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Electro-Optic Materials

Germanium: turning sustainability into a competitive edge

Ivan Zyulkov – SEMICON Europa 2021

Who we are

A global materials technology and recycling group

One of three global leaders in emission control catalysts for light-duty and heavy-duty vehicles and for all fuel types

A leading supplier of key materials for rechargeable batteries used in electrified transportation and portable electronics

The world's leading recycler of complex waste streams containing precious and other valuable metals

PEOPLE
10,859

PRODUCTION SITES
47

R&D | TECHNICAL CENTERS
15

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turning sustainability into a competitive edge

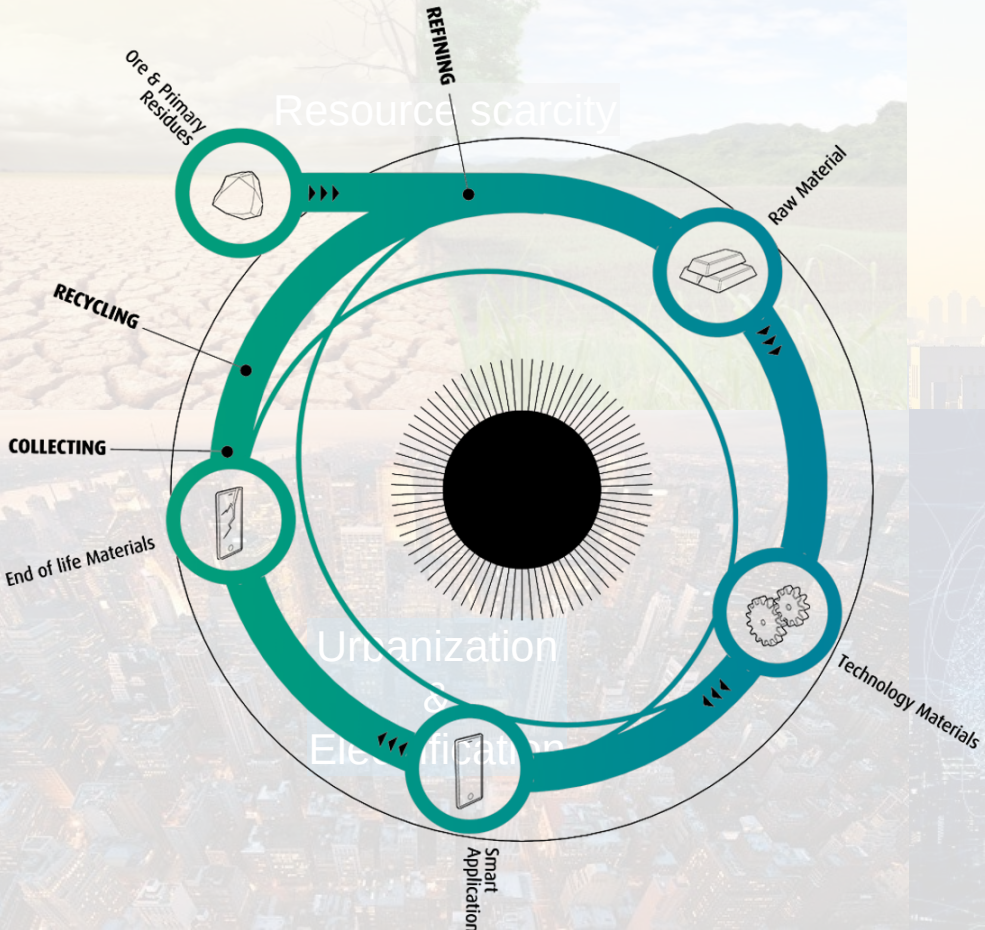

Resource scarcity


Air Pollution
&
Emissions control


Urbanization
&
Electrification


Digitalization

Umicore - sustainable material supplier



- We aim to be a **new kind of material supplier** contributing to **circular economy** and sustainable future.
- We have access to **global raw material supply chain** via our recycling streams enabling **secured supply** to our customers.
- We are chemical & material manufacturer with full control of in-house **scale-up, manufacturing, packaging, quality control & safety.**
- We have **collaborative approach** to address customer needs.

How does it work for Ge?

Umicore enables circularity of Ge-based products

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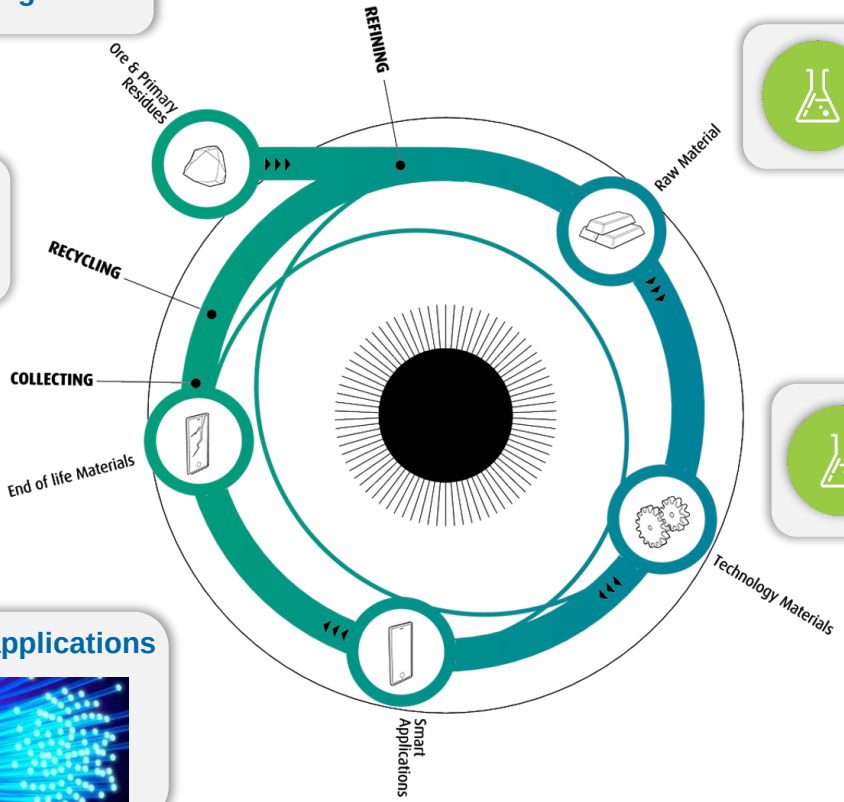
Secured & Responsible sourcing

Germanium Recycling



GeO_2

$GeCl_4$

High Purity Germanium

Germanium Substrates

Existing & Emerging applications

Outline

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GaInP
GaAs
Germanium

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Extra performance

Ge provides a third junction

Extra lightweight

Ge is stronger than GaAs

Extra surface

Ge wafers exist up to 300 mm

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Are we lost in space?

Why could Ge replace GaAs in some terrestrial applications?

Emerging & Existing Germanium applications

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In production

Multi-junction solar cells for space applications

LED for automotive applications

Optical fibers

Emerging

VCSELs for consumer 3D Sensing & LiDAR applications

VCSELs for automotive LiDAR applications

Micro-LEDs for VR applications

Emerging & Existing Germanium applications

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Emerging

VCSELs for consumer 3D Sensing & LiDAR applications

VCSELs for automotive LiDAR applications

Micro-LEDs for VR applications

GaAs substrates have strong **limitations**:

GaAs wafers is very difficult & **expensive to upscale**.

This is especially important for **automotive LiDAR**s where the die size is significant.

GaAs is **not recycled**, and it is landfilled.

As is **highly toxic**, long-term exposure to As from drinking-water and food can cause cancer and skin lesions.

GaAs wafers inherently result in:

- significant wafer bow after Epi
- dislocations
- slips
- doping striations

This can cause **yield problems** and device **failures**.

Germanium is better Epi substrate than GaAs

Overview Ge advantages

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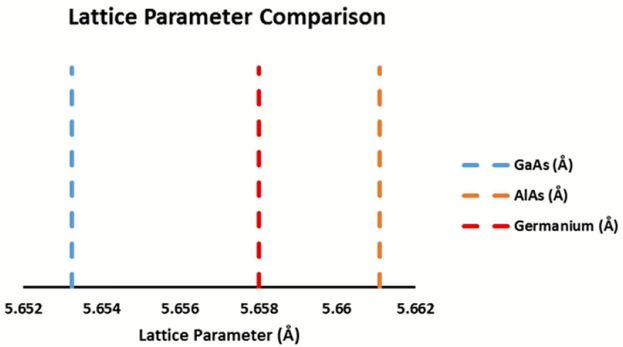
X-Ray topograph of Ge substrate

IQE



Ge lattice parameter is in between GaAs & AlAs leading to **much lower** residual epi **strain for DBR structures.**

Ge substrates offer significant advantages:

- **Ge** wafers are available up to 12'' (300 mm).
- Current Aixtron G4 **tools are 200mm capable** (5x200mm configuration)
- Cost of 6'' Ge wafer is **on par with (VCSEL) GaAs cost**.
- Ge robustness allows growth on thinner substrates – **lower cost / wafer** & lower fab costs.

Ge can be infinitely recycled, which:
- reduces amount of waste.
- allows to recuperate significant part of wafer cost.

Ge is **not toxic**, and it is **safe** to work with.

Ge lattice parameter is in between GaAs & AlAs leading to **much lower** residual epi **strain**:
- much lower bow
- thicker DBRs possible
- larger wafer diameter possible

Ge wafers are **dislocation free** (zero EPD)

Germanium is better Epi substrate than GaAs

Substrate COST considerations

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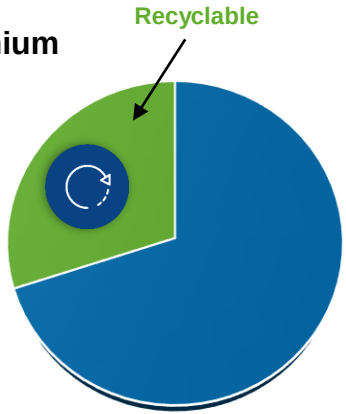
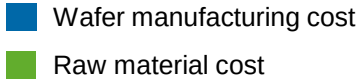
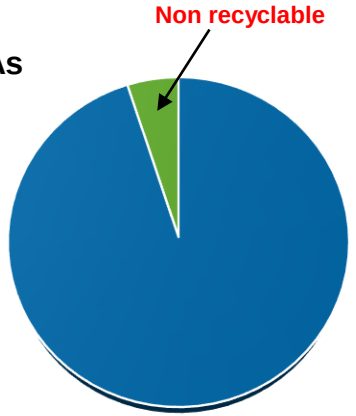
Germanium



Ge wafer **cost is on par** with GaAs
BUT



GaAs



Substrate

Wafer cost **scales similarly to Si** with production volume.	Compound semiconductors are **inherently difficult & expensive** to manufacture.
Ge substrate **can be recycled** to recuperate most of the material cost.	GaAs waste **must be landfilled**.
Thinner substrates can be used in order to lower the wafer cost.	**Minimal** substrate **thickness is limited** by GaAs brittleness.

Germanium is better Epi substrate than GaAs

Wafer bow problem

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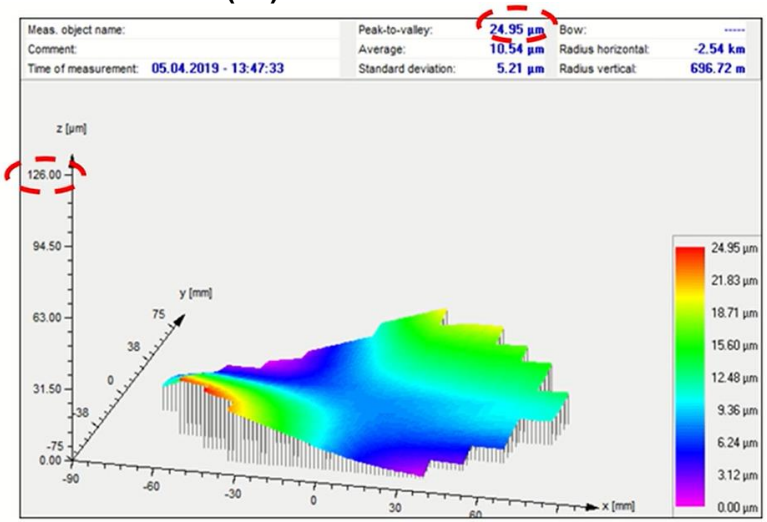
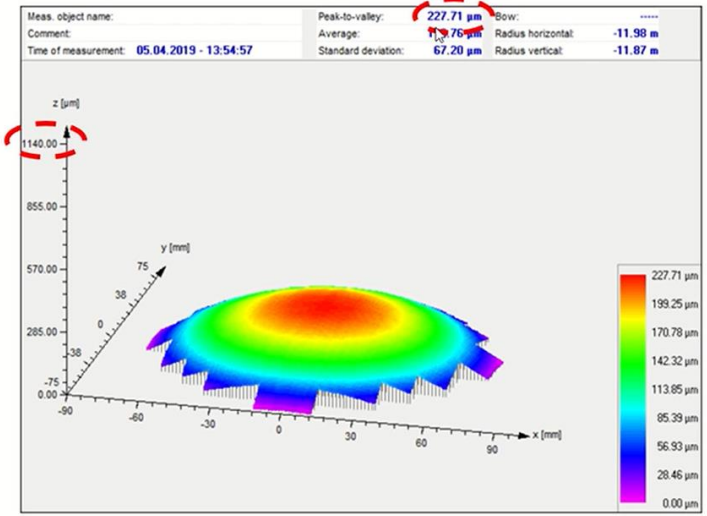
940 nm VCSEL Epi stack deposited on Ge vs GaAs

Germanium (6”)



Ge wafer: Concave bow of **25 microns**

GaAs (6”)



Convex bow of **230 microns**

IQE
IQGeVCSEL™

- Ge wafer **bow is on order of magnitude less** when compared to GaAs (the same VCSEL Epi stack and recipe).
- Together with **zero EPD** this might lead to **better Epi performance**, **yield improvement** and again upscaling to larger wafer diameters.

Germanium is better Epi substrate than GaAs

Defect / yield improvement

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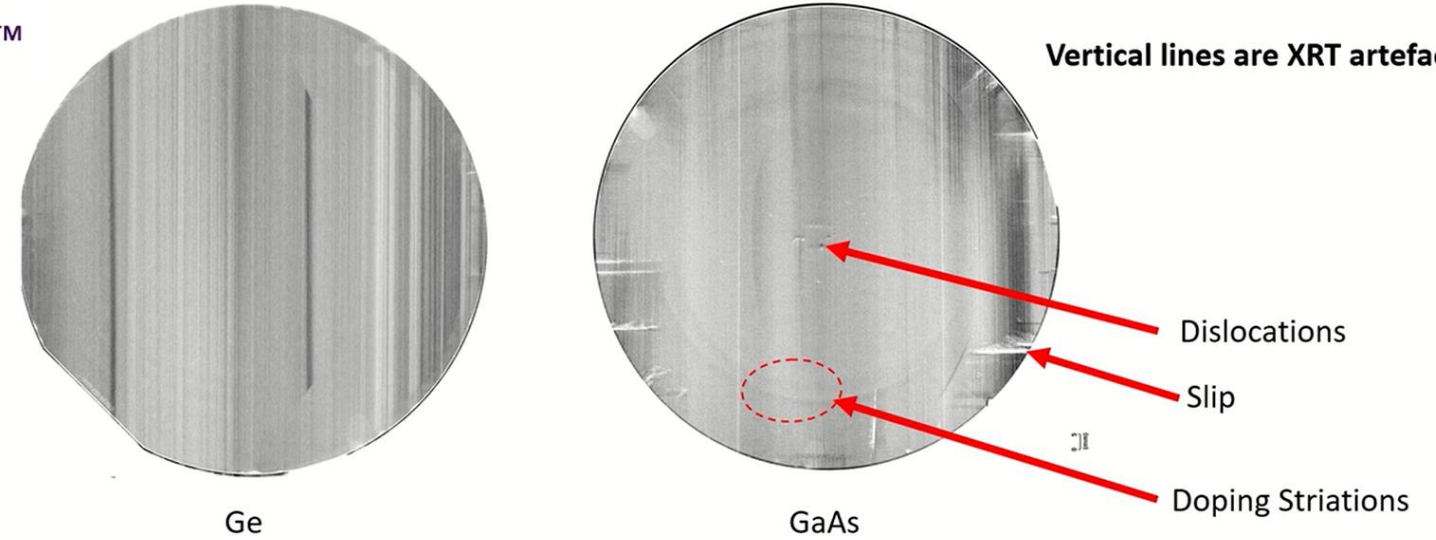
IQE
IQGeVCSEL™

940 nm VCSEL Epi stack deposited on Ge vs GaAs



X-Ray topography results:

- GaAs Epi wafer shows slips, dislocations and doping striations
- Ge wafer is dislocation free and shows minimal slip

Next step in the cost improvement

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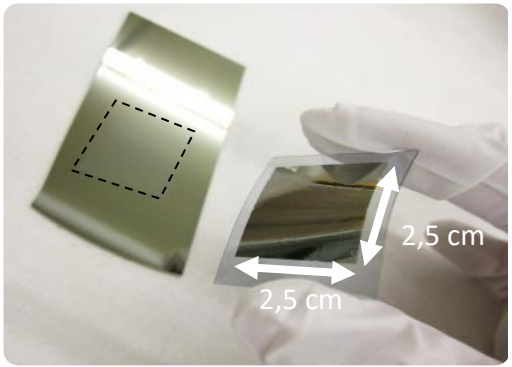
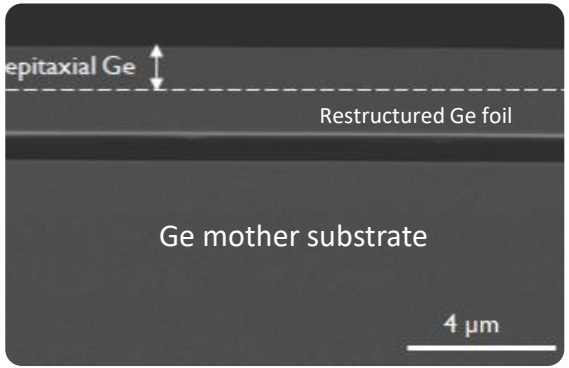
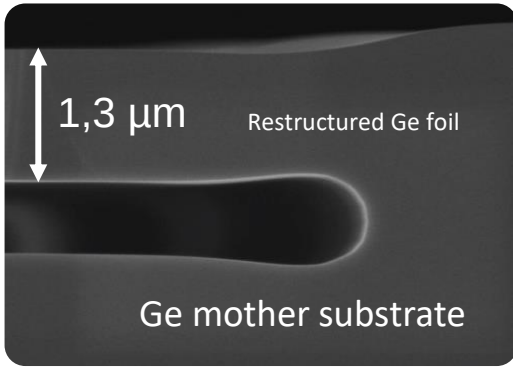
From 165 micron to 1-5 micron

- Same performance, less material required
- Cost benefits
- Less material needed → resource scarcity megatrend

imec



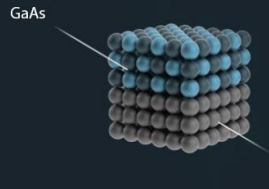




Highlights

Of Germanium as a substrate

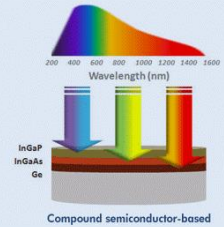
Excellent lattice match right in between **GaAs** and **AlAs**



Zero
Dislocations

30 years
of experience

Stronger and **lighter** than GaAs



Active junction capturing the IR junction

Outline

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Existing & Emerging applications

Germanium Substrates

Secured & Responsible sourcing

Germanium Recycling

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Environmental impact

Global Warming Potential of Germanium Sources

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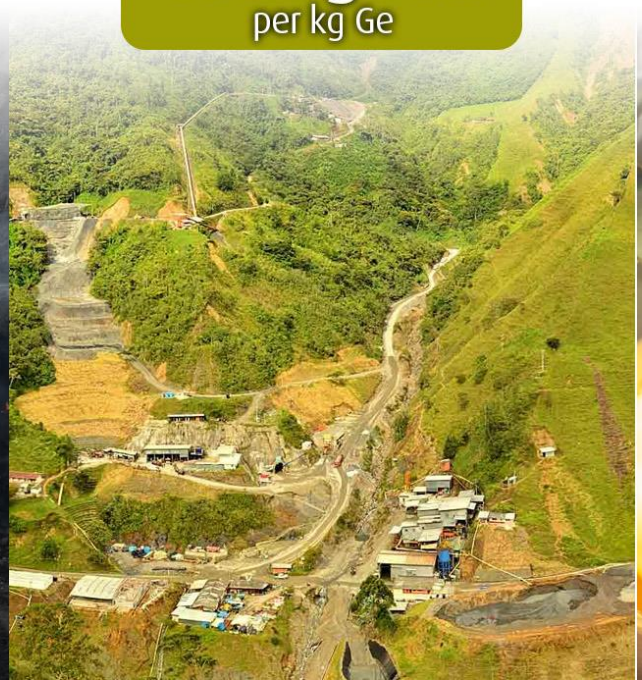
COAL BASED

5.771 kg CO2
per kg Ge

ZINC BASED

852 kg CO2
per kg Ge

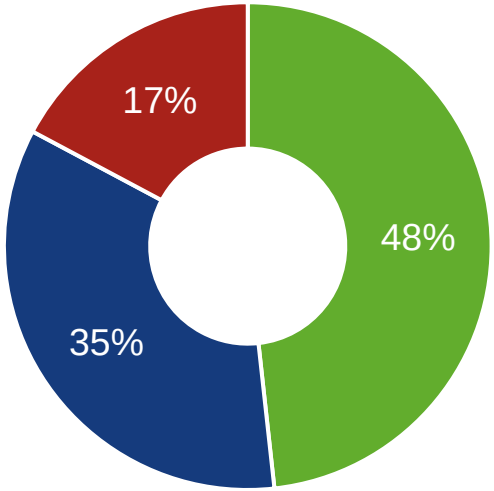


RECYCLED

280 kg CO2
per kg Ge

Umicore Ge sourcing and recycling
Almost half coming from recycling

With almost half already coming from direct recycling and more than one third coming from sustainable sources such as Zinc mining waste, Umicore is considered the most sustainable manufacturer of $GeCl_4$ worldwide.



UMICORE'S SUPPLY

- Recycling
- Zinc/others
- Coal

Umicore Ge sourcing and recycling

Almost half coming from recycling

PLATINUM Top 1%
2020
ecovadis
Sustainability Rating

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Umicore commits to

exclusively source from

low carbon footprint

feed for **Germanium**

from **2022** onwards

UMICORE'S SUPPLY

- Recycling
- Zinc/others
- Coal

Umicore Germanium Recycling

Refining and recycling flow sheet – existing Ge sources

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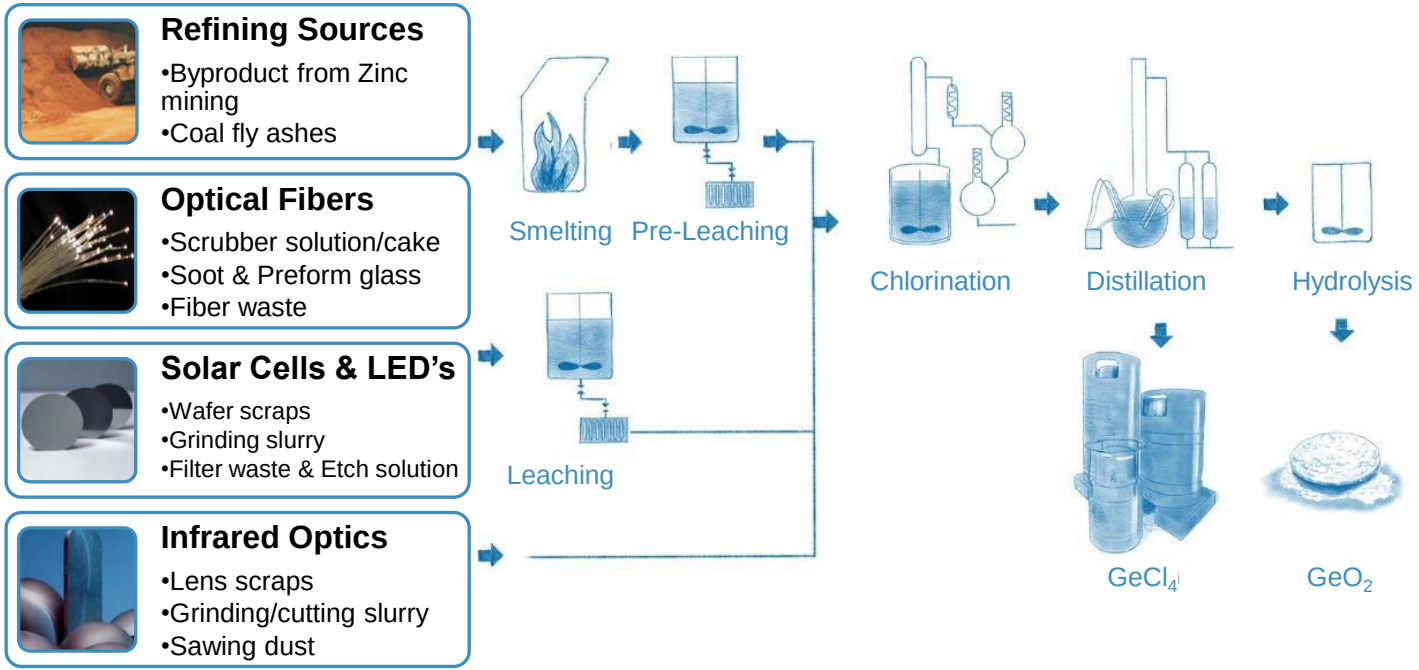

Germanium in deposition

Semiconductor industry

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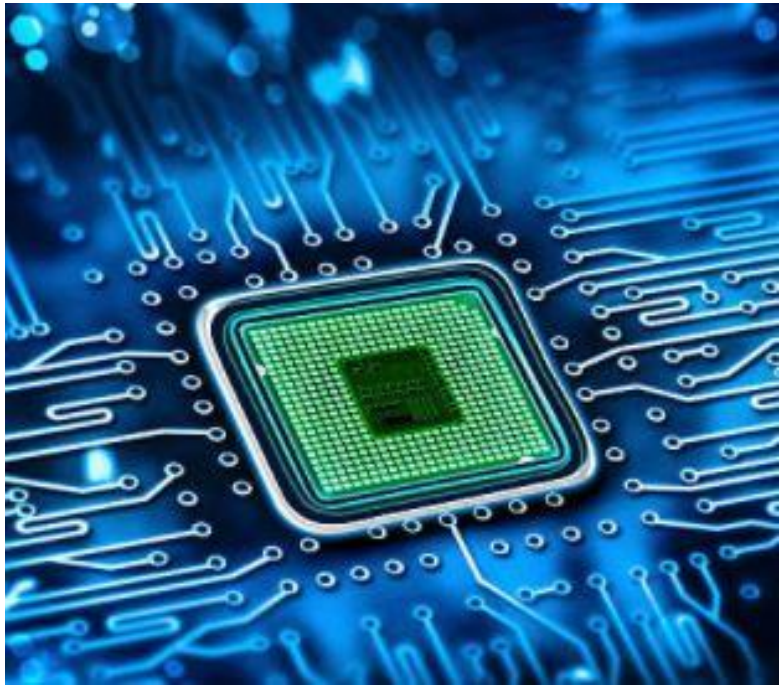

1% of Ge

Ends up on a wafer

The value is in other 99%

Ge recycling solutions for microelectonic industry

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Precursor manufacturer

Ge-precursor
GeH_4, $GeCl_4$, etc.

CVD Process

Wafer surface (X%)

Exhaust (100-X%)

Collection of Ge atoms (in any form available)

Germanium compound
(GeO_2, metal, etc.)

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High capacity

Several thousands of tons of recycling streams annually.

Extensive capabilities

Pyro and hydro metallurgy for complex streams with e.g. silicon and fluorine.

Efficient processes

Germanium can be recovered from streams with Ge content of 0.5 % for solids and 0.5 g/l for liquids.

Financial benefits of recycling

Comparison of $GeCl_4$ price per kg for the optical fiber industry (2018)

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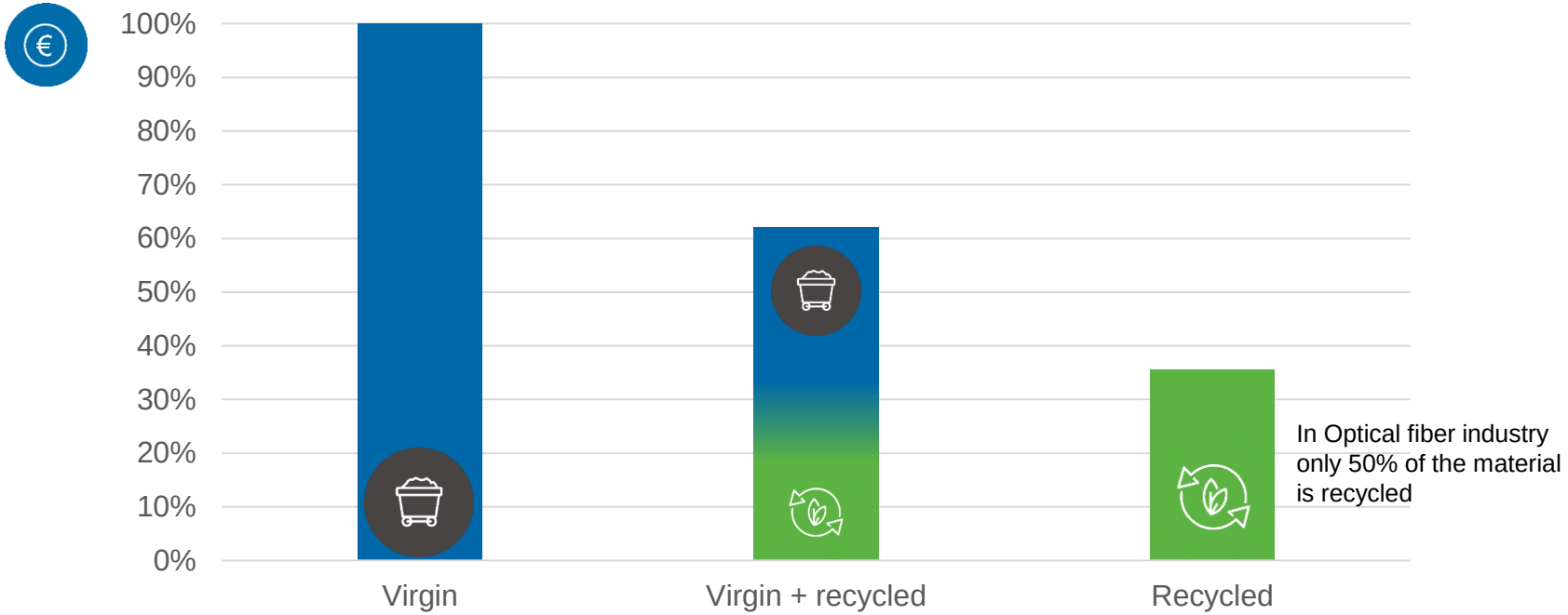

Use of recycled Ge is financially beneficial for Umicore and Umicore customers.

Germanium Recycling

How we differentiate ourselves

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- A **sustainable solution** for all your Ge containing recycling streams

Sustainable recycling solutions

Expertise in transport and EHS regulations

- Profound knowledge about **transport requirements and regulations**
- Treatment of your materials according to the **strictest Environment, Health and Safety requirements**
- Short turnaround times

- **Extensive R&D** to address your needs of today and tomorrow
- On-site technical-scientific support
- In-house sampling/analysis expertise and facilities

Extensive scientific support and in-house sampling

Competitive purchasing / tolling fees

Umicore enables circularity of Ge-based products

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Secured & Responsible sourcing

Germanium Recycling

GeO_2

$GeCl_4$

High Purity Germanium

Germanium Substrates

Existing & Emerging application

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Germanium Solutions

Germanium Recycling

Secured & Responsible sourcing

$GeCl_4$

- **High purity $GeCl_4$** product for optical industry
- Umicore **recycled optical fiber waste** to recuperate some cost
- **Secured Ge supply chain** and provide solutions to treat a wide variety of Ge recycling streams

Germanium Substrates

- **High volume production** of Ge wafers:
  100 mm (4") – **200 mm (8''); 300 mm (12'')** on request.
- **9 Million polished Ge wafers sold** in 20 years
- Epi grade quality with **0 dislocations (0 EPD)**

Infrared Solutions

Infrared solutions based on chalcogenide glass

High Purity Germanium

- World's purest **germanium crystals with a purity of 99.99999999999%**
- Applications: detect and analyze gamma rays in particle accelerators, nuclear power plants and space applications, such as the Gamma Ray Spectrometer on the Mars Odyssey spacecraft.

Electro-Optic Materials: Geographic presence

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Olen, Belgium

EOM HQ
Ge Solutions
→ Ge Recycling
→ GeCl4
→ Ge Substrates

Quapaw, OK, USA

IR Solutions
→ IR Optics

Ge Solutions
→ Ge Recycling & GeCl4

Dundee, Scotland, UK

IR Solutions
→ Thermal imaging coatings
→ CO_2 laser coatings
→ IR filters

Moscow, Russia
Sales & Business Dev.

Tokyo, Japan
Sales & Business Dev.

Seoul, Korea
Sales & Business Dev.

Shanghai, China
Sales & Business Dev.

Taipei, Taiwan ROC
Sales & Business Dev.

Mumbai, India
Sales & Business Dev.

Acigné, France

IR Solutions
→ Glass and molding
→ Design and prototyping
→ IR Optics production

Summary

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- Ge offers technological benefits and cost befits for several emerging applications such as 3D sensing and automotive LiDAR systems.
- Ge can be infinitely recycled to reduce amount of waste and recuperate a part of the cost.
- Umicore has 30 years of experience in Ge business and can provide unique solutions to treat a wide variety of Ge recycling streams as well as to offer high quality Ge products.

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materials for a better life