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materials for a better life

Ge Substrates for Photonics and PV

Ensuring Supply Security, Advancing Recycling and Enabling CMOS Integration

Ivan Zyulkov
CS International
April 16th, 2024

2023 Key figures

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Revenues	Colleagues
€ 3.9 bn	**11 565**
Adj. EBITDA	**Adj. EBITDA margin**
€ 972 mn	**25.0%**
ROCE	**Net zero** Scope 1 & 2 GHG emissions
13.5%	**2035**

- ✓ Resilient performance with > € 200 mn PGM price and inflation headwinds
- ✓ While significantly stepping up investments for future growth

Revenue:
All revenue elements less the value of the following purchased metals: Au, Ag, Pt, Pd, Rh, Co, Ni, Pb, Cu, Ge, Li and Mn

Our Group structure - EOM

BATTERY MATERIALS	CATALYSIS	RECYCLING	SPECIALTY MATERIALS
Umicore Battery Materials	Automotive Catalysts	Precious Metals Refining	**Electro-Optics Materials**
Battery Metals Refining	Precious Metals Chemistry	Jewelry & Industrial Metals	Metal Deposition Solutions
	Fuel Cell & Stationary Catalysts	Battery Recycling Solutions	Cobalt & Specialty Materials
	Precious Metals Management		

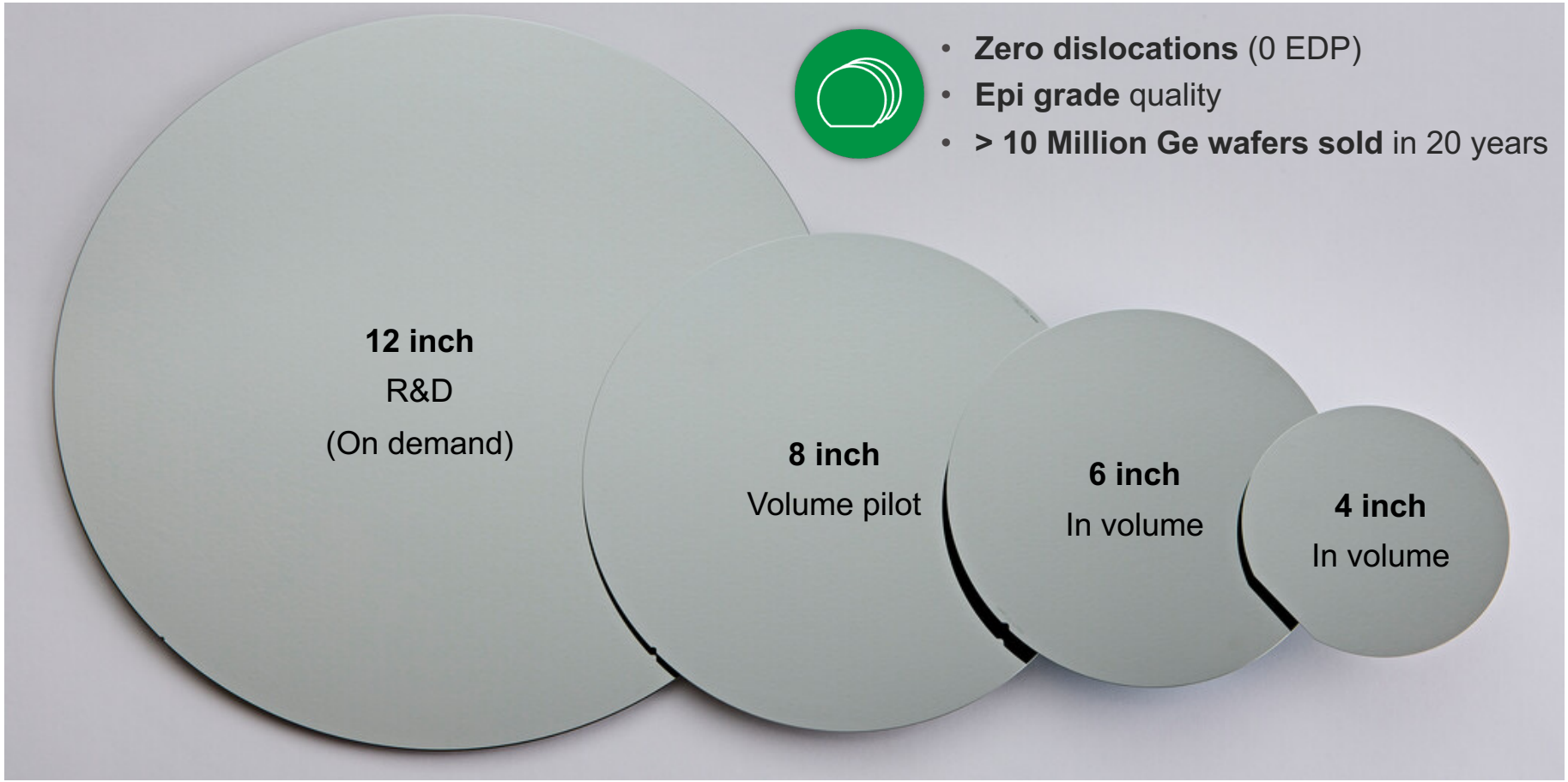
Electro-Optic Materials

2 Business Lines

Contents

- Germanium properties and its applications.
- Photonics and PV applications of Ge substrates.
- Ge sourcing and Recycling.
- Reusable Ge platform.
- Conclusions.

Umicore Germanium substrates



Umicore offers epi-ready Ge substrates of various diameters (from 4” to 12”)

Basic Germanium properties

Property	Silicon	GaAs	Germanium
Crystal structure	Diamond	Zincblende	Diamond
Density (g/cm^3)	2.33	5.32	5.33
Lattice constant (Å)	5.430	5.653	5.658
Bandgap energy at 300K (eV)	1.12	1.42	0.66
Cut-off wavelength (µm)	1,06	0,87	1,6
Electron mobility ($cm^2/V\text{-}s$)	1350	8500	3900
Hole mobility ($cm^2/V\text{-}s$)	480	400	1900
Melting point (°C)	1415	1238	937
Thermal expansion (1/°C)	$2.6\ 10^{-6}$	$5.7\ 10^{-6}$	$5.9\ 10^{-6}$
Thermal conductivity (W/cm°C)	1.3	0.55	0.58
Fracture toughness ($MPa.m^{1/2}$)	0.8	0.3	0.7
Young's modulus (GPa)	130-188	85-130	103-153

Si and Ge are elemental indirect semiconductors with similar up to 12” diameter 0 EPD* crystal processes

Ge and GaAs are lattice matched

Ge cut-off wavelength enables SWIR photodiodes

Ge and GaAs have similar thermal expansion & conductivity

Ge is twice as tough as GaAs

Ge [100] is 18% less prompt to deformation vs GaAs

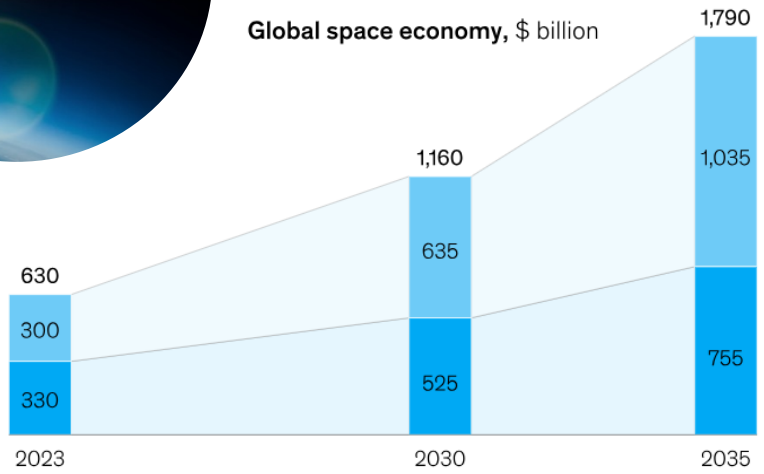
** EPD: Etch pitch density, dislocation density*

PV applications

MJ solar cells

Space power

Space market is set to double by 2030, triple by 2035



Source: Future of Space Economy research

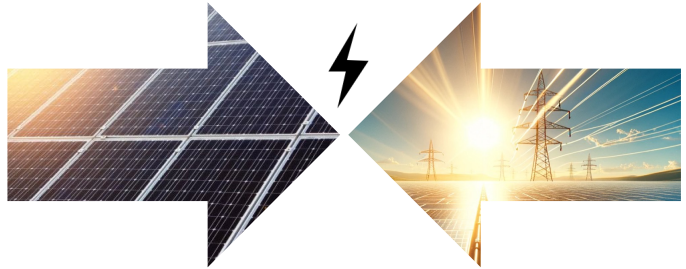
Concentrated PV (CPV)

Re-birth of CPV - Expected to reach GW-scale as of 2030.

RAYGEN

Space-grade high efficiency solar cells

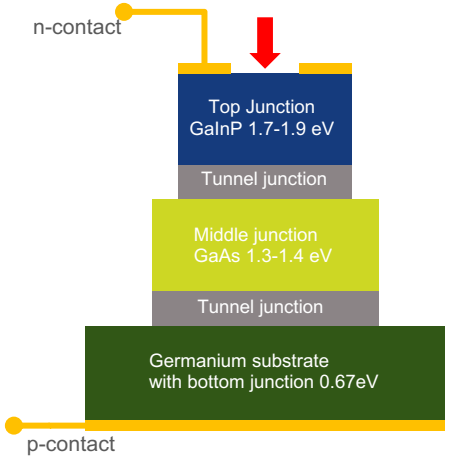
Heat from the concentrated light



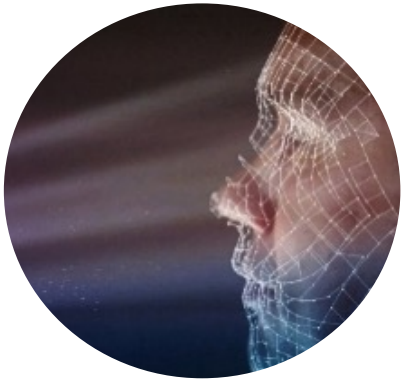
- Ge substrates are stronger than GaAs, thinner and more light weight, provide an extra solar cell junction.
- Swift growth in Space PV and CPV markets drives the demand for Ge substrates.

Photonic applications

Ge lattice match with GaAs allows its use in various photonics application



Triple-junction solar cell structure



VCSELs
3D sensing

SWIR sensors
3D sensing

Micro-LEDs
VR/MR

- Ge lattice constant is beneficial for several photonics applications.
- Multiple developments using Ge substrates in VCSELs, Sensors and micro-LEDs.

Photogenic – Ge based VCSEL for automotive

PHOTOGENIC

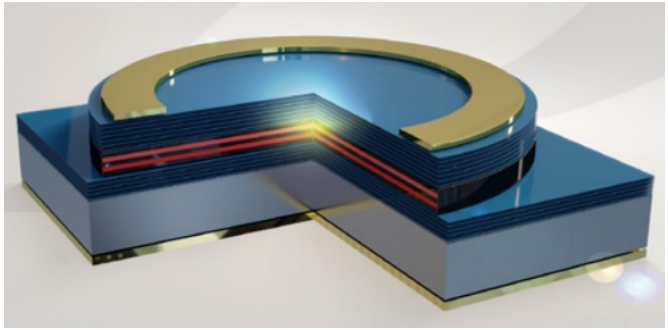
Budget

4.8 M euro

(100% EU-funded)

Duration

36 months



https://horizon-photogenic.eu/

TECHNIKON

TECHNIKON Forschungs- und Planungsgesellschaft mbH Austria (Villach)

VIGO PHOTONICS

pmd IMAGINE YOU CAN

umicore Electro-Optic Materials

Lodz University of Technology

cnrs LAAS CNRS

XenomatiX True solid state lidar

Funded by the European Union

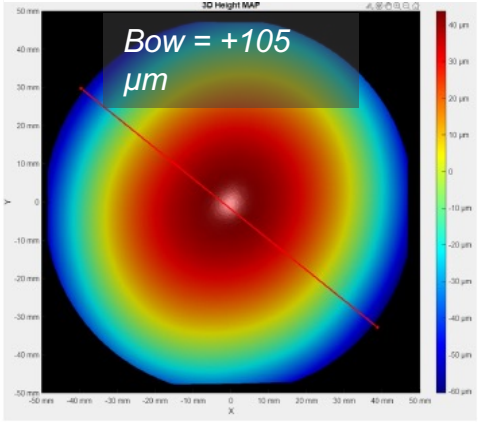
The PhotoGeNIC project is funded by the European Union under grant agreement No. 101069490. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them.

Photogenic – Ge based VCSEL for automotive

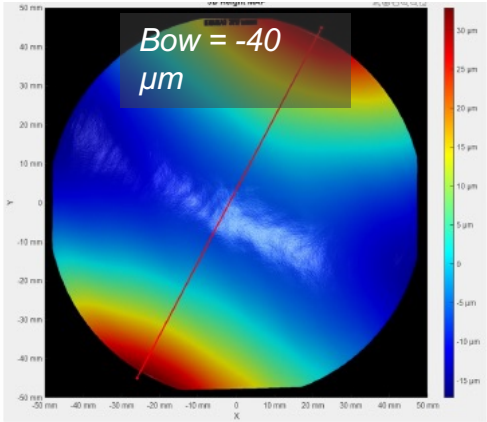
PHOTOGENIC

- VIGO wafers measured by deflectometry at LAAS-CNRS
- GaAs/AlGaAs VCSELs are compressively stressed on GaAs but strain-balanced on Ge

VCSEL on 4'' GaAs



VCSEL on 4'' Ge



Current status:

- Epitaxial growth on Ge with AlGaAs buffer layer
- Functional VCSELs on Ge substrate
- Ohmic contact on n-doped Ge
- Processing of first working devices

Next steps:

- Further Improving Ge-VCSELs Epitaxy & Processing
- Design and Fabrication of Ge-VCSELs for LiDAR and iTOF systems

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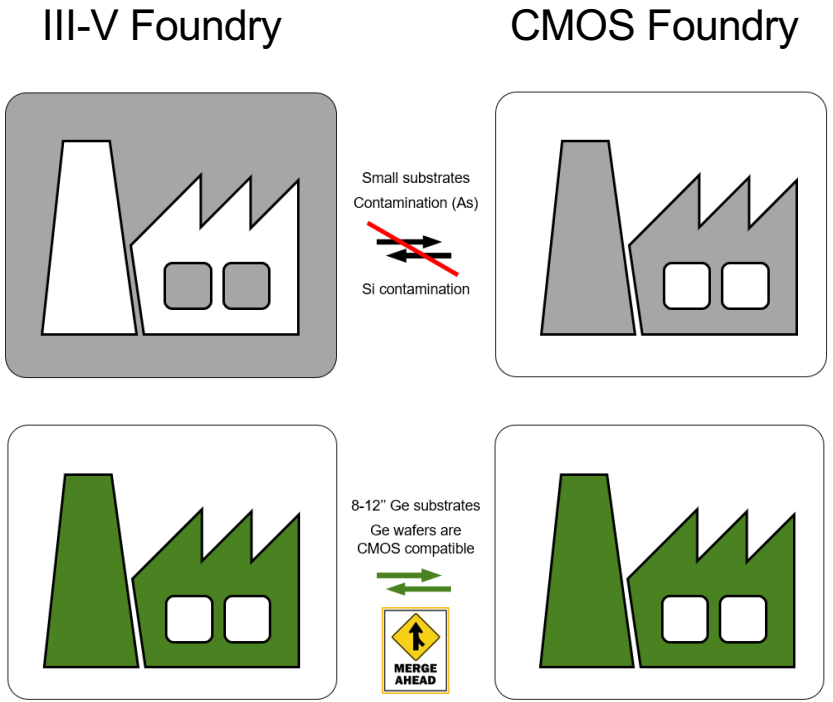
III-V processing in CMOS Fabs



CMOS offers a set of very advanced processing steps and low production cost in high volumes.

Ge substrate is compatible with CMOS production, while other III-V substrates are not (GaAs, InP, etc.)

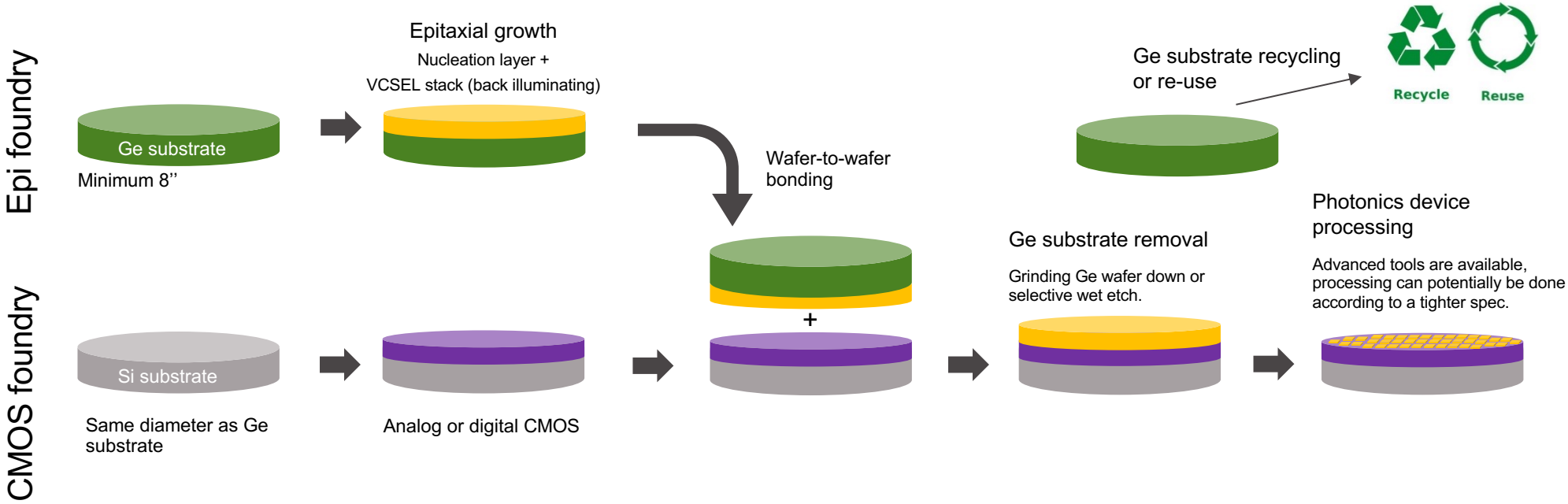
Number of applications benefit from the integration between CMOS and III-V.

Ge substrate can be selectively removed and Ge metal can be recycled to recuperate a part of the substrate cost.

- Ge wafers allow III-V device manufacturing through CMOS fabs – new device concepts, high performance, low cost.
- Umicore 8" Ge wafers were tested at IMEC (e.g. lithography equipment).

Potential avenue: CMOS & III-V fusion

Ge substrate can be selectively removed and recycled



- Ge wafers allow for III-V device processing performed at CMOS foundries.
- In addition, integration of Si CMOS with III-V is possible via wafer-to-wafer bonding.
- Wafer-to-wafer integration enables higher throughput = lower cost. Ge substrate removal avoids unnecessary waste generation and provides extra cost benefits.

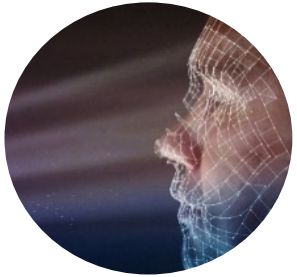
Growing Ge demand in all application segments

MJ solar cells
Space PV

MJ solar cells
CPV

Rapid market growth for
Ge-based solar cells

VCSELs
3D sensing



SWIR sensors
3D sensing

Micro-LEDs
VR/MR

New device development, III-V integration with CMOS

Breaking news from Jul 2023

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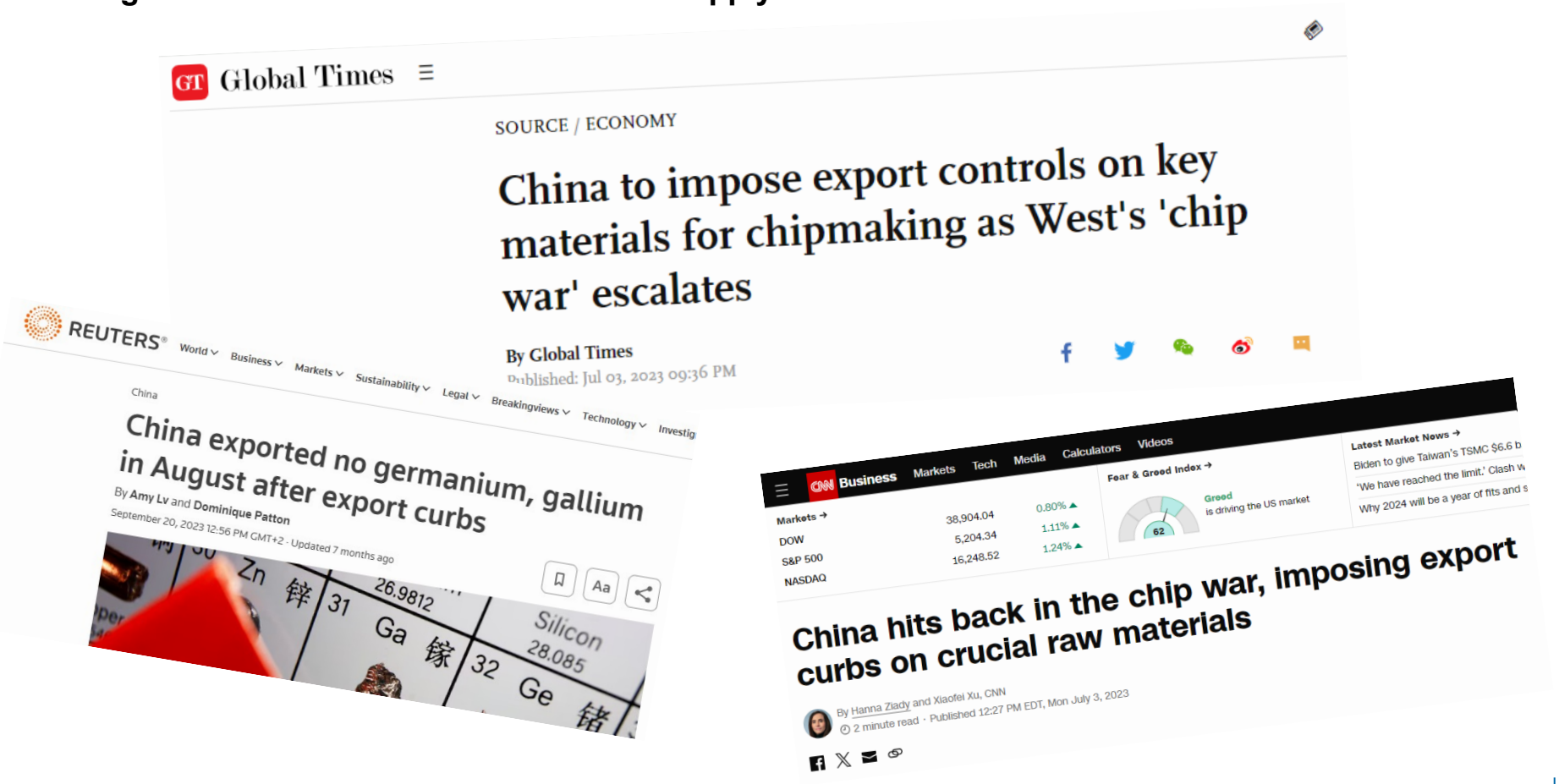
Growing demand for Ge meets raw material supply constraints



Global Times

SOURCE / ECONOMY

China to impose export controls on key materials for chipmaking as West's 'chip war' escalates

By Global Times

Published: Jul 03, 2023 09:36 PM

REUTERS

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China

China exported no germanium, gallium in August after export curbs

By Amy Lv and Dominique Patton

September 20, 2023 12:56 PM GMT+2 · Updated 7 months ago

Zn 锌 31 Ga 镓 26.9812 Silicon 28.085 32 Ge 锗

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Greed is driving the US market

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China hits back in the chip war, imposing export curbs on crucial raw materials

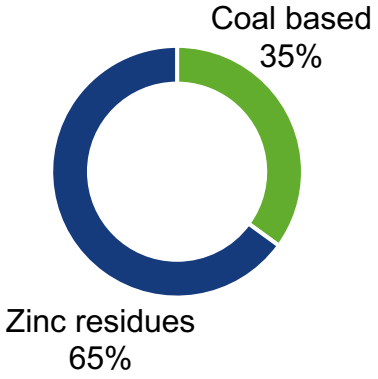
By Hanna Ziady and Xiaofei Xu, CNN

2 minute read · Published 12:27 PM EDT, Mon July 3, 2023

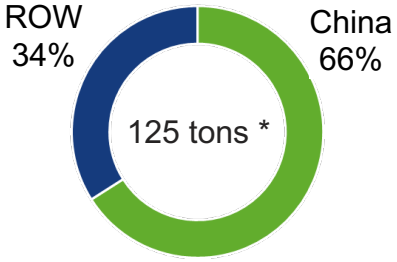
Germanium primary sourcing

Relatively small market with a potential to grow its global supply

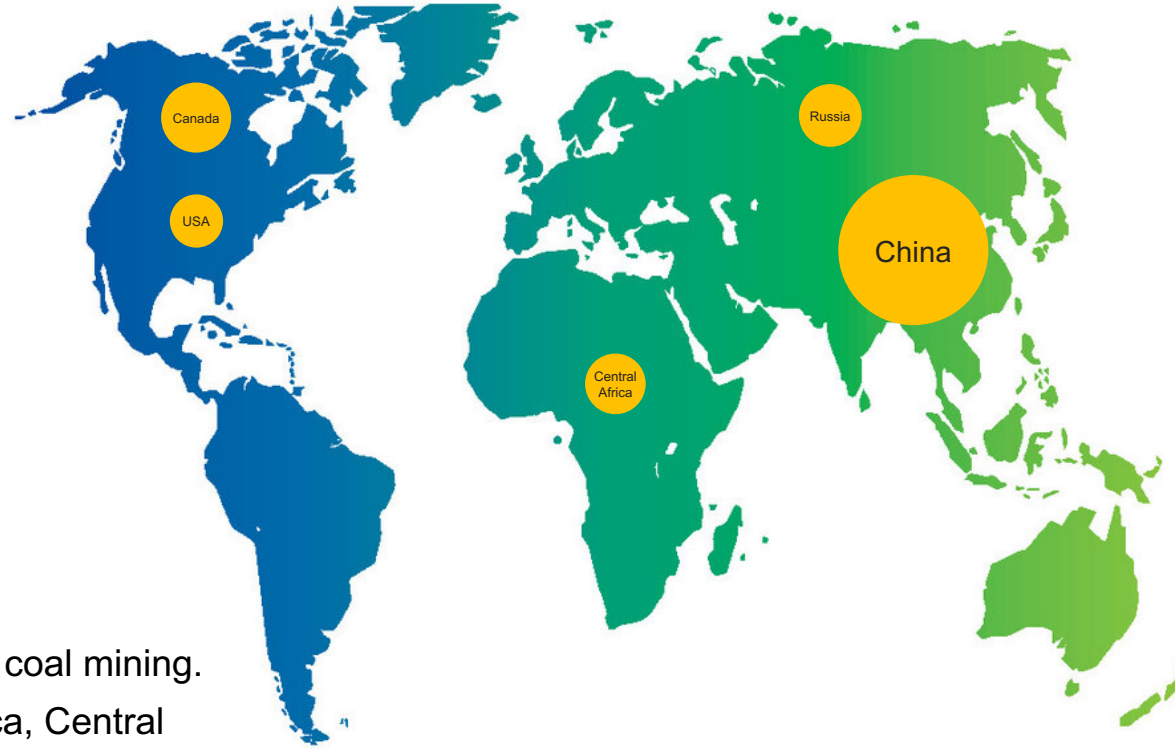
Type of global **primary Ge** supply



Origin of **refined Ge** worldwide



* Annual fluctuations are in the order of ± 15%



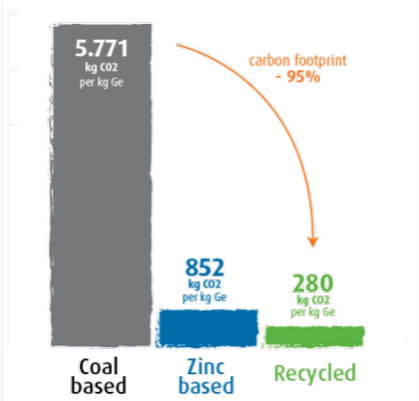
- Germanium is extracted out of feed from zinc and coal mining.
- Active sources are located in China, North-America, Central Africa and Russia.

Germanium – supply security though recycling

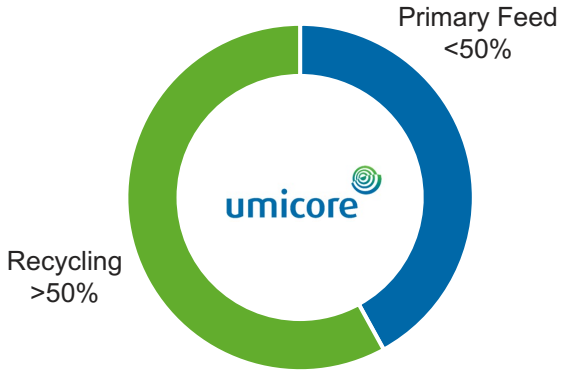
Umicore has well diversified Ge supply chain with above 50% coming from recycling

GOLD 2023 ecovadis Sustainability Rating

Environmental impact of Ge sources



Umicore Primary vs Secondary Sourcing (2022)



- No coal-based Ge in Umicore supply chain.
- Over 50% of our needs met through recycling; none from China.
- Recycling feed from all major Ge industries (fiber optics, solar, IR optics, LED, micro-electronics).
- Global supply diversification strategy active.
- Continual investment in innovations to reduce dependency upon primary sourcing

Refining Sources

- Byproduct from Zinc mining

Optical Fibers

- Scrubber solution/cake
- Soot & Preform glass
- Fiber waste

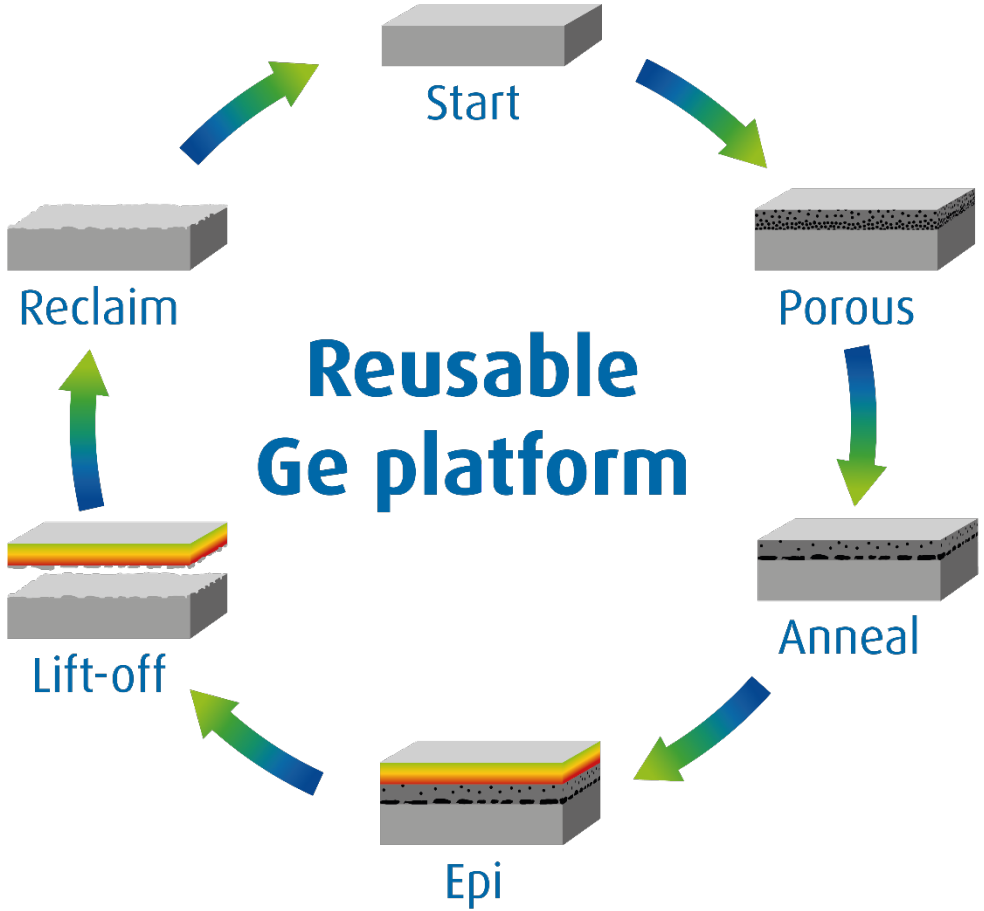
Solar Cells & LED's

- Wafer scraps
- Grinding slurry
- Filter waste & Etch solution

Infrared Optics

- Lens scraps
- Grinding/cutting slurry
- Sawing dust

Next step in reducing primary sourcing dependency



Electrochemical porocification approach

Epi-ready porous wafers, on-target device performance

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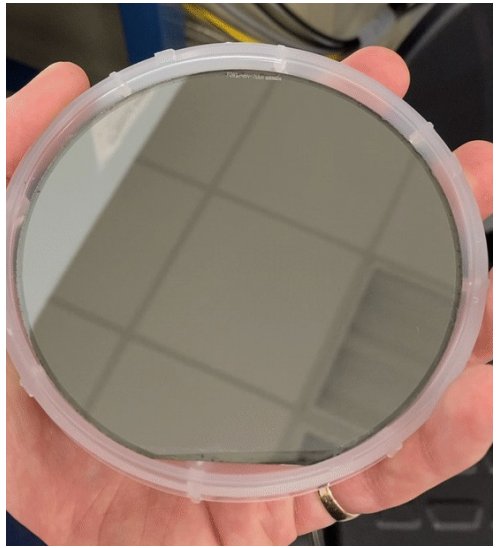
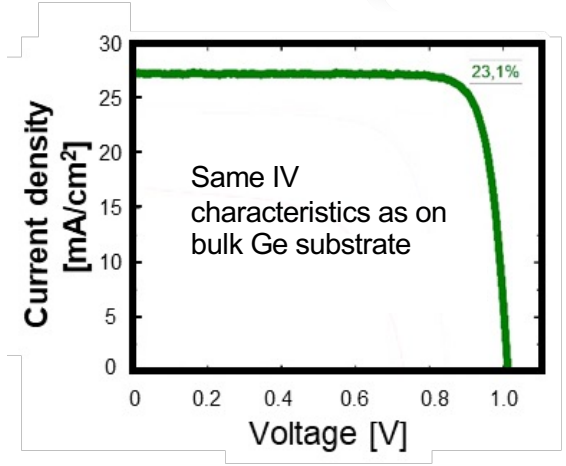
Porous 4” wafer



Porous 4” wafer after Ge epitaxy



Single-junction SC on porous 4” Ge

Proof of concept: completed

Technical insourcing: 2023-2025

Scale up: 2025-2028

Full production: Beyond 2028

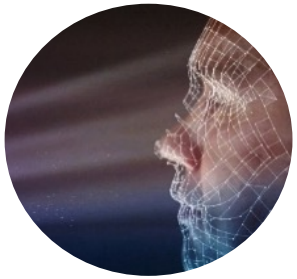
Recycling and Re-using Ge substrates

Lower the cost and Reduced primary material dependency

MJ solar cells
Space PV

MJ solar cells
CPV

VCSELs
3D sensing



SWIR sensors
3D sensing

Micro-LEDs
VR/MR

Recycle

Wafer scraps, substrate thinning

Ge launched to orbit cannot be recycled.

Wafer scraps, substrate thinning

Substrate removal by grinding or wet etching

Reuse

Only few um of Ge present in the final product, the rest is re-used.

Next generation solution for substrate removal in CMOS/backplane integration flow. Re-use instead of recycling.

Conclusions

Ge is a high-quality epi substrate with zero EPD, allowing to manufacture new photonics devices such as long/short wavelength VCSELs, SWIR sensors and micro-LEDs.

Ge is a CMOS compatible material enabling integration between CMOS and III-V materials. Ge wafers can be removed selectively with respect to the III-V stack.

Despite geopolitical challenges in Ge sourcing, Umicore is very well positioned to supply Ge-based products to growing markets thanks to our recycling capabilities & diversified sourcing.

Umicore develops reusable Ge platform which allows to lower the costs, limit the ammount of Ge in the end product and enhance CMOS integration.

Visit our Booth – Galaxy 1 & 2, booth #2

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