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GERMANIUM-ON-NOTHING ROUTE OF THE ELLA PROJECT

ESA-GEON

EXECUTIVE SUMMARY

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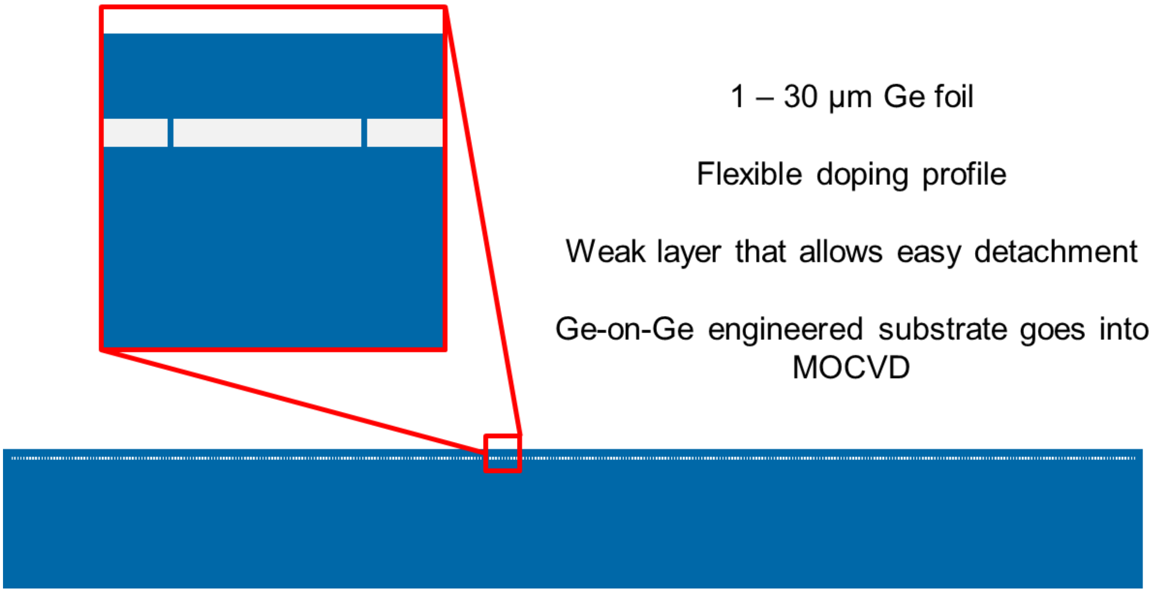
Motivation

The space solar cell market is looking for solutions to optimize three important metrics: W/kg, W/m³ and $/W. Both the weight and volume aspects are linked to the launcher payload capacity to get the satellites to orbit. The germanium wafer plays a significant role in both the cost and the weight elements of these metrics. A solution that allows solar cell manufacturers to use only as much germanium as is strictly necessary for a functioning solar cell, would have a big impact on these metrics. Current approaches rely on backgrinding or etching away the substrate to reduce the amount of superfluous Ge. These solutions have technical limitations and are also sub-optimal from an economic and an ecologic perspective.

The intended development of the ELLA project is a Ge-on-Ge engineered substrate: a germanium substrate that contains a weak layer that is designed to both allow epitaxial growth as well as lifting-off the eventual epitaxial foil of desired thickness from the mother substrate. This should provide a more economic and ecological solution than backgrinding or etching.

The key product features of the Ge-on-Ge engineered substrate are as follows:

1. A re-usable germanium mother substrate
2. A weak layer enabling lift-off while having an epi-ready front surface



Objectives

The main technical objective of the GeON de-risking activity is to apply a process that was fully developed for silicon to germanium for the first time. The scope of the de-risking project is to explore the feasibility of the three first steps of the process (2 weak layer formation steps and Ge epitaxy), while the future ELLA project will cover the complete process cycle. By transferring the first three steps to germanium, all the similarities and differences between the silicon and germanium processes and material parameters are highlighted.

The expected outcome of the de-risking project is a working condition for each step in order to integrate all three and achieve a first demonstration of a detachable Ge epitaxial film. In this way we can identify the main specific challenges of this route and judge whether they may eventually be tackled in the time frame of the future ELLA project. Further process optimization of the three first steps will still be needed in the ELLA project.

One of the major new boundary conditions for the technique in the context of germanium wafers, is the need to maintain the 6° offcut towards the <111> that is key in enabling subsequent III-V epitaxy. Since this is of little importance in Si, this kind of detail had never been studied before even for Si. In principle the technique should result in a perfect copy of the underlying structure but no experimental proof was available at the start of the project. An objective of the project was to demonstrate that the offcut of the surface can be maintained.

Results

Two of the three process steps under investigation needed major adjustments in order to be applied to germanium. The formation of the weak layer consists of two process steps. The first process step is relatively insensitive to the type of substrate that it is applied to and hence it could be copied from the silicon process without major changes. The transfer of the second weak layer process step to germanium required significant changes because for this process the chemistry of germanium comes into play. The third process step had to be adjusted because the thermal budget is different for germanium versus silicon and the surface chemistry of germanium starts playing a role. For all three processes a condition that works well enough could be found and the integration of all three could be made.

The final result of integrating all the developed process steps can be seen in Figure 1. In this cross-section scanning electron microscope image, the Ge-on-Ge engineered substrate structure can be seen. The bottom is the germanium mother substrate, followed by an air gap, followed by a germanium foil that was first created through the weak layer process and then further thickened with germanium epitaxy.

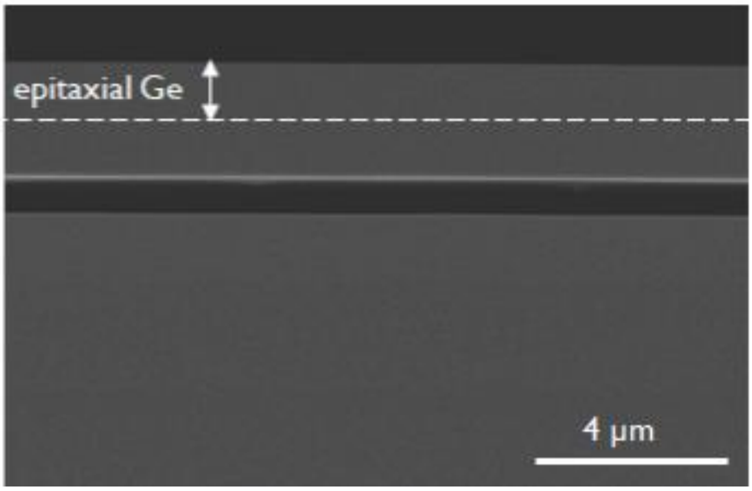


Figure 1: Final structure of the Ge-on-Ge engineered substrate with an additional ~1 μm of epitaxial Ge growth.

The demonstration of the future concept can be seen in Figure 2. This picture shows the first Ge foil that was lifted off from a Ge mother substrate. The foil has a thickness of 1.3 μm and lateral dimensions of 2.5 x 2.5 cm. The foil was lifted of by attaching a plastic foil and peeling it off. The limited thickness of the Ge foil allowed it to be removed without any additional delineation on the edges to separate it from the mother substrate. In the final application of the product, the Ge-on-Ge engineered substrate would be shipped to the customer where III-V epitaxy would occur. Only after III-V epitaxy and front side solar cell processing, the epitaxially thickened foil would be detached from the mother substrate. The mother substrate would be returned to Umicore and the foil can receive further back side solar cell processing. The mother substrate can then be re-conditioned for an additional use. These steps haven't been demonstrated yet.

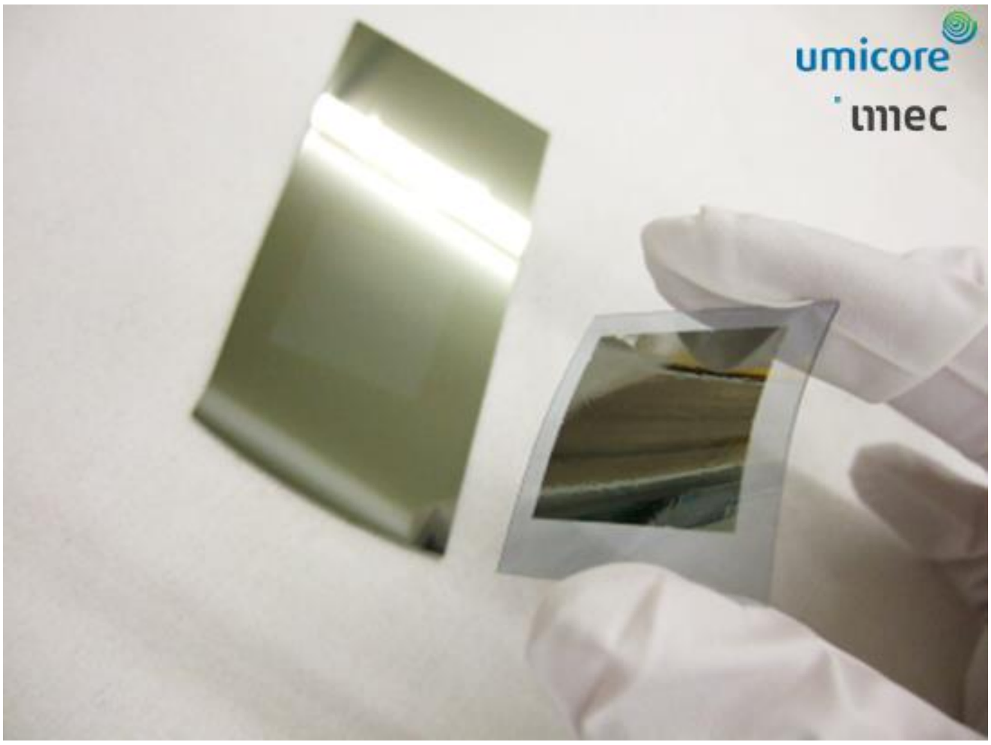


Figure 2: Picture of the first foil that was transferred from a mother substrate to a plastic film.

The resulting structure was characterized in terms of the offcut. The foil was found, like the mother substrate, to be 6° offcut towards the <111> which is perfect to serve as a growth template for III-V epitaxial growth. The front side surface was also characterized in terms of roughness prior to additional germanium epitaxy. The RMS roughness measured on an area of 20x20 µm was 4.34 nm. This can be compared to the 1.3 nm measured on a similar structure made on a 6° offcut silicon wafer.

Sample	Roughness - RMS 20 µm x 20 µm or 10 x 10 µm	
	GeON region	Bulk region
Germanium 6° miscut	4.34 nm	0.830 nm
Silicon 6° miscut	1.3 nm	na

Table 1: Overview of the RMS roughness measured by AFM on Ge-on-Ge samples from the project and benchmarked against results on Si. Values are given for measurements on the foil (GeON region) or on the bulk substrate next to the foil (bulk region).

Conclusion

The project targeted to answer the following list of questions:

- On film formation:
    - Will the weak layer process follow the same behavior as Si? The weak

layer process is similar to Si and a Ge-on-Ge structure is formed.

- On film stability:
  - Will the Ge-on-Ge structure be stable or will it lift-off or collapse too early?
    First indications are that this seems comparable to Si so far. Some lift-off and collapse were seen. This needs to be further studied to understand and prevent these issues.
  - Will the detachment layer be stable with epi-Ge grown on top? More than 1 µm of Ge epitaxy was deposited on top without sign of collapse.
- On film quality:
  - Will the 6° offcut angle of the parent wafer be preserved or will it be lost? The 6° offcut angle is perfectly preserved.
  - Is epitaxial growth of good quality? Decent quality was reached but the epitaxy needs to be optimized for the 6° offcut angle and the rougher foil surface.

The outcome of the de-risking project is positive as the target of finding working conditions for the three process steps is reached. A process developed for Si could be transitioned to Ge and a first demonstration of the Ge-on-Ge structure was obtained. With small modifications to the weak layer formation process, the flow resulted in a true Ge-on-Ge structure and a first film was lifted off the parent substrate.

While the current process is good enough to demonstrate the concept, further optimization of the process steps is needed to obtain a reproducible outcome for the weak layer process and a top-quality foil. Additionally, the current germanium epitaxy process to thicken the foil is also quite limited in its maximum thickness. For customers that want a thicker Ge foil, either from mechanical point of view or from the cell concept point of view, a faster germanium epitaxy step is needed.

In order to truly demonstrate the full potential of the approach and to increase the TRL, three important pieces are still missing: epitaxial growth of III-V layers, processing of the foil into a solar cell device and re-conditioning of the parent substrate. Completing a first iteration of these steps should be a high priority in the early phases of the follow-on activity to identify the problem areas. Further fine-tuning of the weak layer formation process steps only make sense if the targets can better be defined. This requires further integration into a device.