wolfspeed, etc.): These produce their own substrates and seek self-sufficiency, particularly for SiC power electronics. They also supply substrates to third parties.
- **Suppliers dedicated to specialized or semi-specialized substrates:** Stakeholders like Sumitomo cover several materials (GaAs, InP, SiC), while others are more specialized (Freiberger for InP).
- **Epitaxy stakeholders that are moving toward substrates** (IQE, Soitec, etc.): These capture more upstream value by supplying complete wafers.
- **Device manufacturers** (not shown) **that depend on third-party suppliers:** They do not directly produce substrates but focus on the design and manufacturing of finished modules.

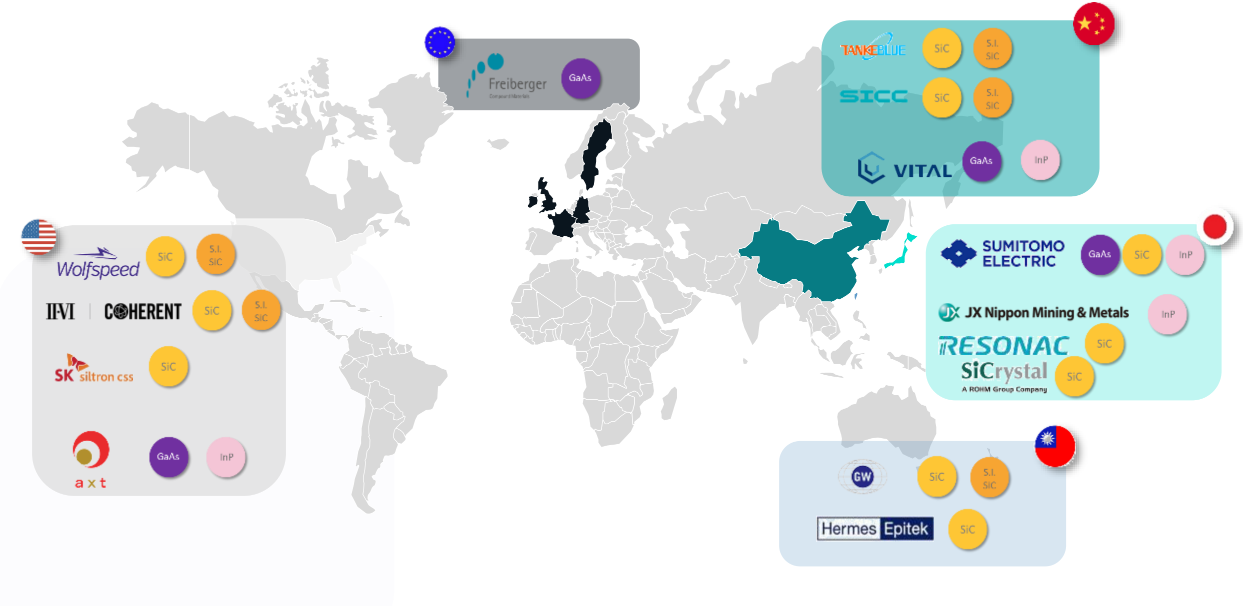
Typical Partnerships

Securing supplies	SICC **$115M Agreement** Signed a 2024-2026 supply agreement worth $110M with a Chinese stakeholder
Integrating key technologies from emerging markets	infineon GaN Systems **$1,140M Acquisition** GaN system acquired by Infineon
Creating industrial synergies	SK siltron IQE GLOBALFOUNDRIES **Strategic alliance for GaN-on-SiC products** Reduce production costs

Main International Substrate Producers

This map shows the main international stakeholders involved in the production of **crystalline substrates** for **SiC, GaAs,** and **InP** compound semiconductors.

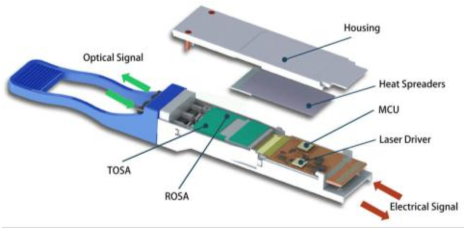
The map focuses on the **upstream portion of the supply chain** (downstream stages like epitaxial growth, active component manufacturing, and circuit/module integration are covered in other segments of this sectoral analysis).



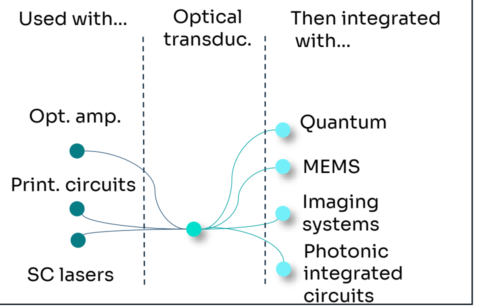
Optical Transducers | Technological Overview

By converting electricity into light and vice versa, optical transducers play an essential role in high-speed data transmission. They are a key component in the digital infrastructures used for telecommunications, data centres (DataCom), and hardware components. They can meet long-distance transmission needs in the telecommunications sector (>100 km) **with coherent and complex technologies.** Conversely, DataCom focuses on **short-range transmissions and has undergone considerable growth with the development of AI and data infrastructures.** The telecom market. **The analysis will focus on the promising DataCom sector, with its greater stability and maturity.**

Schematic Overview



Main Overlap with Other Segments



TECHNOLOGICAL REVIEW AND R&D ISSUES

DataCom.
Telecom

Technological Overview

	Optical Interfacing	**Active Optical Cables (AOC)**	**Ethernet**	Fibre-to-the-Home	Wireless	Multi/Wavelength Multiplexing
Applications	Board-to-board or chip-to-chip	Intra-rack	Inter-rack	Fibre-to-the-home access	Network 5G/6G	Long-distance telecom network
Range	1-3 cm	3-50 m	50m-10 km	<100 km	10-200 km	100-800 km
Lasers	CW-DFB	VCSEL/CW-DFB	EML/DML/CW-DFB	DML/ EML	EML	Based on InP

R&D Challenges Over the Coming Years

Reduce overall energy consumption
Solution: Use linear pluggable optics (LPO) to limit the digital signal processing chip's consumption, new and more efficient materials (TFLN, BTO).

Reduce latency and simplify integration.
Solution: Develop co-packaged optics (CPO) and integrated optical interfaces, reducing distances to a few centimetres.

Achieve rates above 200G/line
Solution: Optimize the channel signal (SerDes 224G), optimized EML/CW-DFB lasers, packaging innovations.

KEY MINERALS AND MATERIALS REQUIRED

01 Photonic Components
Lasers, TOSA, ROSA, Connectors, etc.
Similar to semiconductor lasers
Ga | **As** | **In** | **P** | **Ge** Al_2O_3 | Si | C | Si

02 Electronic Components
DSP, TIA, LD driver, LA, etc.
Si | **Y** | **Ge** | **Er** | Cu | **Au** | **Sb** | **Se** | S | Hf | **Ni** | **Co** | H_2SO_4 | S | CL_2 | BR_2 | SF_6

03 Optical Transducers
Final solution integration
Al | N | F | Cu | N_2 Ar | **He** | Fe | **Ni** | **Co**

Legend:
Very critical
Moderate or less critical

Optical Transducers | Key Active Stakeholders *(non-exhaustive list)*

Observations

→ 1. Stakeholder Typology

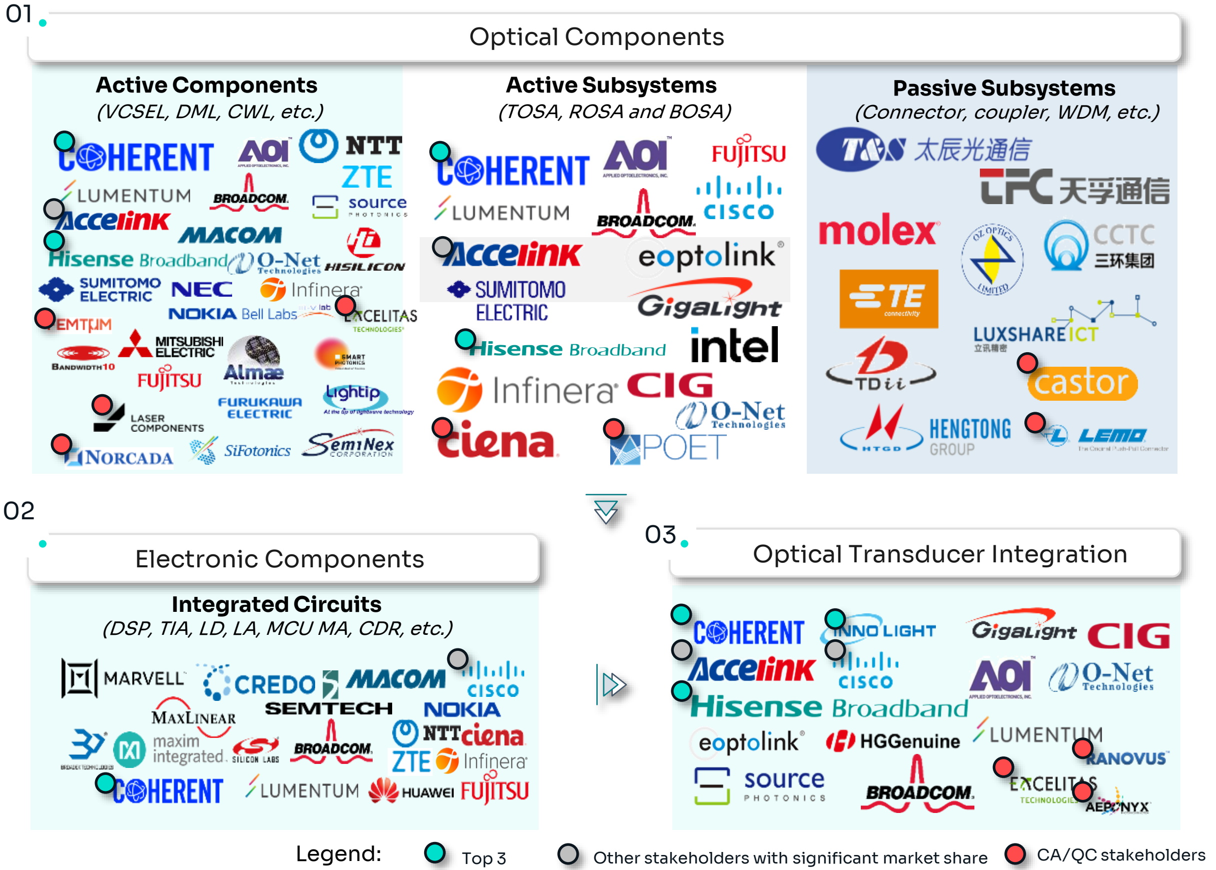
- **Fully integrated champions** (Coherent, Broadcom, Lumentum, AOI, etc.).
- **Specialists in active and passive subassemblies:** Key players in subsystem production, often involved in subcontracting.
- **Suppliers of specialized elementary components** (lasers and photodetectors).
- **Assemblers/integrators:** Frequent white labelling.

→ 2. Value Chain Positioning

- Major stakeholders (Coherent, Lumentum, etc.) **integrate the entire value chain** to optimize costs, accelerate time to market, and consolidate their position in strategic markets. This helps maintain **a degree of opacity regarding the final processing and testing stages**, thus preserving technological sovereignty.
- **Smaller suppliers focus on design and innovation**, abandoning low-margin stages (e.g., assembly and testing <20% margin).

Typical Partnerships

Consolidation of market champions	LUMENTUM → NeoPhotonics **$918M Acquisition** Supply chain expertise and upscaling
Access to new vertical markets	Alphawave → BANIAS **N/A Acquisition** Penetrating new segments (data centres, AI, etc.)
Synergies around mixed platforms	MARVELL → Inphi **$10B Acquisition** Offering CPO or linear technologies

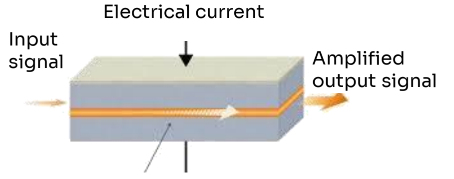


Legend: ● Top 3 ○ Other stakeholders with significant market share ● CA/QC stakeholders

SC Optical Amplifiers | Technological Overview

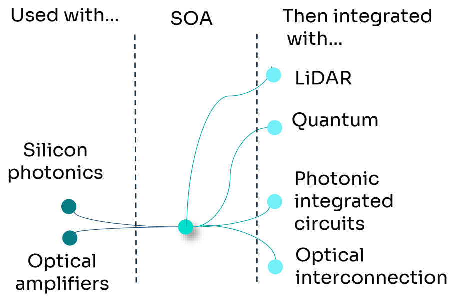
A semiconductor optical amplifier is an **optoelectronic device** generally based on **GaAs or InP compound semiconductor materials** that can **amplify a light signal without converting it to an electrical signal.** When current is injected, the physical properties of GaAs and InP amplify the signal by stimulating photon emission. This device is used for **telecommunications in particular, amplifying signals within fibre optic networks, integrated photonics, and detection systems, including LiDAR.**

Schematic Overview



Semiconductor Optical Amplifiers

Main Overlap with Other Segments



TECHNOLOGICAL REVIEW AND R&D ISSUES

Technological Overview

	Wavelength	Applications	Substrates	Benefits
Amplification by stimulated emission	1200-1700 nm	Telecommunications (fibre optic networks)	InP	Wide bandwidth, compatible with WDM networks. Issue: Noise reduction
Use of quantum wells	1300-1550 nm	Integrated photonics	InGaAs/InP/GaAs	High gain, low power consumption for integrated applications
Controlled polarization	850-980 nm (LiDAR, 3D sensors)	LiDAR systems (detection and telemetry)	GaAs	Compact, integrable into optoelectronic systems like LiDAR

R&D Challenges over the Coming Years

Noise reduction and gain improvement
Solutions: Optimize quantum well structure design and confinement techniques to maximize optical gain while reducing noise and phase distortion.

Polarization and crosstalk
Solutions: Sensitivity to polarization and crosstalk in multiband applications (e.g., LiDAR, WDM) requires advanced designs to stabilize performance.

Bandwidth
Solution: For 5G/6G networks, SOAs must cover wider bands, requiring innovations in materials and structures.

KEY MINERALS AND MATERIALS REQUIRED

01 Substrates

Basic materials for epitaxial development

Ga | **As** | **In** | **P** | N | **Sb**
Al_2o_3 | Si | C | Si | Zn | S

02 Epitaxy

Deposition of active layers and barriers

H_2 | N_2 | **AsH_3** | PH_3,
TMSb | **TMGa** | **TMAl**,

03 Upstream Manufac.

Lithography, wet and dry etching, cleaning, metallization, doping

SiH_4 | **Se** | **Te** | Zn | Mg | Be
Au | **Ni** | **Ge** | **Ti** | Al | **Pt** | **Pd**
H_2SO_4 | H_20_2 | Cl_2 | BR_2 | SF_6

4 Downstream Manufac.

Cutting, assembly, packaging

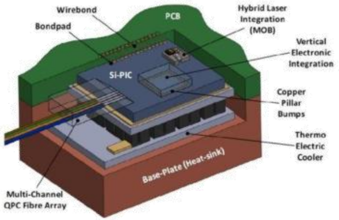
In | Cu | W | Cu | N_2
Ar | **He** | Fe | **Ni** | **Co**

Legend:
Very critical
Moderate or less critical

Photonic Integrated Circuits | Technological Overview

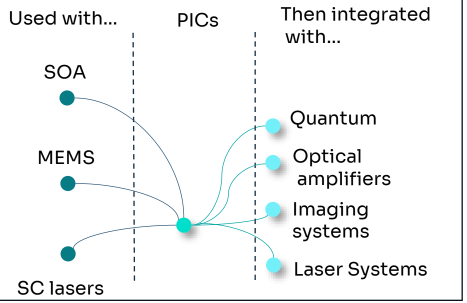
Photonic integrated circuits (PICs) **integrate several optical components** (lasers, modulators, detectors, waveguides, etc.) **on a chip when processing, transporting and analyzing light.** Unlike electronic circuits that rely on electrons, **these circuits use photons, offering low latency, high bandwidth and low consumption.** Based on technological platforms, each circuit comes with its own materials and characteristics: **SOI (CMOS and InP compatible) allows the full integration of lasers in particular, but it remains expensive, SiN provides low loss but no modulation, and LNOI offers fast and efficient modulation but remains immature.** Their adoption is accelerating with the rise of AI, data centres and large-scale production capabilities.

Schematic Overview



courtesy of Tyndall National Institute (Ireland) and SPIE

Main Overlap with Other Segments



TECHNOLOGICAL REVIEW AND R&D ISSUES

Technological Overview

Technological Platforms

InP	SiN
SOI	LNOI

Photonic Functional Blocks

LASERS	MODULES	PHOTODIODE	WAVEGUIDE
InP lasers	Si MZ/MRM TFLN BTO Polymer EA InP modulator	SiGe Ge InGaAs	SiN Si SiO_2

R&D Challenges over the Coming Years

Optical component miniaturization and densification
Solutions: Optimize packaging design, reduce unused Si surface, high-efficiency modulation, and new materials (SiGe, BTO).

Scaling up to 200-400G/λ
Solutions: Integrate TFLN, BTO or polymer modulators on SOI, optimize SerDes 224G, use co-packaged optics with ELS for heat dissipation.

Delay in the characterization and testing process
Solutions: Develop optical test benches, optical interface standardization to accelerate testing, automated active alignment tools.

KEY MINERALS AND MATERIALS REQUIRED

01 Substrates

Basic materials for epitaxial development

Ga | **As** | **In** | **P** | N | **Sb**
Al_2O_3 | Si | C | Si | $LiNbO_3$ |
$BaTiO_3$ | Ge

02 Epitaxy

Deposition of active layers and barriers

H_2 | N_2 | **AsH_3** | PH_3,
TMSb | **TMGa** | **TMAl**,

03 Upstream Manufac.

Lithography, wet and dry etching, cleaning, metallization, doping

SiH_4 | **Se** | **Te** | Zn | Mg | Be
Au | **Ni** | **Ge** | **Ti** | Al | **Pt** | **Pd**
H2SO4 | H_2O_2 |CL_2 | BR_2 | SF_6

4 Downstream Manufac.

Cutting, assembly, packaging

In | Cu | W | Cu | N_2
Ar | **He** | Fe | **Ni** | **Co**

Legend:
Very critical
Moderate or less critical

Photonic Integrated Circuits | Key Active Stakeholders *(non-exhaustive list)*

Observations

1. Stakeholder Typology

- **Tech start-ups focused on PICs:** Ayar Labs, Lightmatter, Xanadu; stemming from universities or spin-offs .
- **Material or component suppliers:** Soitec, IQE, Sumitomo Electric and AXT.
- **Foundries:** Ligentec, TowerJazz, and GlobalFoundries.
- **Large telecom/optoelectronics groups:** Lumentum, Coherent, Broadcom, Cisco, and Huawei; established groups in optical components that design and manufacture PICs internally to increase performance and reduce costs.
- **Design and collaborative R&D specialists:** OpenLight and Luceda Photonics.

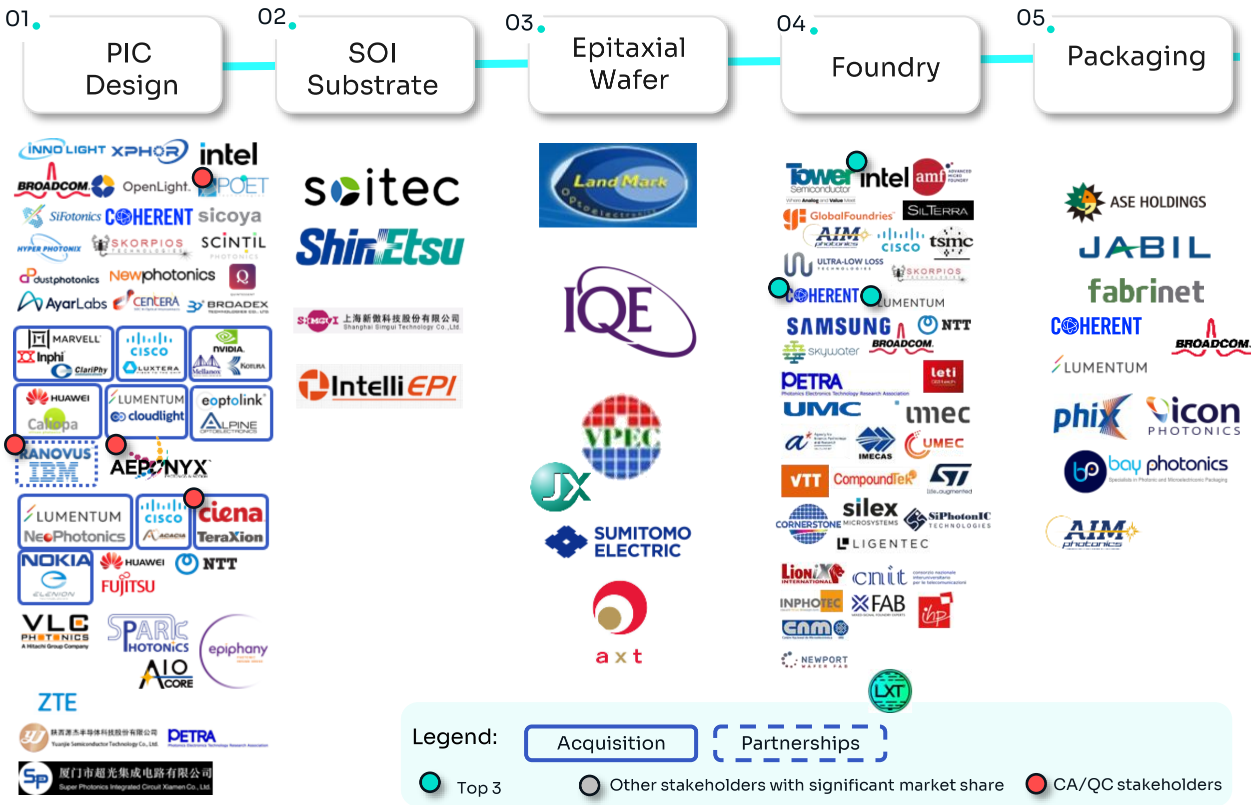
2. Value Chain Positioning

- The major stakeholders (Coherent, Lumentum, etc.) **integrate the entire chain, from design to assembly**, to control performance, costs and lead times, delivering ready-to-use modules.
- **Technological specialists:** IGE, PHIX, Openlight, etc.; positioned to excel in one segment of the chain (design, component, etc.).

Typical Partnerships

Consolidation of market champions	Cisco → Acacia Advanced photonic integration expertise (coherent)	$6.1B **Acquisition**
Co-development of solutions based on each stakeholder's expertise	Ranovus → IBM Odin co-development	N/A **Partnership**
Complete tech ecosystem development	Ciena → TeraXion Laser and filter integration into its coherent PICs.	$44M **Acquisition**

SOI Supply Chain *(Highest Maturity)*



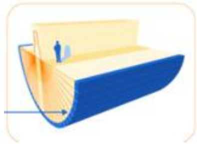
Legend: Acquisition ▭ Partnerships ▭

● Top 3 ● Other stakeholders with significant market share ● CA/QC stakeholders

Quantum | Technological Overview

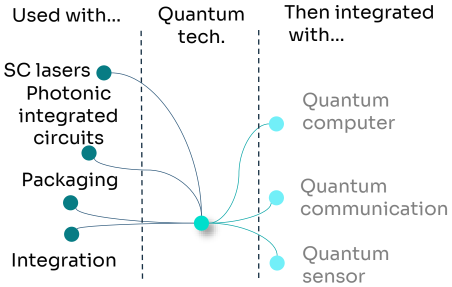
Quantum technologies lie at the **crossroads of key disciplines** like physics, engineering, advanced manufacturing, high-performance computing, telecommunications and cybersecurity. This convergence represents a **strategic driver of innovation**. Still in its **early stages**, this technology shows **considerable potential:** Strengthening communication security, exceeding classical supercomputer capacities, and providing ultra-precise sensors for various applications, including health, navigation and geosciences. Faced with a **growing need for computing power, precision and data protection**, enabling technologies like superposition and entanglement can pave the way to more powerful and resilient systems.

Schematic Overview



Quantum Module Tiles

Main Overlap with Other Segments



Used with...

Quantum tech.

Then integrated with...

SC lasers

Photonic integrated circuits

Packaging

Integration

Quantum computer

Quantum communication

Quantum sensor

TECHNOLOGICAL REVIEW AND R&D ISSUES

Overview of Various Quantum Computer Types

	Brief Description	Development Horizon	Typical Number of Qubits
Annealing	Optimization through quantum tunnelling	Today	Up to 5000+
Simulator	Direct imitation of quantum systems	Today	12 to approx. 100
NISQ	Noise-limited computation	5 to 10 years	50 to 500
FTQC	Universal computation with error correction	10 to 30 years	Millions
Emulator	Software simulation on classical computer	Today and 5 to 10 years	40 to 50

R&D Challenges Over the Coming Years

Quantum error correction
Solution: Reduce the number of physical qubits needed to obtain reliable logical qubits – an essential condition for fault-tolerant quantum computing.

Upscaling qubit platforms
Solution: No dominant type of qubit has yet emerged; efforts are focused on improving fidelity and coherence.

Communication, computing, and detection
Solution: Integrate quantum computing, communication, and detection into interoperable architectures that meet the concrete needs of industry.

KEY MINERALS AND MATERIALS REQUIRED

Neon | Si | **He** | Sapphire Plates | Rb | Rare Earths | Ca | Barium Isotopes

Main suppliers

Criticality
Low
Moderate or less critical
Unknown criticality

Quantum | Key Active Stakeholders *(non-exhaustive list)*

Observations

→ 1. Stakeholder Typology

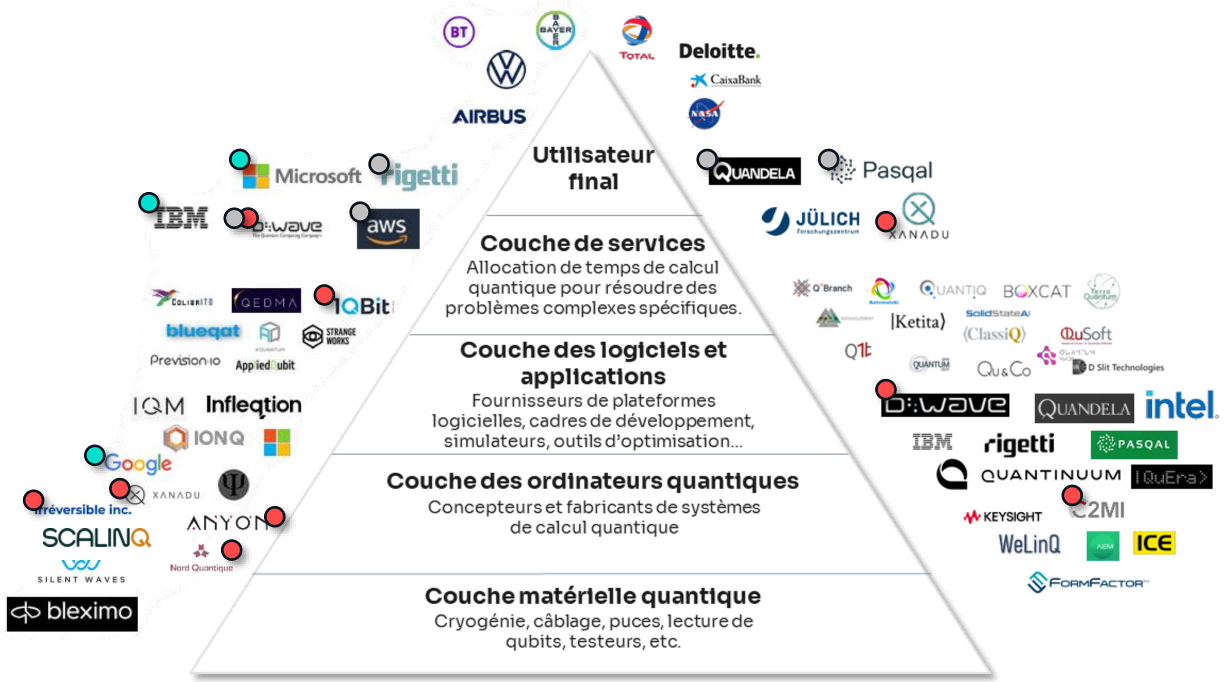
- **Traditional quantum stakeholders:** IBM and D-Wave were investing as early as the 2010s; multisegment presence to consolidate their pioneering roles.
- **Diversifying stakeholders:** Google, Amazon, Microsoft and Intel view quantum technology as a strategic extension of their traditional activities; anticipated technological disruptions.
- **Specialized stakeholders and integrated start-ups:** Start-ups (Pasqal, Xanadu and Quantinuum) have adopted a vertical approach from the outset; need to develop a proprietary end-to-end ecosystem to compensate for the lack of shared standards.
- **Strategic end-users:** Preparing their industrial transformation while co-developing tailored solutions.

→ 2. Value Chain Positioning

- **Strong hybridization of positions** – stakeholders active in several segments.
- **This multi-level integration** seeks to compensate for the lack of clear industry standards and ensure technological coherence while securing critical components in an effort to maximize value within a sector that continues to lack maturity.

Typical Partnerships

Vertical partnerships: Technology integration	PASQAL, Qubit, Atos Technology layer alignment
Public-private alliances: Catalyzing innovation	QUANDELA, cnrs QuantERA project
Usage case co-development: Learning by doing	AIRBUS, PASQAL, BMW Material simulation and industrial optimization



Utilisateur final

Couche de services
Allocation de temps de calcul quantique pour résoudre des problèmes complexes spécifiques.

Couche des logiciels et applications
Fournisseurs de plateformes logicielles, cadres de développement, simulateurs, outils d'optimisation…

Couche des ordinateurs quantiques
Concepteurs et fabricants de systèmes de calcul quantique

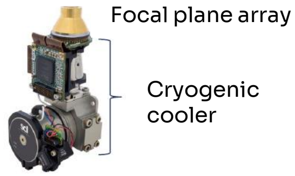
Couche matérielle quantique
Cryogénie, câblage, puces, lecture de qubits, testeurs, etc.

Legend: ● Top 3 ○ Other stakeholders with significant market share ● CA/QC stakeholders

Imaging Systems | Technological Overview

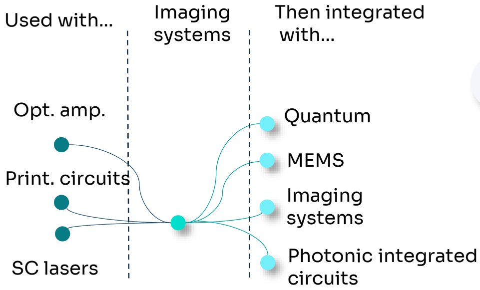
Imaging systems are used for **detection, visualization, and scene analysis** within various applications (medical, industrial, defence, automotive, etc.). An imaging system generally consists of **optical components** (filter, lenses, etc.), a **sensor** (photodiode, microbolometre, etc.), a **readout integrated circuit** (ROIC) and, in certain cases, a **cooling system**. These systems cover several ranges in the electromagnetic spectrum, from **infrared** (near, mid, and far – NIR, SWIR, MWIR, LWIR) to **X-rays**.This analysis **focuses primarily on IR**, a segment expected to experience rapid growth by 2029.

Schematic Overview

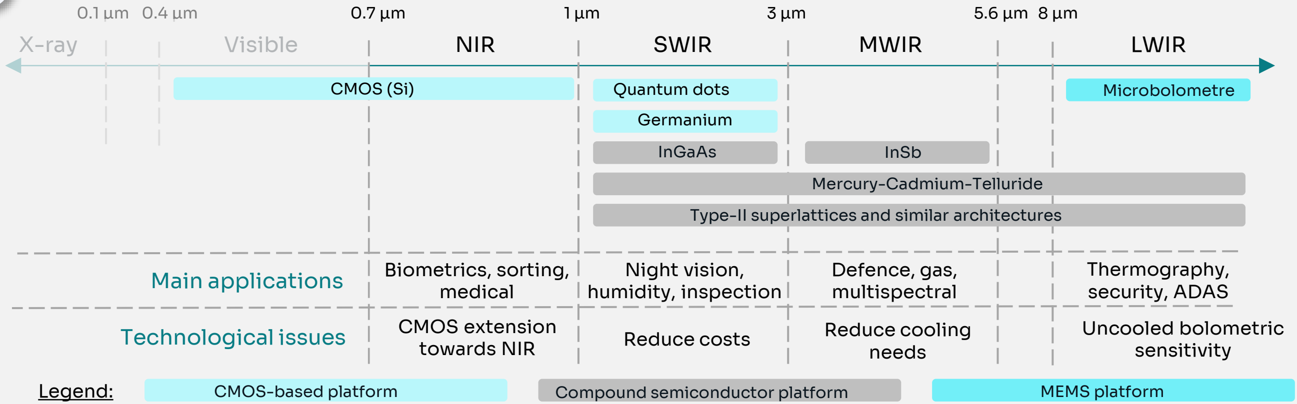


Sensor module + cooling

Main Overlap with Other Segments



TECHNOLOGICAL REVIEW AND R&D ISSUES



	NIR	SWIR	MWIR	LWIR
Main applications	Biometrics, sorting, medical	Night vision, humidity, inspection	Defence, gas, multispectral	Thermography, security, ADAS
Technological issues	CMOS extension towards NIR	Reduce costs	Reduce cooling needs	Uncooled bolometric sensitivity

Legend: CMOS-based platform | Compound semiconductor platform | MEMS platform

KEY MINERALS AND MATERIALS REQUIRED

01 Photonic Components

Lasers, TOSA, ROSA, Connectors, etc.

Similar to semiconductor lasers
Ga | **As** | **In** | **P** | **Ge** Al_2O_3 | Si | C | Si

02 Electronic Components

DSP, TIA, LD driver, LA, etc.

Si | **Y** | **Ge** | **Er** | Cu | **Au** | **Sb** | **Se** | S | Hf | **Ni** | **Co** | H_2SO_4 | S |CL_2 | BR_2 | SF_6

03 Optical Transducers

Final solution integration

Al | N | F | Cu | N_2 Ar | **He** | Fe | **Ni** | **Co**

Legend:
Very critical
Moderate or less critical

Imaging Systems | Key Active Stakeholders *(non-exhaustive list)*

Observations

→ 1. Stakeholder Typology

- **Traditional vertical integrators** (RTX, L3 Harris, BAE systems, etc.): Selling complete systems.
- **SWIR specialists, segmented by market.**
- **Microbolometre champions** (Teledyne Infraray and Hikmicro account for +60% of the market).
- **New technology developers:** Very active in R&D (TriEye, Germanium, SWIR Vision System and Emberion - quantum dots, etc.).

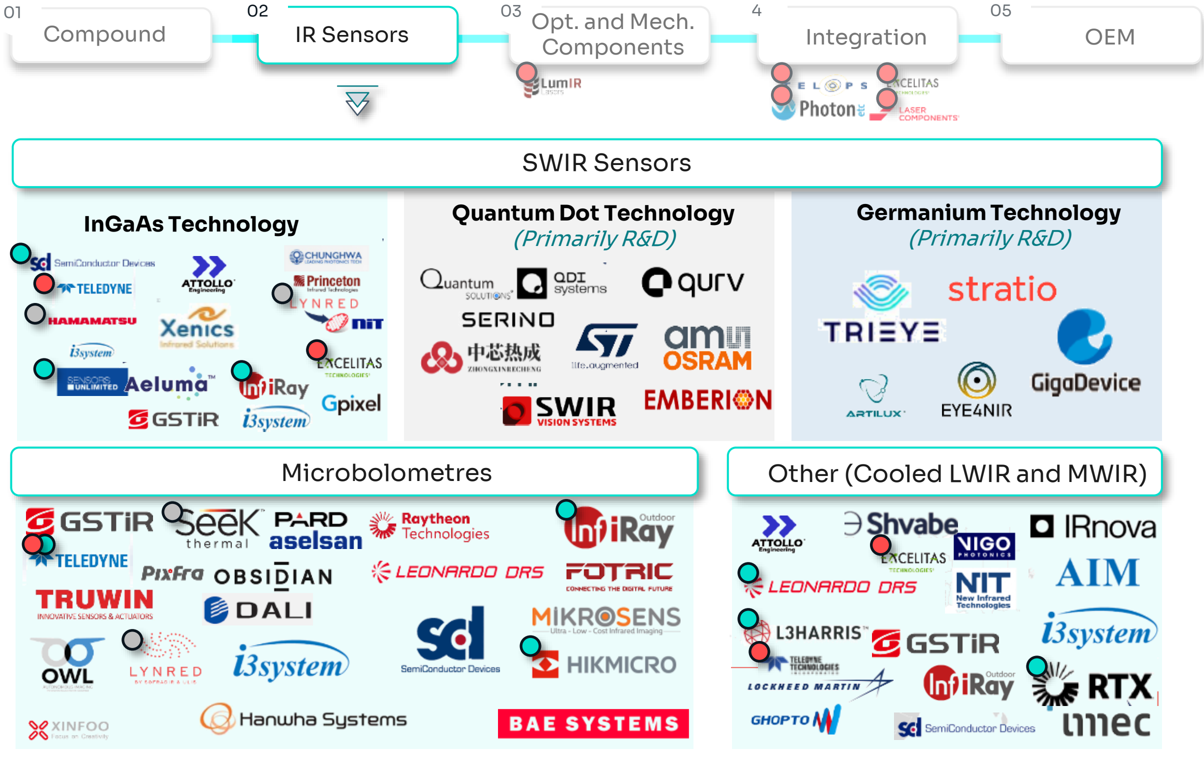
→ 2. Value Chain Positioning

- **Defence market stakeholders** (RTX, L3 Harris, etc.): **Tend to vertically integrate several production steps** for confidentiality reasons.
- Certain stakeholders **position themselves against several technologies** to broaden their range of sensors (Teledyne, Leonardo, etc.).

Typical Partnerships

Economic partnerships to develop R&D and commercialization	TRIEYE → intel capital	$103M Fundraising	Access to financing helped commercialize its Ge technology – cheaper but less mature
Joint system integration	THALES → SAFRAN	N/A Joint venture	Co-creation of Lynred, then sensor integration into Thales systems (binoculars, visors, etc.) and Safran (turrets, naval applications, etc.)
Diversification and technological consolidation	onsemi → SWIR	N/A Acquisition	SWIR quantum dot technology integration into its CMOS sensors

NB: This analysis primarily focuses on infrared sensor manufacturers, who make up the bulk of the technological and commercial value associated with thermal cameras.

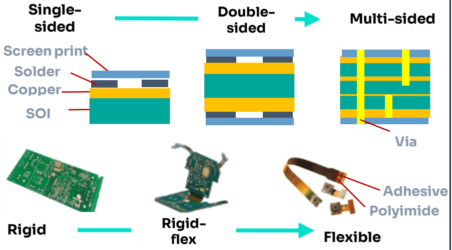


Legend: ● Top 3 ● Other stakeholders with significant market share ● CA/QC stakeholders

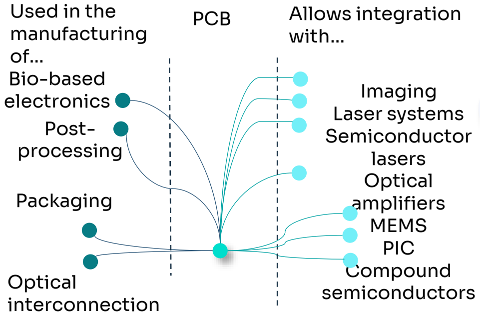
Printed Circuits | Technological Overview

Printed electronics provide a **complementary alternative to traditional microelectronics**, relying on low-temperature additive processes compatible with flexible, biodegradable, or plastic substrates. It provides a more flexible and local production that is less dependent on critical materials. Lacking the precision of microelectronics, it targets **emerging applications** like flexible sensors, smart textiles, and integrated photonics. It uses functional inks and innovative deposition techniques like aerosol jet or screen printing. It has a unique ability to meet specific, device-related needs like lightness, cost, and modularity.

Schematic Overview



Main Overlap with Other Segments



TECHNOLOGICAL REVIEW AND R&D ISSUES

Technological Overview

	Composition	Finish	Typical Applications	Key Advantages
Rigid circuit	FR4 substrate (epoxy resin and fibreglass), copper conductors	HASL, ENIG, etc.	Consumer electronics, computing, automotive	Robust, low cost, mature technology, well marketed
Rigid-flex circuit	Polyimide or polyester substrate, electrolytic or laminated copper	Primarily ENIG.	Phones, onboard cameras, aeronautics	Compact, reliable, fewer connectors
Flexible circuit	Stacking of rigid (FR4) and flexible (polyimide) layers	ENIG or flexible.	Mobile connectors, wearable devices, medical devices	Lightweight, malleable/foldable, vibration/shock resistant
Multilayer circuit	Multilayer FR4 or polyimide with micro-drills and buried vias	Various (HASL, ENIG and OSP)	Motherboards, networking equipment, satellites	High density, high electrical performance
High-frequency circuit	Special resins (BT and ABF) or polyimide, high-performance multilayers	ENI, OSP	Radar, 5G, embedded systems	Low dielectric loss, high precision

R&D Challenges Over the Coming Years

Miniaturization (densification)
Solution: Develop multilayer HDI PCBs with microvias, buried vias, and substrate-embedded components.

High-frequency compatibility (5G/6G)
Solution: Use low Dk/Df and more flexible materials, along with controlled-impedance interconnections to limit signal loss.

Thermal management and lifespan (reliability)
Solution: Integrate thermal vias and IMS substrates to effectively dissipate heat and enhance the reliability of high-density PCBs.

KEY MINERALS AND MATERIALS REQUIRED

	Substrates	Conductors	Finish	Vias/Metallization	Passive Components
	Si | Al | **Br** | **Sb** | Si | F ●	**Cu** | **Ag** | Au | Sn | Pb	**Ni** | Au | Sn | Co | Pb	**Cu** | Ni | Co | Pb	**Ta** ● | **In** ● | **Nd** ● | **Dy** ● | **Pr** ●
Chemistry	*Epoxy polymerization, fluoropolymers, polyimides*	*Electroforming, surface treatment (ENIG, ENEPIG), soldering*	*Flame-retardant resins, ENIG surface treatment (Ni+Au)*	*Electrodeposition*	*Cathode sputtering deposits*

Legend:
Very critical
Moderate or less critical
● Flex only

Printed Circuits | Active Stakeholders

Observations

1. Stakeholder Typology

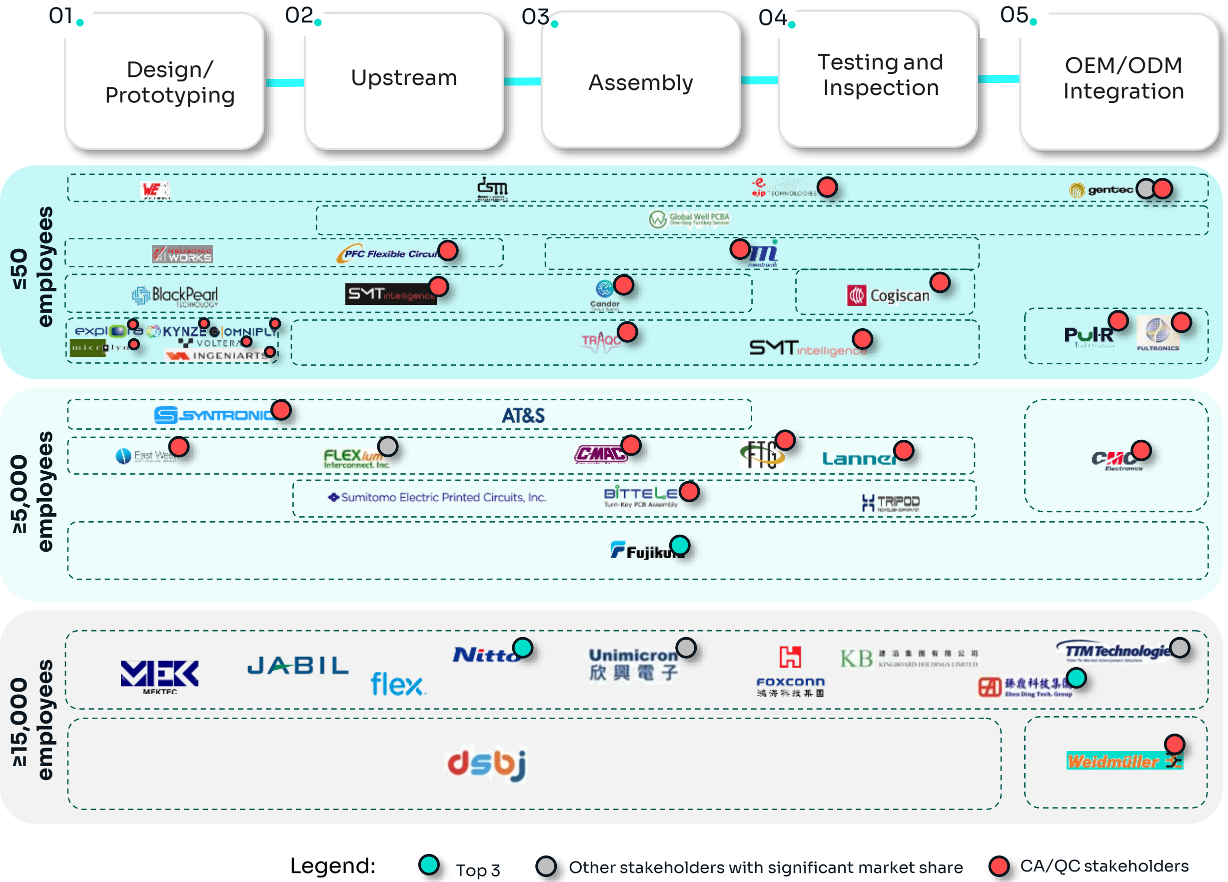
- **Versatile PCB manufacturers:** Directly produce printed circuits (rigid, flexible and rigid-flex). They operate on a large industrial scale (e.g., TTM Technologies, Unimicron, Jabil, etc.).
- **Assemblers/integrators:** Manage electronic component assembly on PCBs, often for third-party clients (e.g., Flexium, CMAC, BITTELE, etc.).
- **Specialized subcontractors:** Provide complementary and specialized services like small-batch manufacturing, complex component assembly, prototype design, PCB engineering and testing (e.g., Gentec, DSM, etc.).

2. Value Chain Positioning

- Some industry leaders like TTM, Jabil, and Unimicron **integrate all stages of the value chain** to reduce costs and time to market, or to increase confidentiality for sensitive clients (defense).
- SMEs like Cogiscan and SMT Intelligence are highly specialized, addressing the specific needs of high-value clients while offering greater flexibility in response to technological changes (e.g., transition to flexible PCBs for portable and embedded electronics).

Typical Partnerships

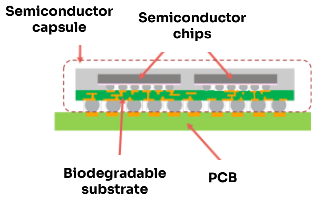
Strategic client-supplier partnership	Securing production capabilities	Unimicron tsmc
Technological and collaborative R&D partnership	R&D partnership to design fully adapted PCBs for a local market	TTM Technologies Panasonic
Vertical integration partnership (manufacturing and assembly)	Alliance intended to provide a complete, turnkey solution	SUMITOMO ELECTRIC FLEXium



Bio-Based Electronics | Technological Overview

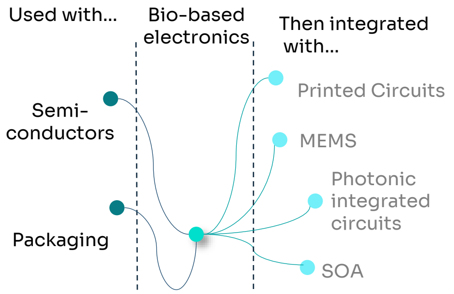
The emerging bio-based electronics sector currently holds a **strategic intermediate position** in the electronics sector while incorporating **renewable materials** like PLA, nanocellulose, and bio-based polyurethanes. Used in **substrates, packaging, flexible components and conductive inks, these materials help create more sustainable, flexible, and occasionally biodegradable devices.** Driven by stricter regulations, growing demand for eco-responsible technologies, and advances in printed electronics, this sector will pave the way to a new generation of electronics. However, these devices continue to pose challenges when managing their performance and end-of-life cycles.

Schematic Overview



Biodegradable Substrate

Main Overlap with Other Segments



TECHNOLOGICAL REVIEW AND R&D ISSUES

Technological Overview

	Materials Used	NMT	Application Examples
Biopolymer-based components	PLA, PBAT, bio-based PE, bio-based PET and nanocellulose	7-9	Cables, insulators, rechargeable batteries, displays and circuit substrates
Bio-based conductive composites	PLA composites, carbon nanofibres and graphene	4-6	Conductive inks and tracks for printed circuits
Flexible and Portable Electronics	Bio-based polyurethanes and flexible PLA	5-7	Smartwatches, medical sensors, solar energy and food packaging
Biopolymer Packaging and Casings	PLA, starch, PHA and bio-based polyesters	8-9	Electronic device packaging and biodegradable packaging

R&D Challenges Over the Coming Years

Bio-based Material Performance Optimization

Solution: Develop composites doped with functional fillers to improve conductivity and thermal stability.

Reduction in Critical Mineral Dependence

Solution: Replace silver and copper with conductive inks made from bio-based carbon and functionalized nanocellulose.

Biodegradable Material Resistance to Standard Temperatures and Solvents

Solution: Develop low-temperature printing processes compatible with biodegradable substrates while standardizing performance.

KEY MINERALS AND MATERIALS REQUIRED

01 Material Synthesis and Formulation

Creation of conductive inks, flexible substrates, functional composites

Ag | C | Cu | **Ga** | **Ge** | Sn | **In**

02 Electronic Component Manufacturing

Printing and integrating circuits, sensors, antennas, transistors on bio-based substrates

Ag | C | Mg | **Zn** | Br | Cl | **Cu**

03 Assembly and Packaging

Grouping components and protecting the device with biodegradable or recyclable materials

Cu | Sn

4 Integration

Used in electronic products: sensors, smart textiles, packaging, smart labels

Cu | **Li**

Legend:
Very critical
Moderate or less critical

Bio-Based Electronics | Key Active Stakeholders *(non-exhaustive list)*

Observations

→ 1. Stakeholder Typology

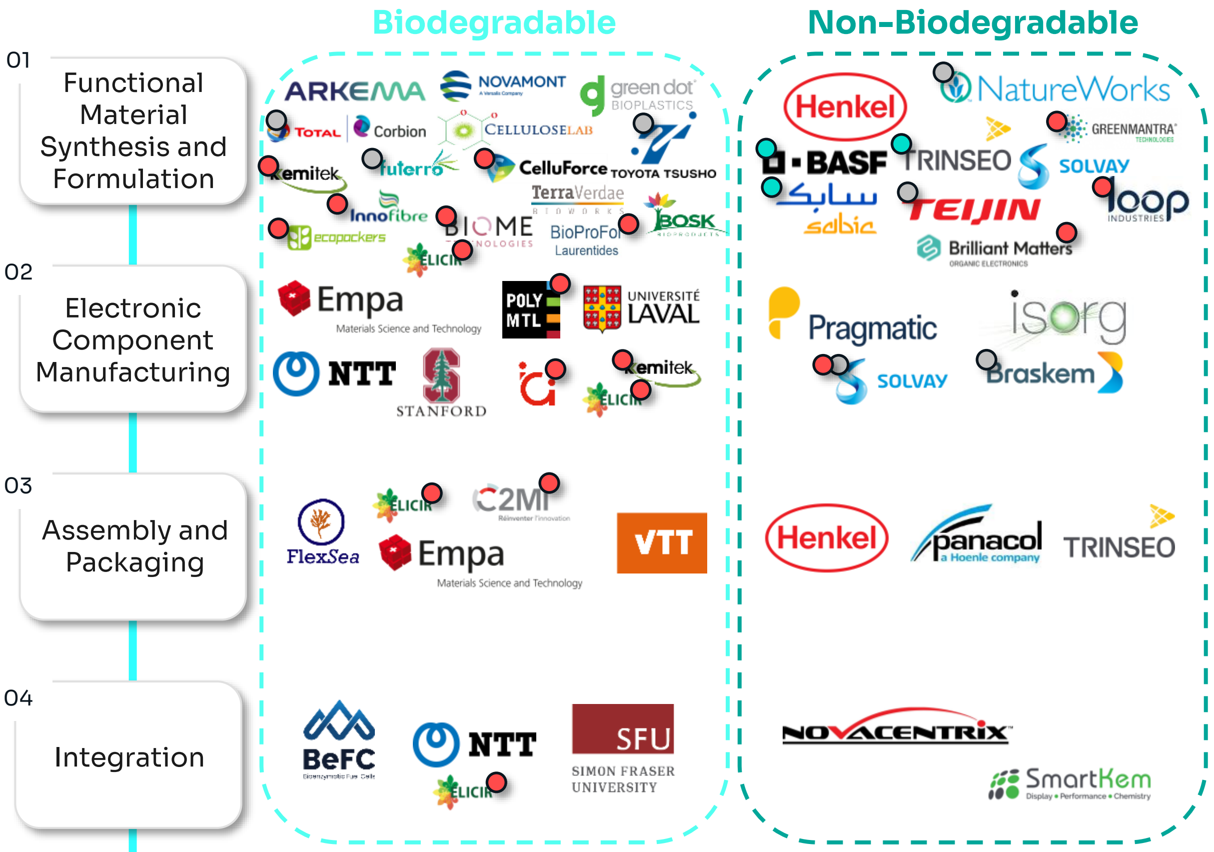
- **Chemistry and materials stakeholders:** Mainly positioned upstream due to their ability to convert bio-based resources into polymers.
- **Traditional electronics stakeholders:** Very little presence in this market due to performance constraints, integration into standardized chains, and low volumes.
- **Technology centres and applied research institutes:** Very active in R&D for stages 1 to 3, they bridge the gap between innovation, materials, and electronics applications; pivotal in validating technologies prior to industrialization.
- **Startups:** Positioned in stages 3 and 4, targeting niches (portable devices, disposable sensors, biosensors, etc.).

→ 2. Value Chain Positioning

- Some stakeholders expand their **operations toward assembly** by adapting their formulations to elec. manufacturing processes.
- Most stakeholders stop short of final integration due to **high costs or misalignment with their core activities** (e.g., formulation vs. product design).
- Vertical startups (stages 3 and 4) attempt to master multiple links to ensure performance and circularity.

Typical Partnerships

Platform molecule supply	Platform molecules derived from residual forest biomass	kemitek BioProFor Laurentides
Collaborative Research	Smart and recyclable labels	ici Innofibre
Demonstration projects	World's first biodegradable printed circuit	JIVA University of Portsmouth

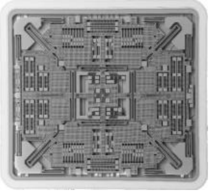


Legend: ● Top 3 ○ Other stakeholders with significant market share 🔴 CA/QC stakeholders

MEMS | Technological Overview

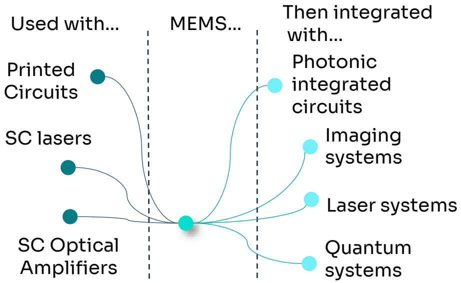
Micro-electromechanical systems (MEMS) integrate **miniaturized mechanical, electronic, and optical functions**, playing a key role in embedded systems. Their development relies on performance advances, cost reduction, and critical material integration. Several technologies remain in the R&D or market validation phase, while others have been widely adopted. Innovation activities focus particularly on **energy harvesting, cooling, advanced sensors and photonic structures, with industrial milestones expected between 2025 and 2029.**

Schematic Overview

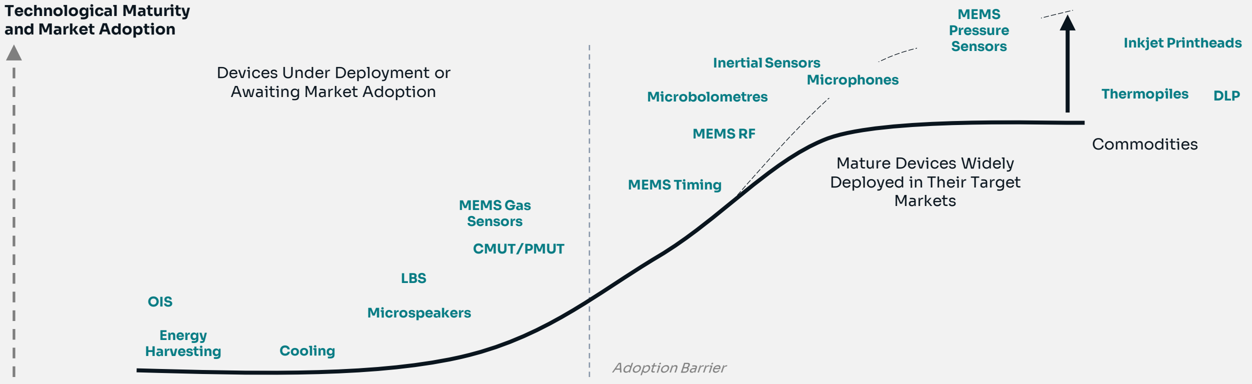


MEMS Gyroscope

Main Overlap with Other Segments



TECHNOLOGICAL REVIEW AND R&D ISSUES



KEY MINERALS AND MATERIALS REQUIRED

Substrate
Si | **Ga** | **As** | **Ge** | **Mo**

Mobile Mechanical Structure
Si | ZnO | Zn | AlN | Al

Actuator
Si | **Pb** | Zr | **AlN** | Ti | **Ta** | **Nb** | **Nd**

Sensor
Si | **In** | **Ge** | **Ga** | **Nd**

Electrode/ Metallization
Cu | Au | **Pt** | **Ru**

Interconnection/ Packaging
Sn | **In** | Au

Optical Components (Opto-mems)
Ga | **As** | **In** | P | **Ge** | Si | **Er**

Integrated Power Source
Si | **Li** | **Ta**

Legend:
Very critical
Moderate or less critical

MEMS

Key Active Stakeholders *(non-exhaustive list)*

Observations

1. Stakeholder Typology

- **Fully integrated manufacturers** internally design, manufacture, and integrate their components primarily for automotive or consumer electronics.
- **Manufacturing subcontractors** focus on production for third-party clients (specialized designers).
- **Assemblers and testers** handle packaging and verification, critical in sensitive areas like the healthcare and automotive sectors.
- **Fabless designers** develop functions while outsourcing manufacturing.

2. Value Chain Positioning

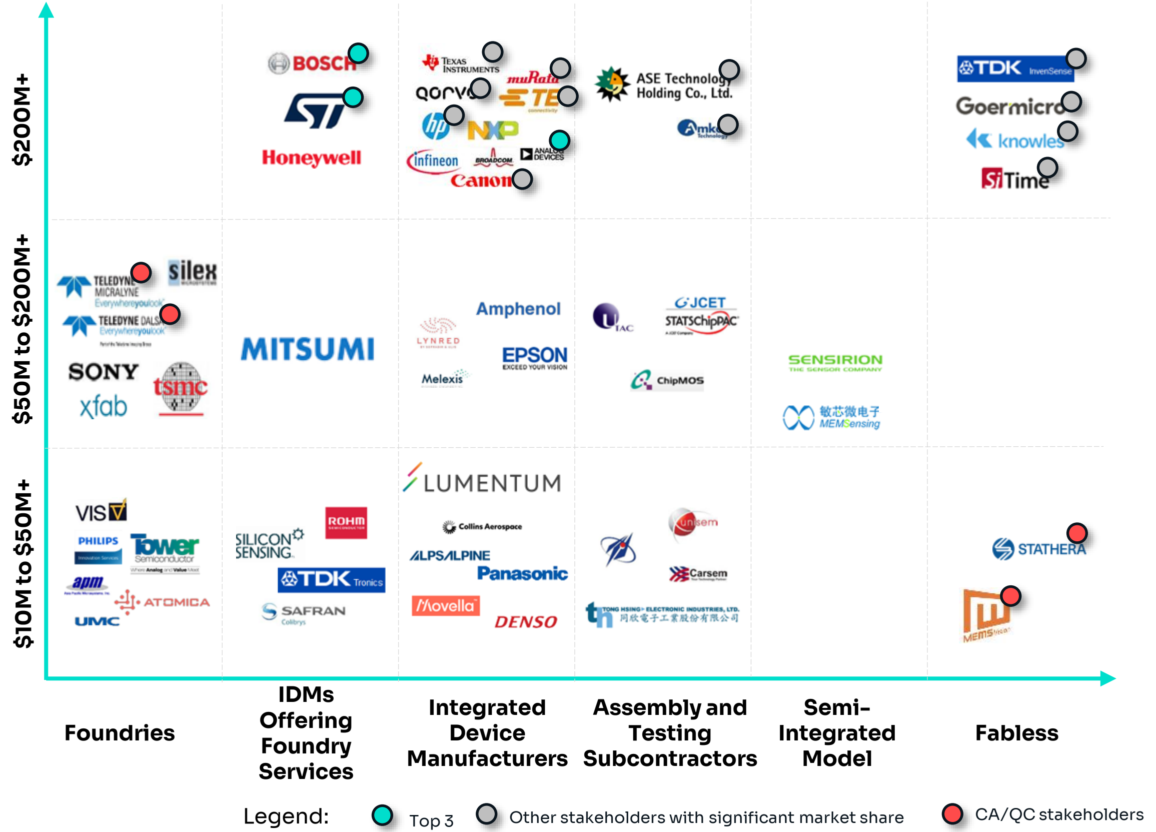
Positioning choices reflect different business models.

- **Integrated manufacturers** seek to secure their supply, control quality, and optimize costs.
- **Specialized designers** focus on functional innovation (precision, miniaturization and low power consumption) to meet increasingly specific needs.
- **Subcontractors and assemblers** are becoming indispensable as components grow increasingly complex and production processes become more standardized.

Typical Partnerships

Technology co-development between industrial stakeholders	TDK, GOODYEAR Development of integrated MEMS sensors in tires
Partnerships between MEMS designers and assemblers/integrators	AAC TECHNOLOGIES, UltraSense SYSTEMS Creation of advanced tactile solutions that incorporate MEMS
Investments and asset acquisitions to strengthen the value chain	TDK → Precision Precision Neuroscience's acquisition of TDK's MEMS factory

MEMS Revenue (2023)



Post-Processing | Outlook

The MEMS post-processing market will be worth an approximate **CAD $665M by 2028**. Currently, it is primarily used for inertial sensors and MEMS oscillators but remains limited to relatively low volumes for other devices like CMUTs and gas sensors. **Three major technological methods coexist, each with their own technical challenges.** Obstacles include the need for chips of comparable sizes and low design flexibility. While most MEMS foundries have the technical capabilities to perform post-processing on CMOS wafers, few actually do so due to the currently low volume of devices requiring this type of integration.

01. Total Market Value (2023)

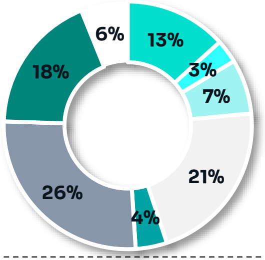
CAD $486M

02. Anticipated Market Growth

CAGR = 6.4%

(2023-2028)

Market Breakdown by Device (2023)



Examples of MEMS PT Applications *(Yole Analysis)*

New functional inkjet printhead elements

HP uses a back-etching process to create MEMS ejection nozzles, while ST integrates CMOS heating elements for precise ink control.

Heterogeneous integration of inertial sensors

TDK relies on TSMC's foundries to perform eutectic bonding (AlGe) between the ASIC and the MEMS structure.

New functional thermopile materials

TSMC provides the base CMOS wafers while Sensirion performs the final MEMS manufacturing step, including thermal micromachining.

MEMS + ASIC packaging for MEMS synchronization

SiTime designs ASIC circuits for MEMS timing, Bosch provides oscillating MEMS structures, and ASE performs the final assembly.

MARKET PROSPECTS

MEMS Sensors | Limited Usage

The use of post-processing remains marginal for most MEMS sensor devices. Monolithic architectures are often difficult to implement and their adoption limits design flexibility, thus reducing industrial interest in post-processing within this segment.

Strong High-Volume Market | Some Major Stakeholders

High-volume segments like inertial sensors and oscillators are largely handled by dominant stakeholders like TSMC and ASE, who already integrate critical steps internally. PT has also grown within other sectors of interest, including imaging, where high market volumes help amortize the advanced integration costs.

Emergence of 300-mm MEMS Wafers | Easier Integration

By 2028, certain types of devices will undergo a gradual shift to 300-mm MEMS wafers. These primarily include capacitive ultrasonic transducers (CMUTs), inertial measurement units (IMUs), and MEMS oscillators. Since most CMOS wafers are already manufactured in 12-inch formats (300mm), adopting this MEMS format will facilitate wafer bonding and strengthen compatibility with integrated MEMS-CMOS post-processing methods.

Post-Processing | Quebec Vision

Quebec has the **strategic assets to acquire new business opportunities involving MEMS post-processing**, primarily through specialized infrastructures like those at C2MI and Teledyne. The province already masters the 200-mm format, but the 300-mm format may eventually be considered for specific needs (e.g., micro-assembly and hermetic packaging) in high-potential segments (e.g., CMUT, IMU, MEMS oscillators). A number of stakeholders are currently seeking partners who can offer post-processing facilities adapted to these uses, ideally in a shared context to ensure profitability. In this context, Quebec has an opportunity to structure an **integrated and flexible offer that can attract clients seeking specialized, custom solutions.**

	Segment Observations	Quebec Specificities
INFRASTRUCTURES	MEMS manufacturing requires advanced facilities for bonding, packaging, and testing operations, all of which are essential in post-processing activities.	Teledyne and C2MI: MEMS/CMOS lines, bonding, packaging, and testing
	A 300-mm transition is crucial for certain high-volume markets; compatibility with this format can help attract these segments.	200-mm expertise; potential to develop 300-mm formats for targeted niches
EXPERTISE AND TALENT	MEMS/CMOS integration is at the heart of post-processing; it enables device compactness and performance.	Active C2MI, NRC, INRS, and 3IT
	The development and operation of complex processes requires a workforce trained in MEMS technologies, advanced materials, and hybrid processes.	Université Laval, Université de Sherbrooke and Polytechnique: Expertise in processes, materials, MEMS and photonics
MARKET AND POSTIONING	Post-processing is only profitable under sufficient volumes and when the product belongs to a high-value niche.	Quebec cannot directly compete with the volume generated by large Asian centres. It must therefore position itself within differentiated technological niches that provide higher margins (e.g., cryogenic bonding, integrated photonics, specialized inertial MEMS, and biomedical microfluidics).
	An active local market where exports can help maximize returns for a dedicated post-processing production line.	Quebec could seek to consolidate the local market (by pooling a dedicated line) or provide export services to North America, where few specialized PT options currently exist.
INTEGRATION AND VALUE CHAIN	Integrated services attract clients who prefer one-stop shopping.	Ecosystem structured around C2MI, covering design, manufacturing, post-processing and packaging.

A FEW QC STAKEHOLDERS

C2MI *Positioned*
Collaborative innovation centre with equipment and an industrial environment that can produce prototypes, as well as small production volumes involving technologies like bonding, MEMS, wafer preparation and packaging. Expertise in post-processing development for 200-mm wafers.

Teledyne *Positioned*
Industrial site with MEMS manufacturing lines, along with expertise and experience in high-volume 200-mm post-processing.

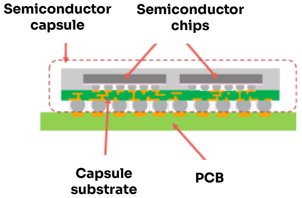
INO *Positioned*
Involved in optical/photonic design and prototyping and has microfabrication capabilities that can support 200-mm post-processing prototypes. They are an integral part of the development chain thanks to their design expertise regarding products that require post-processing.

Technum Québec *Potential*
Seeks to develop this capability in the medium term. They have a strategic interest in shared lines that primarily involve 300-mm formats for NGS microfluidics.

Packaging | Technological Overview

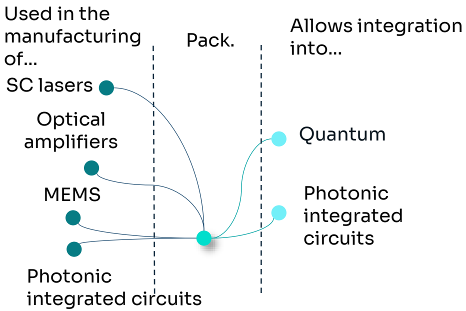
Packaging is **fundamentally transforming the role of assembly in the semiconductor industry**, integrating critical functions that are now part of system performance. Technologies like hybrid bonding, 2.5D/3D integration, and optical interconnections are pushing the limits of traditional architectures. Platforms like CoWoS, Foveros, and InFO **unite miniaturization, performance, and modularity.** This evolution meets a **growing demand for high-performance applications** (AI, HPC, AR/VR) while imposing **new challenges for design, manufacturing, and heat management.**

Schematic Overview



Packaged Semiconductors

Main Overlap with Other Segments



TECHNOLOGICAL REVIEW AND R&D ISSUES

Technological Overview

	Principle	Typical Applications	Key Advantages
Fan-out	I/O redistribution via RDL layers on a mould without substrate	Mobile, RF, SiP, packaged systems	Thin profile, low cost, good density
Flip-chip	Flip-chip connected to the substrate via balls (Cu, Sn)	GPU, CPU, FPGA, memory	High I/O density, mature, compatible with FC BGA/CSP
2.5D interposer	Lateral integration of multiple chips on a Si interposer	HPC, AI, data centres	High bandwidth, heterogeneous interconnection
3D packaging	Vertical chip stacking via TSV or hybrid bonding	HBM, 3D-integrated circuit, image sensors	Space saving, reduced latency, efficiency
Heterogeneous integration	Integration of varied chips in a single package	HPC, AI, 5G, embedded systems	High functional density, modularity, system performance

R&D Challenges Over the Coming Years

Interconnection pitch reduction

Solution: Bumpless hybrid bonding (e.g., TSMC SoIC and Intel Foveros Direct) allows ultra-dense metal-to-metal/oxide-to-oxide connections.

3D and HBM stacking thermal management

Solution: Multilayer copper hybrid bonding (Samsung) and technologies like BSPDN.

Heterogeneous chiplet integration

Solution: Platforms like EMIB (embedded multi-die interconnect bridge), CoWoS (chip-on-wafer-on-substrate), VIPack (vertical integration) provide modularity and high-performance interfacing.

KEY MINERALS AND MATERIALS REQUIRED

Fan-Out
Cu | **Sn** | Au | Si

Flip-Chip
Cu | **Sn** | Au | Ni | **Co** | Si | Ta

Fan-Out (UHD)
Cu | **Co** | Ni | Sn

Fan-Out (HD)
Cu | Sn | Ni | Si

2.5D Interposer
Si | **Cu** | Sn | Ta | Au | **Co**

3D Stacked Memory
Cu | Sn | Au | **Co** | W | Ge | **In**

Integrated Si Bridge
Si | **Cu** | Ni | Sn | **Co**

Hybrid Bonding
Cu | **Co** | Ta | Ge | **In** | Hf

Legend:
Very critical
Moderate or less critical

Packaging | Key Active Stakeholder *(non-exhaustive list)*

Observations

→ 1. Stakeholder Typology

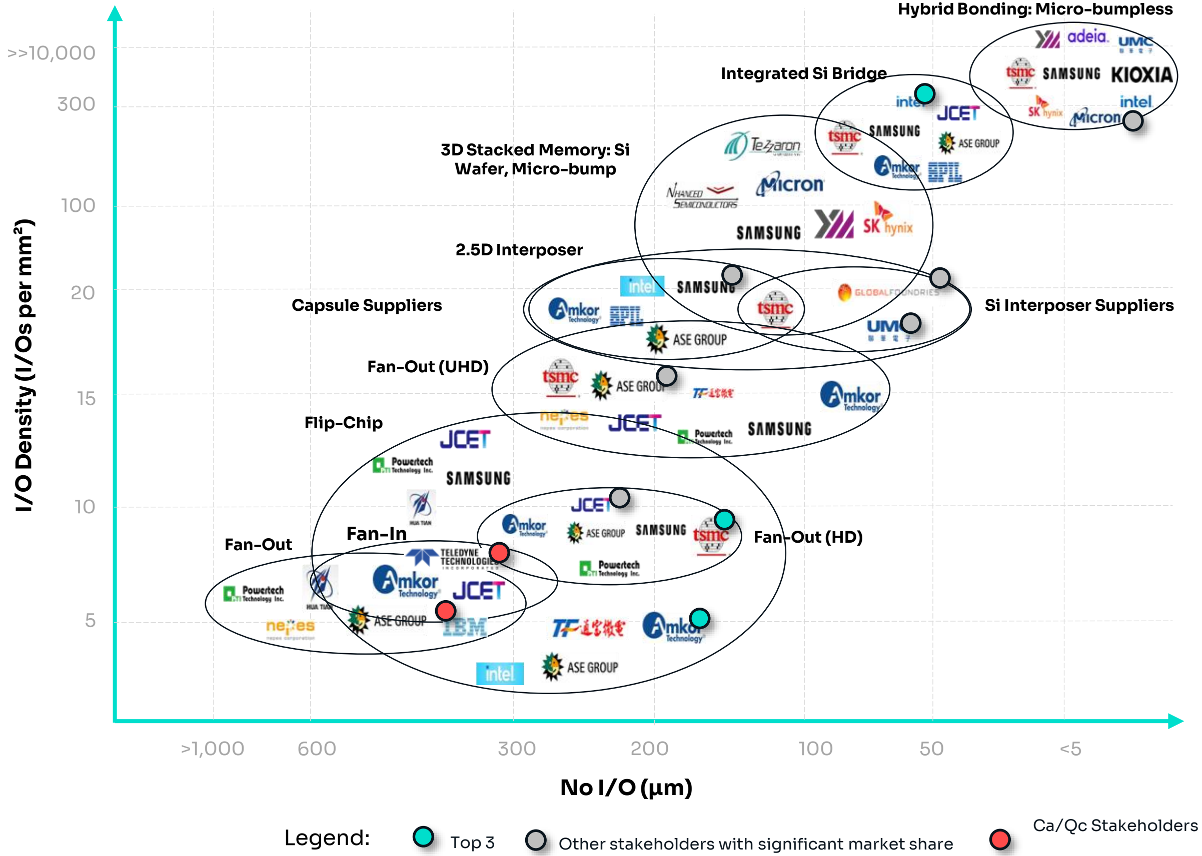
- **Integrated stakeholders** (TSMC, Intel): Chip, interposer, and packaging expertise with vertical technology control.
- **Alternative assembly and testing providers** (ASE, Amkor, JCET): Traditionally focused on mid-range (fan-out and flip-chip), moving up-market through investments in UHD fan-out and chiplet integration.
- **Specialized suppliers** (UMC, Adeia, Micron): Active in key technological bricks (TSV, bridges, HBM), often in co-development with chip manufacturers.

→ 2. Value Chain Positioning

- Expertise across the entire chain helps optimize performance and technological control: Method adopted by TSMC, Intel, and Samsung.
- Conversely, certain stakeholders like ASE and Amkor **invest in the mid range.**
- Others, like UMC and Micron, focus on specific technological bricks like interposers or bump creation for interconnections.

Typical Partnerships

Technological co-development	Joint hybrid platform development Amkor tsmc
Technology licensing agreements	adeia KIOXIA Use of hybrid bonding patents
Industrial joint ventures	Set up OSAT factories in emerging countries (India, Vietnam) TATA Micron



Summary | Market Outlook and Growth *(1/2)*

The microelectronic and photonic markets under consideration show contrasting dynamics: **Stable growth for printed circuits and MEMS, rapid expansion for advanced packaging, optical transducers, and semiconductor lasers, and strong technological segmentation for infrared imaging.** These developments are driven by a variety of applications that include consumer electronics, mobility, defense, telecommunication, and data centres.

Segment	Overall Market Description	Market Share* *2024*	Main Applications* *2024*	Trend* ($B) 2024	Trend* ($B) 2029	CAGR* *(2024-2029)*
PRINTED CIRCUITS	The printed circuit market is growing alongside **electronics, 5G, and the IoT. Flexible models are advancing**, but China continues to dominate production, creating sovereignty issues for Europe and the United States.	**$102B**	Consumer Electronics 36% Automotive and Mobility 21% Industry 16%	102	165	5.8%
PACKAGING	The packaging market is evolving rapidly, driven by **AI and HPC.** As a strategic lever, it goes beyond the traditional assembly role to enhance performance, competitiveness, and sovereignty in the global semiconductor ecosystem.	**$60B**	Consumer Electronics 73% Telecom / DataCom 12% Automotive and Mobility 10%	60	97	11%
MEMS	The global MEMS market is driven by the **automotive, healthcare, industrial, and consumer electronics sectors.** Used in **detection, actuation, and timing,** they are integrated into smart and connected devices.	**$21B**	Consumer Electronics 52% Automotive and Mobility 19% Industry 18%	21	27	5%
OPTICAL TRANSDUCERS	**DataCom is growing rapidly thanks to AI and data centres,** adopting **silicon photonics** for short links. Telecommunications are evolving at a slower pace, targeting coherent long-distance solutions.	**$18B**	DataCom 61% Telecom 39%	18	31	11%
IMAGING SYSTEMS	The infrared imaging market is divided between **SWIR growth** (inspection, defense), **military MWIR, cooled LWIR for demanding environments, and uncooled LWIR microbolometres,** which dominate the automotive and industrial sectors.	**$6.8B**	Industry 1st Consumer Electronics 2nd Defense 3rd	6,8	9,1	6%
SEMICONDUCTOR LASERS	**Consolidated by strong investments (>$28B),** the market is growing alongside telecoms, data centres, AI, the automotive sector, and LiDAR. VCSELs are advancing in biometrics, while EELs dominate the industrial and telecom sectors.	**$3.9B**	Telecom / DataCom 41% Consumer Electronics 37% Industry 13%	3,9	6,6	17%

*Source: Market Study – Yole Group

Legend: Consumer Electronics · Automotive and Mobility · Telecom · DataCom · Defense · Industry

Summary | Market Outlook and Growth *(2/2)*

High-growth markets focus on compound semiconductors, semiconductor optical amplifiers, quantum technologies, and photonic integrated circuits, each driven by key applications that include power electronics, telecoms, data centres, high-performance computing, and LiDAR. **Emerging bio-based electronics** could lead to more sustainable solutions, notably in healthcare, agri-food, and the IoT.

Segment	Overall Market Description	Market Share *2024*	Main Applications* *2024*	Trend* ($B) 2024	Trend* ($B) 2029	CAGR* *(2024-2029)*
COMPOUND SEMICONDUCTORS	The market is structured around several applications: SiC and GaN in **power electronics** for vehicles; GaAs and GaN in RF for 5G, defense and **satellite communications**; InP and GaAs in photonics for optical transducers and 3D detection, as well as conventional LEDs and microLEDs used in displays.	**$2.1B**	🔲 65% 📡 20%	2.1	4.5	17%
SC OPTICAL AMPLIFIERS	The market is divided between **telecommunications**, fast-growing integrated photonics with silicon photonic circuits for **data centres**, **LiDAR** for autonomous vehicles and remote sensing, and complementary applications like spectroscopy and tunable lasers.	**$1.6B**	🗄 📡 80% 📶 20%	1.1	2.1	11%
QUANTUM	The market is divided between **computing** (poised to dominate with QaaS and annealing computers), communications limited to point-to-point links but expected to evolve with the arrival of **quantum repeaters**, and **detection** (still a niche interest but promises ultra-precise measurements).	**$1.3B**	🔲 1st 📶 2nd	1.3	5.2	31%
PHOTONIC INTEGRATED CIRCUITS	The market covers a range of applications, including **telecommunications, data centres,** HPC, and AI. Emerging applications like **detection** and **biomedical devices** also leverage various platforms supported by R&D efforts and the integration of new materials.	**$0.4B**	📡 1st 🗄 2nd 📶 3rd	0.4	2.4	43%
BIO-BASED ELECTRONICS	The market relies on hybrid flexible electronics for **a variety of applications in healthcare, agri-food, and the IoT.** This approach paves the way to renewable and compostable materials (suitable for the circular economy), while providing opportunities in wearable electronics through lightweight, durable biopolymers.	**$0.1B**	🔲 1st 🏭 2nd	0.12	0.24	16%

*Source: Market Study – Yole Group

Legend: 🔲 Consumer Electronics 🚗 Automotive and Mobility 📡 Telecom 🗄 DataCom ✈ Defense 🏭 Industry 📶 Detection

Summary | Québec Positioning *(1/2)*

Quebec's diversified position is recognized for its strength in packaging, MEMS, optical transducers and imaging, as well as its emerging potential in printed circuits and printed electronics. **Driven by an active industrial ecosystem, strong scientific foundations and structuring regional initiatives, the province holds key skills and innovation hubs that can meet the strategic technological needs involved while strengthening its sovereignty.**

Segment	Overall Position Description	QC Stakeholder Examples	Quebec Specificities	Interest/Capabilities
PRINTED CIRCUITS	Quebec is home to a strong assembly ecosystem despite its **modest position in rigid PCBs**. **Printed electronics** provide a complementary pathway that can promote local production and new applications in photonics and the IoT.	e2ip TECHNOLOGIES mi	• A hub that covers **the entire value chain** • **Major scientific assets**	• **New market** and **competitive advantage** • **Structuring** projects
PACKAGING	Quebec holds significant **technological capabilities** and a **customized packaging** differentiator. A number of regional initiatives seek to create a coherent offer within this segment.	IBM C2MI	• Proximity to **American foundries** • **Solid** existing infrastructure	• **Cutting-edge** stakeholders • **Volume** deficiencies
MEMS	Quebec provides favourable conditions that can help develop a competitive MEMS sector thanks to an **active industrial ecosystem**, a **recognized scientific base**, and **structuring public levers**.	MEMS Vision STATHERA	• **SME specialization** within technological niches • **Integrated innovation chain**	• Critical for future sectors • **Prototyping** and **upscaling**
OPTICAL TRANSDUCERS	Quebec is **recognized for its expertise** in testing, silicon photonics, passive components, connectivity, and network architectures, all of which **complement integration capabilities found elsewhere in Canada.**	RESONETICS EXFO	• **Complementary ecosystem** (e.g., passive components) • Excellence in **optical testing**	• **Transition** to integrated photonics • **Technological sovereignty**
IMAGING SYSTEMS	Quebec is home to an **advanced imaging** ecosystem that integrates **optics, AI and data processing**, along with many specialized stakeholders, despite **lacking a complete sensor chain.**	Photon etc TELOPS	• Specialized in high-complexity **niche technologies** • Strong **functional network**	• **Sensitive sectors** (defence, security, etc.) • Solid business **core**

Summary | Québec Positioning *(2/2)*

Quebec possesses unique assets across many strategic segments. Its strengths in research and innovation support the development of semiconductor lasers, compound semiconductors and quantum technologies, while its skills cover the entire value chain, reinforcing its positioning in photonic integrated circuits. Bio-based electronics benefit from a structured ecosystem but remain hampered by a lack of specialized suppliers.

Segment	Overall Position Description	QC Stakeholder Examples	Quebec Specificities	Interest/Capabilities
SEMICONDUCTOR LASERS	Quebec stands out for its semiconductor lasers thanks to its research and development activities, specialized training centres, innovative capabilities, and **strong potential for industrialization and scaling.**	LASER COMPONENTS excelitas	• **Strategic niche** (biomedical, advanced imaging) • **Customization** as a strategic differentiator	• **Limited number** of industrial stakeholders • **Local manufacturing** under consideration
COMPOUND SEMICONDUCTORS	Quebec stands out for its **critical mineral resources and niche applications**, furthering the need to structure local and integrated photonic supply chains.	TransEON NANOWAVE Technologies Inc.	• Strong **hybrid circuit** position • Advanced prototyping platforms on **III-V compound semiconductors**	• **Differentiating** lever • **Weak coordination** between upstream mining and downstream techno-industrial sectors
QUANTUM	Quebec is establishing itself as a **key player in quantum technology**, driven by an ecosystem that combines cutting-edge research, innovative companies and government support, along with strong connections between fundamental science and industrial applications.	ANYON Nord Quantique	• **Shared platforms** for industrial experimentation • Solid **start-up** base	• Strong **integrated photonics** niche • **Technological sovereignty**
PHOTONIC INTEGRATED CIRCUITS	Photonic integrated circuits lie at the crossroads of AI, quantum technologies, microelectronics and photonics, placing Quebec in a favourable position thanks to its expertise in **design, testing, packaging, and promising technology platforms.**	ciena AEPONYX	• **Complementary** ecosystem/Strong **functional network** • Specialization in **high-complexity technological niches**	• **Strategic** application markets • **Lack of any dedicated foundry**
BIO-BASED ELECTRONICS	Quebec is home to a **structured ecosystem** that combines green chemistry, biomass, and printed electronics, all of which promote network collaborations. A number of stakeholders are already integrating these technologies, but a **lack of platform molecules and suitable substrate suppliers** remains an issue.	kemitek CelluForce	• Active, **innovative and specialized stakeholders** • **Privileged biomass access**	• Potential **North-American champion in sustainable electronics** • **Lack of** platform molecule **suppliers**

04

Critical Minerals and Materials

A. Methodology

B. Geographic Resource Distribution

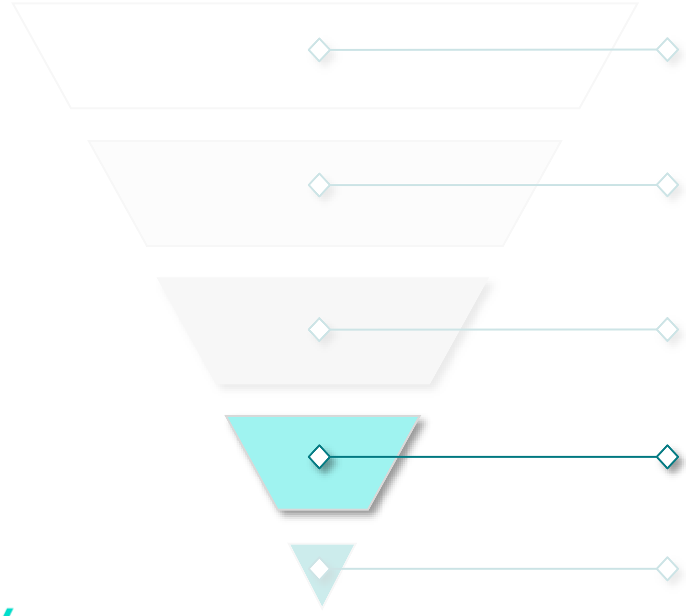
C. In-Depth Study of 15 CSMs

D. Quebec Vision and Business Opportunities

Critical Minerals and Materials | Issues and Objectives (Recap)

This section **analyzes the critical minerals and materials used in photonics and microelectronics** to assess Quebec's current position within these value chains. The objective is to **identify the available resources, strategic links and potential levers that can strengthen Quebec's role within these priority technological sectors.**

Link With the Overall Methodology



1. Capitalizing existing resources and identifying of the scope

2. Analyzing the international and local microelectronics/photonics ecosystem

3. Preselecting and analyzing the 13 segments of interest

4. Analyzing the materials and minerals

5. Drafting the analysis summary

MAIN ISSUES

- **Complexity and the large number of materials and minerals involved in these value chains:** More than 85 elements have been identified.
- **Access to data from exploration, production and material processing projects:** The MRNF and ISED helped collect and compile this information.

SCOPE

- Geographical scope – **International, Quebec**
- Study scope – **Materials, minerals and reagents/precursors**

Main Mineral/Material Categories | Classification

More than **85 distinct elements have been identified** in the material/technology cross-analysis. The diversity of their nature, functions and transformation states increases the complexity of any direct classification. To facilitate the interpretation, comparative analysis and processing, the study uses three major functional categories: **Raw materials, processed materials, and process reagents/precursors.**

RAW MATERIALS – *42 ELEMENTS IDENTIFIED*

DESCRIPTION

Chemical elements or minerals extracted directly from the ground (ore, gas, and raw salt), requiring little or no chemical transformation prior to their integration into industrial and manufacturing processes.

KEY CHARACTERISTICS

→ These stem from mining, metallurgical and gas extraction

→ Little chemical transformation at this stage

EXAMPLES

Metals	Cu	Ni	Co	Ga
Non-metals	Si	As	P	S

PROCESSED MATERIALS – *9 ELEMENTS IDENTIFIED*

DESCRIPTION

Materials that have undergone advanced physical or chemical transformation from raw materials to obtain compounds with specific properties (optical, electrical, mechanical, dielectric).

KEY CHARACTERISTICS

→ These stem from one or more transformation processes

→ Suitable as substrates, active layers, etc.

EXAMPLES

Ceramics	Al_2O_3	$BaTiO_3$	$LiNbO_3$
Other	SiC	SiO_2	

PROCESS REAGENTS AND PRECURSORS – *34 ELEMENTS IDENTIFIED*

DESCRIPTION

Chemical elements or compounds (often gaseous, liquid or volatile) used in advanced manufacturing processes (chemical deposition, doping, etching, passivation) but not directly present in the final product composition, or present in trace amounts.

KEY CHARACTERISTICS

→ These play a temporary or indirect role (carrier, catalyst, etc.)

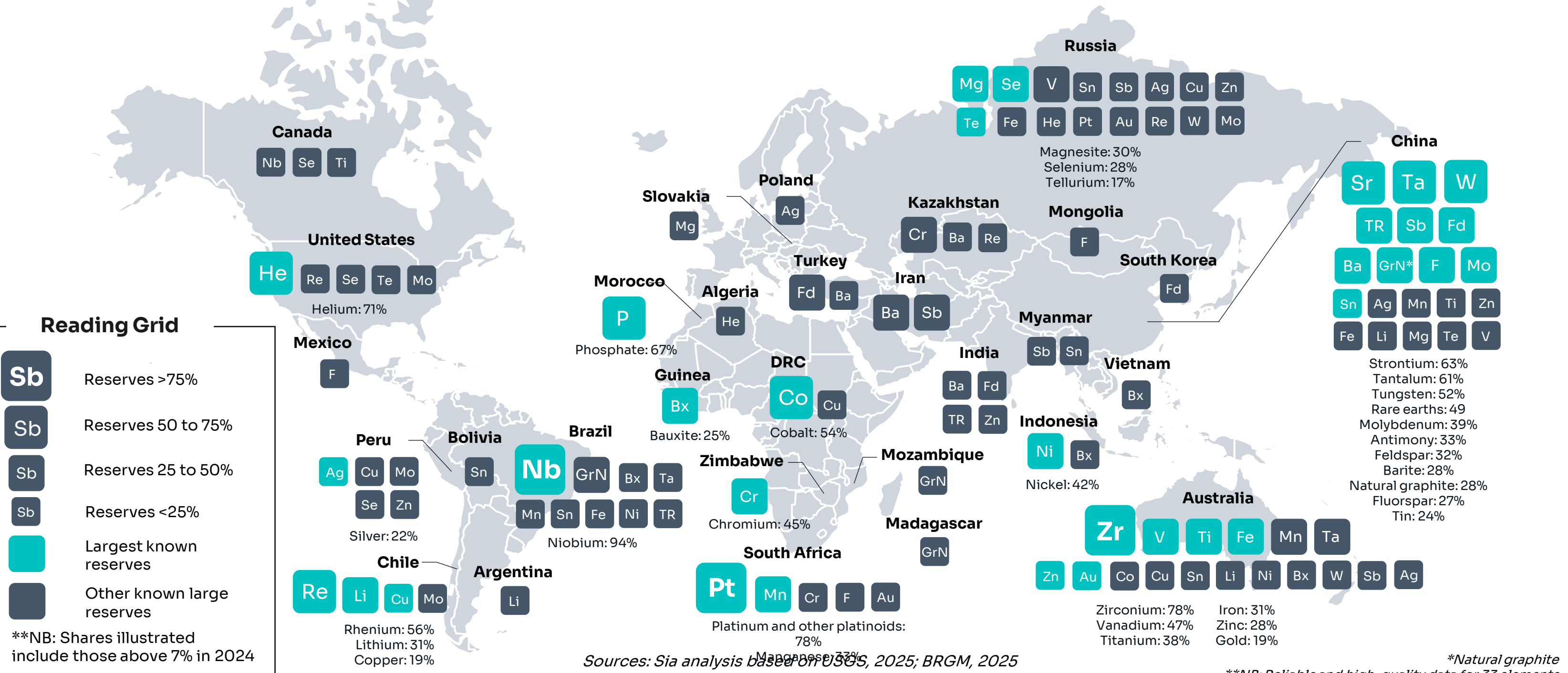
→ Used in technologies like CVD, MOCVD, etc.

EXAMPLES

Deposition gas	Cl_2	SF_6	BCl_3
Doping agent	H_2O_2	$SiCl_4$	PH_3

Geographic Distribution | Reserves***

Despite the relatively even global distribution of reserves, **China and Australia** are among the **top three holders** of nearly half of the **33 critical and strategic minerals** analyzed.** The **very high concentration of reserves**–a single country holds more than one-third of the resources for more than half of the minerals–reinforces the centralization of supply chains and their vulnerability to geopolitical tensions. **Of the 15 critical minerals present in Canada,** or 45% of the CSMs analyzed, **only three exceed 7% of global reserves.**



Reading Grid

Sb	Reserves >75%
Sb	Reserves 50 to 75%
Sb	Reserves 25 to 50%
Sb	Reserves <25%
🟦	Largest known reserves
⬛	Other known large reserves

**NB: Shares illustrated include those above 7% in 2024

Sources: *Sia analysis based on USGS, 2025; BRGM, 2025*

Symbols:

Antimony (Sb)
Silver (Ag)
Barite (Ba)
Bauxite (Bx)
Chromium (Cr)
Cobalt (Co)
Copper (Cu)
Tin (Sn)
Feldspar (Fd)
Iron (Fe)
Fluorspar (F)
Natural graphite (GrN)
Helium (He)
Lithium (Li)
Magnesite (Mg)
Manganese (Mn)
Molybdenum (Mo)
Nickel (Ni)
Niobium (Nb)
Gold (Au)
Phosphate ore (P)
Platinum and other platinoids (Pt)
Rhenium (Re)
Selenium (Se)
Strontium (Sr)
Tantalum (Ta)
Tellurium (Te)
Rare earths (RE)
Titanium (Ti)
Tungsten (W)
Vanadium (V)
Zinc (Zn)
Zirconium (Zr)

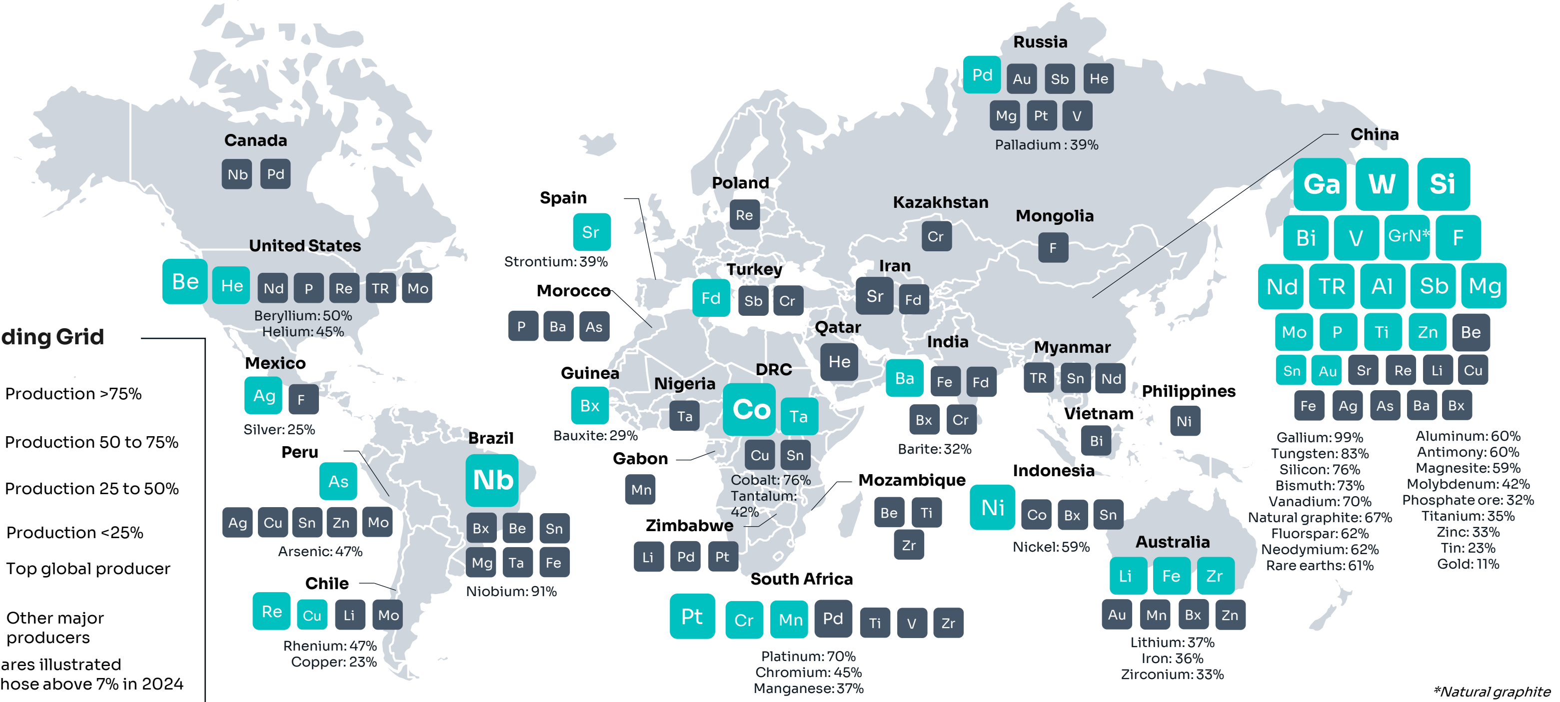
**Natural graphite*

***NB: Reliable and high-quality data for 33 elements*

****"Economically exploitable" reserves, as defined by the USGS report, Mineral Commodity Summary, 2025*

Geographic Distribution | Production

Capacity concentrations increase along the value chain. Of the 39 critical minerals analyzed,** **the world's leading producer controls at least one-third of production in nearly 80% of cases.** A quarter of the minerals reveal a concentration equal to 65% or more, indicating a monopoly. China, **the leading producer in nearly half of all cases**, accounts for **nearly two-thirds of these monopolies**. Canada is barely visible on the map (due to shares below the 7% threshold); it nevertheless takes part in **more than 1% of global production for more than one-third of the minerals under consideration.**



Reading Grid

Sb	Production >75%
Sb	Production 50 to 75%
Sb	Production 25 to 50%
Sb	Production <25%
🟦	Top global producer
⬛	Other major producers

**NB: Shares illustrated include those above 7% in 2024

*Natural graphite

***NB: Reliable and high-quality data for 33 elements*

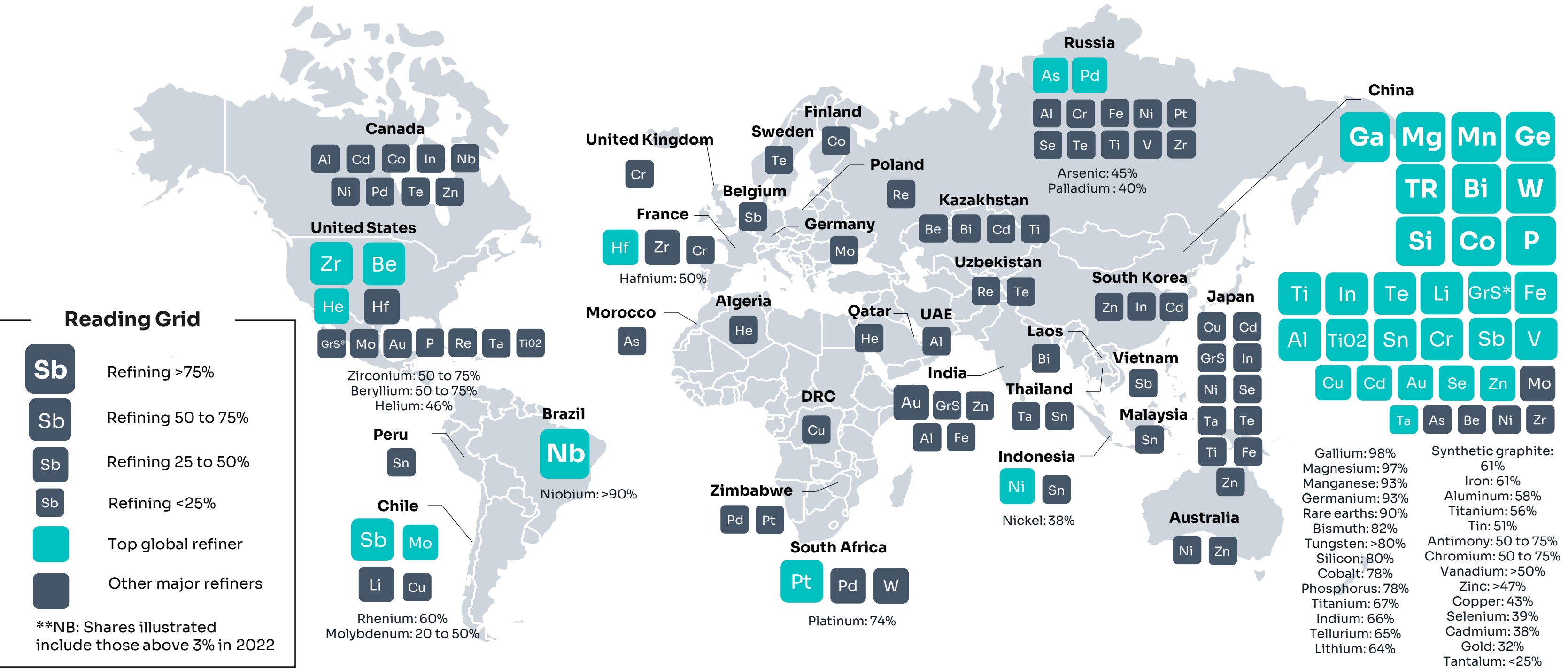
Sources: Sia analysis based on USGS, 2025; BRGM, 2025; IEA, 2025

Symbols:

Aluminum (Al)
Antimony (Sb)
Silver (Ag)
Arsenic (As)
Barite (Ba)
Bauxite (Bx)
Beryllium (Be)
Bismuth (Bi)
Chromium (Cr)
Cobalt (Co)
Copper (Cu)
Tin (Sn)
Feldspar (Fd)
Iron (Fe)
Fluorspar (F)
Gallium (Ga)
Natural graphite (GrN)
Helium (He)
Lithium (Li)
Magnesite (Mg)
Manganese (Mn)
Molybdenum (Mo)
Neodymium (Nd)
Nickel (Ni)
Niobium (Nb)
Gold (Au)
Palladium (Pd)
Phosphate ore (P)
Platinum (Pt)
Rhenium (Re)
Silicon (Si)
Strontium (Sr)
Tantalum (Ta)
Rare earths (RE)
Titanium (Ti)
Tungsten (W)
Vanadium (V)
Zinc (Zn)
Zirconium (Zr)

Geographic Distribution | Refining

Refining represents the highest concentration of activities at the international level. Of the 40 critical minerals analyzed, the top refiner holds at least **50% of global capacity** in nearly **75% of cases** and at least **one third in 95%** of cases. China, **the leading producer behind 75% of these minerals**, accounts for 13 of the 16 monopolies (where one stakeholder controls 65% or more of global production). Canada must strengthen its capacity at this stage of the value chain. Despite its refining capacities for 11 of the 40 CSMs analyzed, **only nine of these exceed 3% of global refining capacity** (these are therefore included on the map).



Symbols:

Aluminum (Al)
Antimony (Sb)
Arsenic (As)
Beryllium (Be)
Bismuth (Bi)
Cadmium (Cd)
Chromium (Cr)
Cobalt (Co)
Copper (Cu)
Tin (Sn)
Iron (Fe)
Fluorspar (F)
Gallium (Ga)
Germanium (Ge)
Synthetic graphite (GrS)
Hafnium (Hf)
Helium (He)
Indium (In)
Lithium (Li)
Magnesium (Mg)
Manganese (Mn)
Molybdenum (Mo)
Nickel (Ni)
Niobium (Nb)
Gold (Au)
Palladium (Pd)
Phosphorus (P)
Platinum (Pt)
Rhenium (Re)
Selenium (Se)
Silicon (Si)
Tantalum (Ta)
Tellurium (Te)
Rare earths (RE)
Titanium (sponge) (Ti)
Titanium (oxide) (TiO2)
Tungsten (W)
Vanadium (V)
Zinc (Zn)
Zirconium (Zr)

Sources: Sia analysis based on USGS, 2023; BRGM, 2025; RMIS, 2025

**Synthetic graphite*

***NB: Reliable and high-quality data for 40 elements*

Detailed Analysis | 15 Selected CSMs

Following the work, **15 minerals were selected for an in-depth analysis** due to their **central role in photonics and microelectronics, their high global criticality, and Quebec's potential strategic positioning with regard to their extraction, processing, and recovery/recycling.** This selection seeks to closely examine the raw materials essential when structuring photonic and microelectronic value chains.

A FEW ANALYSIS POINTS REGARDING THE 15 CSMs UNDER CONSIDERATION:

Al	Used for interconnections and chip structure. Critical primarily due to its energy-intensive production.
Ti	Used in alloys and as a diffusion barrier. Strong dependence on Russia.
Cu	Key conductor in microelectronics. Strong demand and pressure on global extraction.
Sc	Aluminum-scandium alloy for batteries and RF components. Extremely limited supply, emerging value chain.
Pd	Contacts and catalysts. Highly critical, dominated by Russia, difficult substitution.
Co	Alloys and batteries. Supply concentrated in the DRC, high geopolitical and ethical risks.
Ga	Compound semiconductors. Critical due to its near-total dependence on China.
Ge	Optoelectronics and infrared. Limited supply, highly dependent on China.
Ni	Alloys and metal contacts. Concentrated supply, refined mainly in China.
In	Displays, lasers and compound semiconductors. Rare by-product, supply chain dominated by China.
Li	Increasing integration with optoelectronic devices. Criticality linked to the rapid growth of global demand.
Nb	Used in superconducting alloys, TFLN and LiNbO3. Supply concentrated in Brazil and Québec.
Si	Base material in semiconductors. Abundant but requires very high purity achieved by few players.
Gr*	Anodes, sensors and flexible electronics. Chain dominated by China, strategic in electrification.
REE**	Magnets, dopants and alloys. High criticality for their transversal role and supply dominated by China/Russia.

*Gr: Graphite

**Rare Earth Elements (excluding Scandium)

Detailed Analysis | Tensions and Trade Restrictions

Since 2022, **an increase in trade tensions around critical and strategic minerals has been observed.** Through its dominant position, for example, China holds a powerful **geoeconomic lever** that can **directly influence trade flows.** For other major producers (Congo, Russia, etc.), export restrictions help **control supply on international markets while encouraging local processing and the imposition of targeted global sanctions.**

TRADE RISKS

- **High geopolitical risk:** Export restrictions or strong control by China

Sc Ga Ge Gr In Mo Zr

- **Specific trade policies:** Export ban to promote local processing

Co Cu Ni

- **Targeted restrictions:** Specific context involving Russian instability, imposition of tariffs

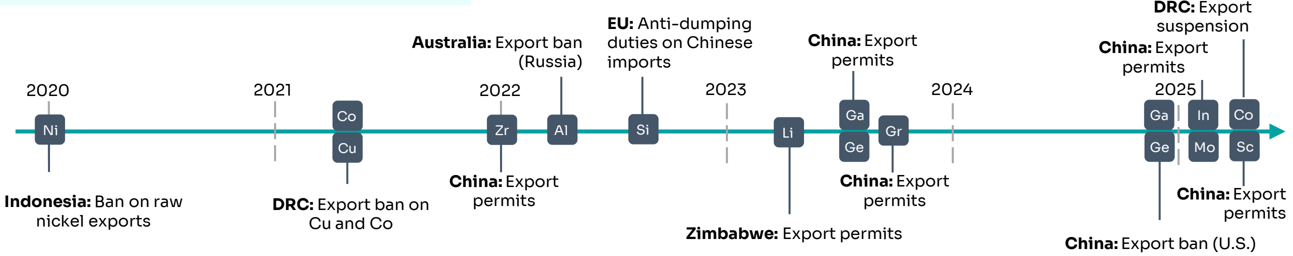
Al Si

- **Latent risk:** Supply concentration. Vulnerability to the potential tightening of exports

Li Nd Pr Ti Nb

● China ● DRC ● Indonesia
● Australia ● G7 ● EU

CHRONOLOGY OF EXPORT RESTRICTIONS:



2020 2021 2022 2023 2024 2025

Ni – **Indonesia:** Ban on raw nickel exports

Co, Cu – **DRC:** Export ban on Cu and Co

Zr – **China:** Export permits

Al – **Australia:** Export ban (Russia)

Si – **EU:** Anti-dumping duties on Chinese imports

Li – **Zimbabwe:** Export permits

Ga, Ge – **China:** Export permits

Gr – **China:** Export permits

Ga, Ge – **China:** Export ban (U.S.)

In, Mo – **China:** Export permits

Co – **DRC:** Export suspension

Sc – **China:** Export permits

GENERAL TRENDS

Tightened control by China – China imposes the most export restrictions on CSMs, primarily through permits required for seven of the 15 minerals under analysis. These permits help China control–and even block–some of the outgoing flows. **Gallium** and **germanium** are subject to tighter controls due to their military uses, with an explicit ban on exports to the United States.

Ban on raw mineral exports – Indonesia banned exports of unprocessed nickel in January 2020 in an effort to develop its local processing industry. In February 2025, the DRC followed a similar approach when it banned unprocessed **cobalt** exports, leading to a 67% price rebound.

Sanctions linked to the conflict in Ukraine – CSMs are also used in sanctions against Russia. Australia banned its aluminum exports to Russia and the G7 banned the import of Russian gold.

Bypassing and strategic negotiation – The United States bypassed Chinese restrictions using third countries like Belgium, where germanium exports jumped by 224% between 2022 and 2024, despite an overall decline. This bypass illustrates the limits of control measures. At the same time, U.S. tariffs served as a lever that led to an agreement in June 2025, whereby China agreed to issue temporary licences to re-export certain CSMs to the United States.

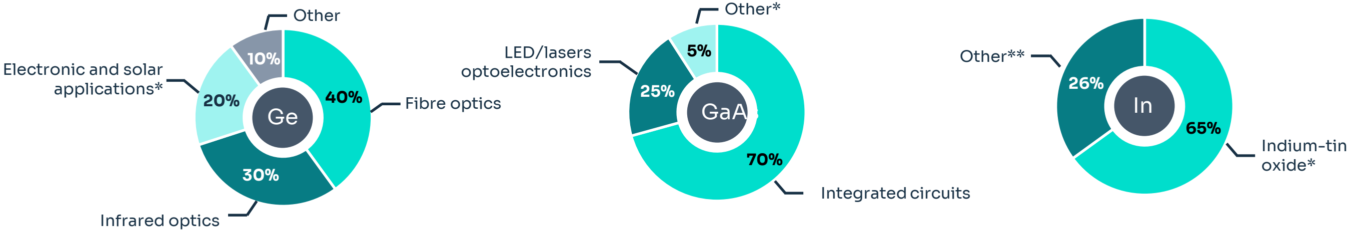
Detailed Analysis | Main Application Study

Although strategic, **the microelectronics and photonics sectors are not the primary outlets for most of the CSMs under analysis.** Very high purity requirements further limit access to materials when other fast-growing sectors like batteries, solar power and aeronautics already take up a significant share of the available supply. **An excessive dependence on these dominant sectors creates a vulnerable supply:** Any instability or strategic reorientation within these markets can directly impact the availability of CSMs.

SECTORAL CONCENTRATION

- **Batteries:** The rise in battery use accounts for a significant share of certain minerals, with **87%** of the demand for Li, **73%** of the demand for Co, **40%** of the global Gr, and **16%** of the global Ni.
- **Solar:** PV demand accounts for **95%** of the demand for high-purity Si, or about 1/3 of the global demand for Si.
- **Solid oxide fuel cells:** Accounts for 55% of the global consumption of Sc.
- **Aeronautics and industrial applications:** Accounts for 85% of the global demand for Ti.
- **Automotive:** The use of Pd in automotive catalytic converters represents, by far, its main application, accounting for approximately **80%** of the demand.

PRIMARY GERMANIUM, GALLIUM, AND INDIUM APPLICATIONS:



**Semiconductors, photodetectors, multi-junction cells for satellites*
***Other: Polymerization catalysts, chemotherapy, metallurgy, phosphors*

**Other: CIGS solar cells, gallium alloys*

**Used primarily in various types of flat screens (LCD/OLED)*
***Other: Alloys and solders, chemical compounds, electrical components, semiconductors*

APPLICATION COMPETITION

Dominant use of microelectronics/photonics – Only **germanium, gallium, and indium** are noted for their specialization in microelectronics and photonics.

Strong competition from other sectors – **Lithium, cobalt, and graphite** are primarily used in batteries, high-purity **silicon** is used in solar technology, **gold** serves as a store of value, **titanium** is used in aeronautics, and **palladium** is used in the automotive sector, making these materials particularly vulnerable within microelectronics/photonics applications.

The concentration of the demand around fast-growing sectors (solar, batteries, aeronautics), combined with **the low substitutability of certain CSMs,** increases the risk of supply tensions. Any new supply **risks immediate captured by these dominant markets,** limiting access for the microelectronics and photonics sectors.

Recycling and Recovery | Quebec Business Opportunities

Effluents and waste from the mining industry abound within secondary, exploitable sources. Quebec is home to considerable assets that can help develop these sectors and has only begun to structure its circular economy. To fully leverage its recycling advantage, **the circular approach must evolve toward the systematic integration of stakeholders (mines, foundries, research centres and innovation zones)** to reduce the sector's fragmentation. This industrial synergy will help **turn environmental constraints into economic levers around CSMs** through collaborative innovations promoted by sector-based industrial research clusters (RSRIs).

KEY FINDINGS

A FEW POINTS OF INTEREST IN THE QUEBEC SECTOR

Strong political will for recycling – The MRNF and MEIE have jointly invested over CAD $14M since 2022 through various support programs that seek to improve CSM circularity in Quebec.

- **Nickel, cobalt and copper:** These receive a considerable portion of funds (46%, 42%, and 25%*, respectively) due to their versatility in the microelectronic and battery sectors, in particular.
- **Indium, gallium and scandium:** Despite a lack of primary production in Quebec, these receive only 3%, 2%, and 2% of funding, respectively.

A sector undergoing industrialization – Several innovative, Quebec-based CSM initiatives are currently in the maturation phase, supported by a favourable framework. With help from the CRITM and PRIMA Quebec, the MRNF supports projects that seek to develop and promote recycling. Amendments to the *Mining Act* now clarify the definition of mining residue exploitation, incorporating the principles of a circular economy.

- **GreeNovel:** The extraction of over 65 metals and elements from unconventional sources like petroleum and electronic waste.
- **Rio Tinto Iron and Titanium (RTIT):** Residue recovery from titanium dioxide production to extract scandium oxide.

QUEBEC CHAMPIONS

GEOMEGA	Pr Nd Nb Co	Recycling of rare earths contained in magnets
Lithion	Li Co Gr Ni	Battery recycling
enim	Pd Cu	Metal recovery from urban mines
5N+	Te In Zn Sb	Largest tellurium processing complex in the world

A Few Projects of Interest

Géoméga Resources: With support from Quebec totalling CAD $3M, this rare earth recovery project is the first pilot plant of its kind in North America.
enim: With over CAD $6.8M in federal and provincial backing, enim operates a cyanide- and mercury-free electronic waste recycling pilot plant (200 t/year).
RTIT: North America's first producer of high-purity scandium.

QC'S DIFFERENTIATING ELEMENTS

Potential for extremely critical minerals – A pilot project in Vaudreuil is underway to extract **gallium** at Rio Tinto's aluminum production plant. Similarly, tests have been conducted to extract **germanium** from zinc by-products.

Strategic projects already underway – Quebec stands out with pioneering projects like Géoméga (rare earths) and RTIT (scandium), the first of their kind in North America.

Local expertise – Quebec is recognized for its metallurgy and chemical engineering know-how, essential in critical mineral recovery.

Research ecosystem – An active network that combines research centers (CNETE, CTTÉI, CTRI, Corem, etc.) and companies (enim, NeoCtech, etc.) is currently developing critical mineral recycling processes.

Clear political support – The province's strategy actively supports the development of recycling and mining residue recovery through targeted financial assistance.

**Sum exceeds 100% due to overlapping mining projects.*

Materials and Minerals | Quebec Business Opportunities

Quebec is particularly well positioned to extract value from the upstream microelectronic/photonic chains. Some extremely critical CSMs with restricted supply chains, like **indium, gallium and germanium**, show strong local recovery potential. Combined with an **existing industrial base for silicon, aluminum,** and **rare earths** in the medium term, this potential could lead to a targeted development strategy.

	International Criticality	Use in Microelectronics/Photonics	Quebec Potential
Indium	●●●● *Supply dominated by China and export restrictions*	●●●● *Essential in photonics (displays, SC, etc.)*	●●●○ Recovery already in place + zinc residue potential
Aluminum	●●●○ *60% of the supply comes from China*	●●○○ *Interconnections and optoelectronic alloys (AlGaAs)*	●●●● Mature chain (8 aluminum plants)
Titanium	●●●○ *68% of metallic titanium comes from China*	●●●○ *Conductive barrier in advanced chips*	●●●○ Ilmenite mining and good potential in Quebec
Copper	●●○○ *Global supply but concentrated applications*	●●●● *Essential metal for interconnections*	●●●● High potential, existing foundry/mine
Scandium	●●●● *Low worldwide production concentrated in CN/RU*	●●○○ *Used in laser doping and conductive alloys*	●●●● RTIT, RTA, and Scandium Canada Sc sector dev.
Palladium	●●●● *Strong dependence on Russia*	●○○○ *Anti-corrosion wire/contact plating*	●●○○ High geological potential, produced in small quantities
Cobalt	●●●● *Very strong dependence on the DRC*	●●○○ *Used for advanced chip contacts*	●●●○ One operational mine produces 200 t/year
Gallium	●●●● *98% of primary production in China*	●●●● *Essential in lasers, LEDs, chips, etc.*	●●○○ Pilot project for aluminum residue recovery
Germanium	●●●● *China accounts for over 60% of the global market*	●●●● *Particularly essential in photonics*	●●○○ Minor recovery, zinc residue potential
Nickel	●●●○ *Extraction concentrated in Indonesia and the Philippines, refining in CN*	●●○○ *Metal contacts, electrodes, and MEMS*	●●●● 42 Kt/year production, high geological potential
Lithium	●●●● *China represents 60% of refining, skyrocketing demand*	●●●● *$LiNbO_3$ + battery for electronic devices*	●●●○ High geological potential + several active projects
Niobium	●●●○ *Supply concentrated in Brazil (>85%)*	●●●○ *$LiNbO_3$, TFLN, and other superconductor components*	●●●● 6% of world production, 2nd largest global producer
Silicon	●○○○ *Abundant quartz resources*	●●●● *Basis for semiconductors*	●●●○ Two silica mines, two Si metal producers
Graphite	●●●● *Strong dependence on China*	●●●○ *Anode materials + flexible electronics*	●●●○ Graphite and graphene plants
Rare earths	●●●● *Extreme criticality – concentrated in China*	●●○○ *Permanent magnets, optical modulators*	●●●○ Several recovery projects underway

Legend: ●○○○ / ●●●●
Low ▲ ▲ *High*

05

Summary and Conclusion: Seven Themes of Interest

Summary and Conclusion | Introduction

TECHNOLOGY AND MARKET

FIRST PRIORITIZATION STEP COMPLETED

From a technological and commercial standpoint, the **13 photonics and microelectronics segments**, along with the **15 strategic minerals and materials** previously analyzed, **represent the Quebec sector's main business and research opportunities.**

These business opportunities would allow for the following:

- Reducing **dependence on imports**
- **Diversifying export markets** towards allied countries
- **Strengthening national security and defense capabilities**

CANADIAN AND QUEBEC POLICIES

Several major initiatives should be considered when **creating public drivers** aimed at supporting the development and seamless integration of the value chains for photonic and microelectronic products:

Defense budget and investment – As a NATO member, Canada has agreed to increase its annual defense and security spending from 1.3% of GDP in 2023 to 5% in 2035, **rising from CAD $41B per year to more than CAD $150B.**

Canada/Quebec collaboration – The Canadian and Quebec governments intend to collaborate on the implementation of major mining, energy, and industrial projects while improving the integration of CSMs into national supply chains.

The Québec Plan for the Development of Critical and Strategic Minerals – The government is currently developing a new version of Quebec's CSM and recycling strategy.

This provides an opportunity for Quebec companies and the organizations that support them to **assess these opportunities and consider those that appear most relevant** in their positioning strategies, actions, and support services. We recommend focusing measures on the **seven themes of interest** that emerged after conducting this study.

Theme of Interest | Critical Mineral Resources

SIGNIFICANT POTENTIAL FOR CRITICAL MINERAL RESOURCES

Quebec holds a considerable amount of critical mineral assets for microelectronics and photonics. Certain CSMs with restricted supply chains but deemed extremely critical (e.g., **indium, gallium, and germanium**) reveal a strong potential for local development.

Combined with an existing industrial base for **silicon, nickel, copper, aluminum and rare earths** over the medium term, this potential could support local and export-oriented microelectronics and photonics sectors.

REFLECTION POINTS – Strengthening industrial links between CSMs and their applications within strategic sectors (defense, telecom, datacom, etc.), combined with better coherence between Canadian and Quebec CSM strategies and sectoral priorities, would help maximize economic and technological benefits.

Two complementary methods could be combined to further develop local value chains: **Seeking sufficient volumes to reach a critical mass** in the market, and **consideration for sovereignty imperatives,** without neglecting smaller-scale production.

REFLECTION POINTS – Increased support for collaborative R&D and local production of next-generation substrates and materials (GaN, LNOI, bio-based polymers, BTO, etc.), thus leveraging Quebec's current strengths (including its expertise in material chemistry and nanomanufacturing, for example), would create more value from the processing of these resources.

Theme of Interest | Value Chain Integration

FRAGMENTED AND INCOMPLETE VALUE CHAINS

Quebec's CSM, photonics, and microelectronics value chain is fragmented, with few connections between **upstream, midstream, and downstream segments.** Raw materials (minerals and alloys) are mostly exported without local processing, while many intermediate inputs (components, refined materials, etc.) are imported and **thus vulnerable to foreign tariffs and export restrictions.**

Moreover, **few bridges exists between technology developers and end-user sectors.** This situation hinders the emergence of integrated and strategically positioned value chains. These sectors present complementarities that would benefit from greater exploitation.

EXAMPLE OF INTER-SECTOR SYNERGY – Recovering gallium from industrial residues would help the production of photonic components (lasers, compound semiconductors, etc.). Conversely, infrared camera technologies can be used in mining exploration to analyze cores and identify critical minerals.

Improved coordination would help link **upstream segments** (extraction, refining) **to downstream applications** (defense, telecom, datacom, etc.), by identifying synergies and missing links.

REFLECTION POINTS – A number of Quebec stakeholders seem to gravitate toward compound semiconductor technologies and photonic integrated circuits, particularly in relation to quantum photonics, silicon photonics and packaging. However, these dynamics are unfolding in a context where local manufacturing capacity continues to lag behind.

Theme of Interest | Collaborative R&D

STRENGTHENING VALUE CHAINS THROUGH COLLABORATIVE INNOVATION

Collaborative innovation remains essential when de-risking and developing **technological leadership** in areas where **Quebec is well positioned.** These areas are **undergoing robust global growth**, like quantum photonics, date centre components, silicon photonics, and advanced imaging systems.

In Quebec, several innovative SMEs remain active in these areas; **these could be accelerated through strong bridges between research and industry** to facilitate the transition from R&D to industrialization.

This collaborative innovation role should not be limited to downstream technology. It should extend to the entire value chain, including **upstream** (mineral processing, materials chemistry, etc.) **and intermediate stages** (manufacturing processes, packaging, recycling, etc.).

EXAMPLE OF COLLABORATIVE R&D TOPICS UPSTREAM FROM THE VALUE CHAIN – In an effort to overcome the main competitiveness challenges inherent in Quebec-based projects, R&D activities involving minerals, materials and processes could help the province obtain high-purity oxides, for example, or recycle electronic products and recover by-products at lower costs while developing newer products and materials to replace rarer ones.

RSRIs could help support these initiatives and **strengthen the link between industry and research**, since their role involves connecting industrial needs with research expertise. By promoting **inter-sectoral and stakeholder collaboration**, RSRIs provide a structural lever that could accelerate the development of collective projects.

EXAMPLE OF COLLABORATIVE R&D TOPICS ON RECYCLING/RESIDUE RECOVERY – Electronic product recycling and low-cost by-product recovery could play a pivotal role when strengthening critical material autonomy. For example, reintegrating CSMs into urban mine production chains demands very high levels of purity.

Theme of Interest | Mining Residues and Urban Mines

EFFLUENTS AND WASTE FROM THE MINING AND ELECTRONICS INDUSTRIES PROVIDE RICH, EXPLOITABLE SECONDARY SOURCES

Quebec is home to **significant deposits of secondary resources from mining residues, industrial flows, and electronic waste,** offering a tremendous opportunity to strengthen its supply of critical and strategic minerals.

Initiatives are already underway involving battery and electronic circuit recycling, along with mining by-product recovery, with support from the 2020 Québec Plan for the Development of Critical and Strategic Minerals (QPDCSM). Bringing together and **connecting the mining, metallurgical and electronics sectors, as well as research centres,** would help accelerate structuring efforts for this ecosystem.

The **urban mine concept**, still underutilized, also represents a promising path for CSM recovery from high value-added electronic waste (copper, rare earths, gallium, etc.). To ensure adequate purity levels, the **reuse and reintegration of CSMs** in microelectronics and photonics must leverage existing research capabilities.

INTERNATIONAL EXAMPLE – At the internationally level, several countries are strengthening their electronic waste flow regulations in an effort to create local urban mines. The European Union, for example, has imposed more stringent restrictions regarding the export of electronic waste, while the United States is currently studying similar legislative proposals. These initiatives seek to limit the loss of critical materials while encouraging local reprocessing.

LOCAL EXAMPLE – Rio Tinto has produced primary gallium by refining alumina and intends to build a commercial plant in Saguenay-Lac-Saint-Jean (40 t/year, or 5 to 10% of global production), subject to conclusive results. Several similar projects have been implemented, while others are currently under study in an effort to recover scandium oxide and germanium.

Theme of Interest | Industrial Upscaling

MARKET ACCESS AND FINANCING AS STRUCTURING FACTORS

The Quebec market remains limited in size, prompting stakeholders in microelectronics and photonics to expand their presence beyond the provincial territory to support their development. Thus, **most of the clients attracted by the province's stakeholders work outside Quebec** (for example, 75% of the Canadian Photonics Fabrication Centre's clients are foreign).

Market access and commercialization capacities must be developed to help companies **industrialize their activities**.

REFLECTION POINTS – Access to **public markets could help stimulate local demand** and support the commercialization of Quebec technologies. **Integrating criteria that promotes locally developed electronic and photonic components** within strategic sectors (defense, telecom, datacom, etc.) would help secure an initial volume of activity and facilitate industrialization.

INTERNATIONAL EXAMPLE – The U.S. Department of Defense designated a "Trusted Foundry" program for its microcircuits during the 2000s, with the aim of **storing certain critical supplies for approved domestic foundries and assemblers,** thus securing a closed market for national stakeholders and military needs.

Moreover, access to capital when transitioning from R&D to industrialization remains a challenge in Quebec. Quebec excels in R&D and prototyping, but **the lack of capital during growth phases pushes several companies to seek international financing.**

The difficult transition from R&D grants to venture capital **can limit local development while promoting early acquisitions.** In photonics in particular, **the vertical structuring behind the large international groups** that concentrate innovation and value often facilitates their acquisition of growth companies.

Theme of Interest | Creating Alliances

ALLIANCES THAT EXPAND MARKET ACCESS

However dynamic, **the Quebec market and ecosystem face certain limitations regarding scale and access.** Developing interprovincial **collaborations, notably between Ontario and Alberta**, as well as partnerships between SMEs and large companies–both in Quebec and Canada–would help pool resources, strengthen supply chain complementarity, and increase the commercial reach of locally developed solutions.

COLLABORATION EXAMPLE – Collaborations already underway between the the CPFC (home to compound semiconductor manufacturing capabilities) and Quebec's packaging, laser and photonic integrated circuit ecosystem could pave the way for a deeper integration of value chains between the two provinces.

At the international level, **existing collaborations with the United States** could help develop complementary partnerships while **intensifying new collaboration pathways with European and Asian ecosystems.**

This approach would help **strengthen the resilience of value chains, develop new international export markets, expand financing sources, and stimulate innovation without undermining established relationships.**

INTERNATIONAL COLLABORATION EXAMPLE – The United States-Japan semiconductor partnership intends to co-develop advanced chips and research post-2nm technologies while strengthening supply chains. It mobilizes public and industrial stakeholders while strengthening commercial ties between both countries.

Theme of Interest | A Culture of Convergence

AN EMERGING CULTURE OF COLLABORATION AND A SHARED VISION

The study **established an initial mapping of Quebec's CSM, advanced materials, microelectronics, and photonics sectors,** identifying their key strengths, weaknesses, and business opportunities, along with the **interconnected relationships** that exist within their value chains and technological segments.

The work also **highlighted several topics of collective interest,** as well as **potential complementarities between these sectors.** A need remains for additional analyses targeting specific niches and axes to **deepen its findings, confirm the opportunities cited, and identify the levers** that require mobilization.

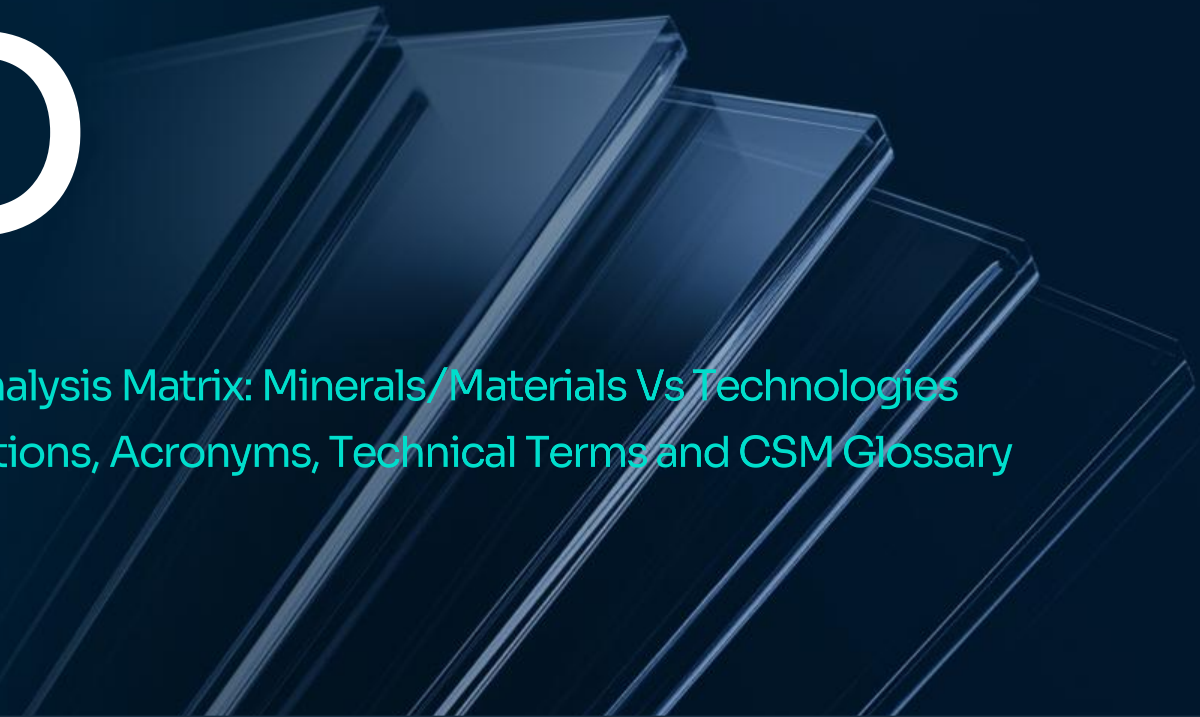
Alongside its analytical contributions, the study has, to some extent, helped **promote closer ties among the stakeholders involved in the development of these sectors.** By bringing together representatives from diverse backgrounds (industry, support organizations, public institutions, etc.), it helped **broaden the awareness** of the interdependencies that exist along the value chains.

This dynamic may have strengthened the perception of a common interest, helping to **establish the foundations of a more integrated sectoral culture that is conducive to the development of coordinated projects** and better strategic coherence between existing initiatives.

REFLECTION POINTS – Encouraging initiatives that promote closer ties, discussions, and collaboration among these stakeholders can help consolidate the emergence of a shared culture among stakeholders in microelectronics, photonics, advanced materials and CSMs while strengthening the coherence of collective actions and developing a more integrated ecosystem.

06

Appendices



Minerals and Materials | Correspondence Table *(1/4)*

This cross-analysis highlights the **links between each technology and the materials required in order to build an overall vision** by identifying **the occurrences of each material and their critical overlap.**

RAW MATERIALS

Product	Si	In	Al	Ti	Ni	GaAs	As	P	Ge	Sb	Zn	Au	N	Pd	Co	C	Pt	Cu	Sn	Sc	Li	Ta	Nd	Fe	Pb	Ag
Optical Transducers	X	X	X		X	X	X	X	X				X		X	X										
SC Lasers	X	X	X	X	X	X	X	X		X	X	X	X	X			X									
Imaging Systems	X	X	X		X	X	X	X	X	X			X		X	X		X		X	X			X		
Quantum	X																						X			
Packaging	X	X	X	X	X				X			X		X	X		X	X	X	X		X				
MEMS	X	X	X	X		X	X	X	X	X	X	X					X	X	X	X	X	X	X		X	
PIC	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X									X		
Printed Circuits	X	X	X	X	X					X	X	X		X	X			X	X			X	X		X	X
Bio-Based Electronics				X							X					X		X	X		X					X
Compound SC	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X									
SC Optical Amplifiers	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X									
TOTAL	10	9	9	8	8	7	7	7	7	7	7	7	6	6	5	5	5	5	4	3	3	3	3	2	2	2

Minerals and Materials | Correspondence Table *(2/4)*

This cross-analysis highlights the **links between each technology and the materials required in order to build an overall vision** by identifying **the occurrences of each material and their critical overlap.**

	RAW MATERIALS															MATERIALS								
Product	Ne	Rb	Ca	Mo	Zr	Nb	Er	Gd	Y	Br	S	Bi	Mg	Dy	Pr	Al_2O_3	Si_3N_4	SiC	SiO_2	HfO_2	Ba	AlN	$LiNbO_3$	$BaTiO_3$
Optical Transducers																X	X	X						
SC Lasers																X			X	X				
Imaging Systems																X	X	X						
Quantum	X	X	X											X	X	X					X			
Packaging																								
MEMS				X	X	X	X	X	X													X		
PIC																X	X		X				X	X
Printed Circuits										X	X	X							X					
Bio-Based Electronics													X											
Compound SC																X		X						
SC Optical Amplifiers																X	X							
TOTAL	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	7	4	3	3	1	1	1	1	1

Minerals and Materials | Correspondence Table *(3/4)*

This cross-analysis highlights the **links between each technology and the materials required in order to build an overall vision** by identifying **the occurrences of each material and their critical overlap.**

PROCESS REAGENTS AND PRECURSORS

Product	N_2	Cl_2	He	H_2	AsH_3	PH_3	HCl	Se	Te	Be	Hf	H_2SO_4	Cl	SF_6	BR_2	$SiCl_4$	Ar	TMGa	TMIn	F	Ru	SiH_4	B_2	H_2Se
Optical Transducers	X	X	X								X	X	X			X	X						X	
SC Lasers	X	X		X	X	X	X	X	X	X				X				X	X					X
Imaging Systems	X	X	X								X	X			X	X	X			X				
Quantum			X																					
Packaging											X										X			
MEMS																					X			
PIC	X		X	X	X	X	X	X	X	X			X					X	X					
Printed Circuits													X							X				
Bio-Based Electronics																								
Compound SC	X	X		X	X	X	X	X	X	X		X		X	X							X		
SC Optical Amplifiers	X	X		X	X	X	X	X	X	X				X	X							X		
TOTAL	**6**	**5**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**3**	**3**	**3**	**3**	**3**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**1**	**1**

Minerals and Materials | Correspondence Table *(4/4)*

This cross-analysis highlights the **links between each technology and the materials required in order to build an overall vision** by identifying **the occurrences of each material and their critical overlap.**

PROCESS REAGENTS AND PRECURSORS

Product	BCl_3	O_2	C_2H_6	C_2H_4	Br_2	TMSb	TMAl	H_2O_2
Optical Transducers								
SC Lasers	X	X	X	X	X			
Imaging Systems								
Quantum								
Packaging								
MEMS								
PIC						X	X	
Printed Circuits								
Bio-Based Electronics								
Compound SC								X
SC Optical Amplifiers								
TOTAL	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**

The analysis **placed a particular emphasis on raw materials** due to their strategic importance, Quebec's potential with regard to extraction, refining and recycling, and their critical upstream role in value chains.

Abbreviations

Semiconductor Optical Amplifiers

SOA	Semiconductor Optical Amplifiers
FMCW	Frequency Modulated Continuous Wave
LA	Limiter Amplifier
LiDAR	Light Detection And Ranging

Printed Circuits

ABF	Ajinomoto Build-Up Film
BT	Bismaleimide-Triazine
Df	Dissipation Factor
Dk	Dielectric Constant
ENEPIG	Electroless Nickel Electroless Palladium Immersion Gold
ENI	Electroless Nickel Finish
ENIG	Electroless Nickel Immersion Gold
FR4	Glass Fibre-Reinforced Epoxy
HASL	Hot Air Solder Leveling
HDI	High-Density Interconnection
HMI	Human-Machine Interface
IMS	Insulated Metal Substrate
ODM	Original Design Manufacturer
OSP	Organic Surface Protection

Photonic Integrated Circuits

LiNbO3	Lithium Niobate
LNOI	Lithium Niobate On Insulator
OSFP-XD	Octal Small Form Factor Pluggable – Extended Density

Bio-Based Electronics

PE	Polyethylene
PET	Polyethylene Terephthalate
PHA	Polyhydroxyalkanoates
PLA	Polylactic Acid

Packaging

BSPDN	Backside Power Delivery Network
CHP	Chiplet
CoWos	Chip-on-Wafer-on-Substrate
CSP	Chip-Scale Package
EMIB	Embedded Multi-Die Interconnect Bridge
FC BGA	Flip-Chip BGA Package
Foveros	Foveros 3D Packaging
HBM	High Bandwidth Memory
HPC	High-Performance Computing
InFO	Integrated Fan-Out

Abbreviations

RDL	Redistribution Layers
SoIC	System On Integrated Chip
VIPack	Versatile Integrated Packaging

Post-Processing

ASIC	Application-Specific Integrated Circuit
DMD	Digital Micromirror Devices
Print	Printing
NGS	Next-Generation Sequencing
xMR	Magnetoresistive Sensor

Quantum

FTQC	Fault-Tolerant Quantum Computing
NISQ	Noisy Intermediate-Scale Quantum
QSaas	Quantum Software as a Service
QCaas	Quantum Computing as a Service

Compound Semiconductors

DC-DC	Direct current
FR3	Frequency Range 3
MBE	Molecular Beam Epitaxy
MOCVD	Metalorganic Chemical Vapor Deposition
OBC	Onboard Charger

Imaging Systems

InSb	Indium Antimonide
kU	Thousand Units
LWIR	Long-Wave Infrared
MWIR	Mid-Wave Infrared
NIR	Near-Infrared
SWIR	Short-Wave Infrared
TIA	Transimpedance Amplifier

Laser Systems

EUV	Extreme Ultraviolet Lithography
FBG	Fibre Bragg Grating
LMD	Laser Metal Deposition
LPSSL	Laser-Pumped Solid-State Laser

Optical Transducers

AOC	Active Optical Cables
BOSA	Bidirectional Optical Subassembly
CDR	Clock and Data Recovery
CPO	Co-Packaged Optics
DML	Directly Modulated Laser
DSP	Digital Signal Processor
DWDM	Dense Wavelength-Division Multiplexing

Abbreviations

EML	Electro-Absorption Modulated Laser
FTTx	Fibre to the X
GPON	Gigabit PON
LPO	Linear Optics
MCU	Microcontroller Unit
PON	Passive Optical Network
TOSA	Transmitter Optical Subassembly
XGS-PON	10-Gb/s Symmetric PON
Transverse	
ADAS	Advanced Driver-Assistance Systems
BTO	Barium Titanate
CA	Canada
CAD	Canadian Dollar
CCTT	Centre Collégial de Transfert de Technologies
IC	Integrated Circuits
PIC	Photonic Integrated Circuits
cm	Centimetre
CMOS	Complementary Metal-Oxide Semiconductor
CMUT	Capacitive Micromachined Ultrasonic Transducers
CW	Continuous Wave

DataCom	Data Communication
DFB	Distributed Feedback Laser
DLP	Digital Light Processing Projector
DPSSL	Diode-Pumped Solid-State Laser
DUV	Deep Ultraviolet Lithography
I/O	Input/Output
EEL	Edge-Emitting Laser
U.S.	United States
Flex	Flexible
B	Billion
GaAs	Gallium Arsenide
GaN	Gallium Nitride
Gb/s	Gigabit Per Second
LE	Large Enterprise
Ge	Germanium
GHz	Gigahertz
Gov	Government
AI	Artificial Intelligence
IMU	Inertial Measurement Unit
InGaAs	Indium Gallium Arsenide
InP	Indium Phosphide

Abbreviations

IoT	Internet of Things
IR	Infrared
km	Kilometre
kW	Kilowatt
LD	Laser Diode Driver
LED	Light-Emitting Diode
M	Million
m	Metre
AM	Advanced Materials
CSM	Critical and Strategic Minerals
MEMS	Micro-Electromechanical System
mm	Millimetre
N/A	Not Applicable
NDT	Non-Destructive Testing
nm	Nanometre
OEM	Original Equipment Manufacturer
OLED	Organic Light-Emitting Diode
PCB	Printed Circuit Board
IP	Intellectual Property
SME	Small and Medium-Sized Enterprises

PMUT	Piezoelectric Micromachined Ultrasonic Transducers
QC	Quebec
AR	Augmented Reality
R&D	Research and Development
RF	Radio Frequency
ROSA	Receiver Optical Subassembly
UK	United Kingdom
VR	Virtual Reality
CS	Compound Semiconductor
NAICS	North American Industry Classification System
SiC	Silicon Carbide
SiGe	Silicon-Germanium
SiN	Silicon Nitride
SiP	System In Package
SiPh	Silicon Photonics
SOI	Silicon on Insulator
Tb	Terabit
Tb/s	Terabit Per Second
CAGR	Compound Annual Growth Rate
TFLN	Thin-Film Lithium Niobate on Insulator
VSE	Very Small Enterprise

Abbreviations

TRL	Technology Readiness Level
EU	European Union
USD	U.S. Dollar
UV	Ultraviolet
VCSEL	Vertical-Cavity Surface-Emitting Laser
W	Watts
WDM	Wavelength-Division Multiplexing
ZR	Zero Radius

Acronyms

3iT	Interdisciplinary Institute for Technological Innovation
ALLS	Advanced Laser Light Source
C2MI	MiQro Innovation Collaboration Centre
CFPC	Canadian Photonics Fabrication Centre
CIFAR	Canadian Institute for Advanced Research
CII	Centre d'Innovation Industrielle
COPL	Centre for Optics, Photonics, and Lasers
CRITM	Consortium de Recherche et d'Innovation en Transformation Métallique
CRIAQ	Consortium de Recherche et d'Innovation en Aérospatiale au Québec
CRIBIQ	Consortium de Recherche et Innovations en Bioprocédés Industriels au Québec
NSERC	Natural Sciences and Engineering Research Council of Canada
CRVI	Centre de Robotique et de Vision Industrielles
EMT	Énergie Matériaux Télécommunications
FRQ	Fonds de Recherche du Québec
I-CI	Institut des Communications Graphiques et de l'Impression
INO	Institut National d'Optique
INRS	Institut National de Recherche Scientifique

INTRIQ	Transdisciplinary Institute for Quantum Information
IQ	Investissement Québec
IQ-UdeS	Institut Quantique (Université de Sherbrooke)
ISED	Innovation, Science and Economic Development Canada
ISEQ	Industrie des Systèmes Électroniques du Québec
ITAR	International Traffic in Arms Regulations
MEIE	Ministère de l'Économie, de l'Innovation et de l'Énergie
MILA	Institut Québecois d'Intelligence Artificielle
MRNF	Ministère des Ressources Naturelles et des Forêts
NASA	National Aeronautics and Space Administration
NORAD	North American Aerospace Defense Command
OEM	Original Equipment Manufacturer
PART-IT	Programme d'Aide à la Recherche et au Transfert en Innovation Technologique
PCBA	Protecting Circuit Boards Act
PINQ^2	Plateforme d'Innovation Numérique et Quantique du Québec
PolyMTL	Polytechnique Montreal
ReSMiQ	Regroupement Stratégique en Microsystèmes du Québec
NRCan	Natural Resources Canada
SIA	Semiconductor Industry Association
SPIE	International Society for Optics and Photonics
UdeM	Université de Montréal
UdeS	Université de Sherbrooke
ULaval	Université de Laval

English Translation of Technical Terms

Affichage	Display
Apprentissage automatique	Machine learning
Assembly	Assembly
Boîte quantique ou point quantique	Quantum dot
Sous unité modulaire de puce	Chiplet
Consommation/Consommation grand public/Grande consommation	Consumer
Effet tunnel	Tunneling
Émetteurs-récepteurs optiques	Optical transceivers
Extended packaging	Fan-Out
Encapsulation/Encapsulation avancée	Packaging
Excimer	Excimer
Fonderie	Semiconductor foundry
Informatique	Computing
Post traitement	Post-processing
Puce	Chip
Puce retournée	Flip-Chip
Reconnaissance faciale	FaceID
Séparateur	Splitter
Tranche ou gaufrette	Wafer

CSM Glossary

Ag	Silver
Al	Aluminum
Al_2O_3	Aluminum oxide
AlN	Aluminum nitride
AlO_3	Alumina (aluminum oxide)
Ar	Argon
As	Arsenic
AsH_3	Arsine
Au	Gold
B_2	Diboron
Ba	Barium
$BaTiO_3$	Barium titanate
BCl_3	Boron trichloride
Be	Beryllium
Bi	Bismuth
Br	Bromine
Br_2	Dibromine
Bx	Bauxite

C	Carbon
C_2H_4	Ethylene
C_2H_6	Ethane
Ca	Calcium
Cl	Chlorine
Cl_2	Dichlorine
Co	Cobalt
Cr	Chromium
Cu	Copper
Dy	Dysprosium
Er	Erbium
F	Fluorine
Fd	Iron (alternate form)
Fe	Iron
GaAs	Gallium
Gd	Gadolinium
Ge	Germanium
GrN	Graphene nitride
H_2	Hydrogen (molecular)
H_2O_2	Hydrogen peroxide
H_2Se	Hydrogen selenide

CSM Glossary

H_2SO_4	Sulfuric acid
HCl	Hydrogen chloride
He	Helium
Hf	Hafnium
HfO_2	Hafnia
In	Indium
Li	Lithium
$LiNbO_3$	Lithium Niobate
Mb	Molybdenum (alternate form)
Mg	Magnesium
Mn	Manganese
Mo	Molybdenum
N	Nitrogen
N_2	Nitrogen (molecular)
Nb	Niobium
Nd	Neodymium
Ne	Neon
Ni	Nickel
O_2	Oxygen or dioxygen
P	Phosphorus
Pb	Lead

Pd	Palladium
PH_3	Phosphine
Pr	Praseodymium
Pt	Platinum
Rb	Rubidium
Re	Rhenium
Ru	Ruthenium
S	Sulfur
Sb	Antimony
Se	Selenium
SF_6	Sulfur hexafluoride
Si	Silicon
Si_3N_4	Silicon Nitride
SiC	Silicon Carbide
$SiCl_4$	Silicon tetrachloride
SiH_4	Silane
SiO_2	Silicon dioxide
Sn	Tin
Sr	Strontium
Ta	Tantalum

CSM Glossary

Te	Tellurium
Ti	Titanium
TMAl	Trimethylaluminum
TMGa	Trimethylgallium
TMIn	Trimethylindium
TMSb	Trimethylantimony
RE	Rare earths
V	Vanadium
W	Tungsten
Y	Yttrium
Zn	Zinc
Zr	Zirconium

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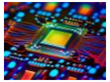
Status of MEMS Industry


Status of the CMOS Image Sensor Industry


Silicon Photonics - Focus on SOI, SiN, and LNOI platforms


Digital X-Ray imaging


Global Market of Lasers 2025

Technologies, Markets, Applications and Future Trends

Global market of lasers


SWIR, MWIR and Cooled Infrared Imaging


Status of the Camera Module Industry


Thermal Imaging and Sensing


Status of the Advanced Packaging Industry


Semiconductor Laser Industry


Optical Transceivers for Datacom and Telecom


Overview of the Semiconductor Device Industry


Status of the Compound Semiconductor Industry


Quantum Technologies


Status of the Compound Semiconductor Device Industry


Semiconductor Trends in Data Centers


Semiconductor Trends for Automotive


Status of the Wafer Fab Equipment Industry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