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GeSiR: Low Ge Alternative Space Triple Junction Solar Cells on SiGe Engineered Substrates and Ge Recovery from Grinding Slurry of Wafer Thinning

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Ge is a critical raw material. Yet, Ge wafers are the basis of today’s European space solar cells. Thus about 2 tons of Ge/year are sent to space due to solar cells alone A further drawback is its relatively high CO_2 equivalent and environmental impact associated with Ge mining or sourcing from coal ashes, purifying, crystal pulling and wafering processes. Thus, it is of great importance to reduce the Ge consumption for existing and future space solar cells. Exactly this target is addressed in the project “*Low Ge Alternative Space Triple Junction Solar Cells on SiGe Engineered Substrates and Ge Recovery from Grinding Slurry of Wafer Thinning*” (GeSiR). The project consists of two parts. The first part is addressing the recouperation of Ge from grinding slurries which occur either during wafering or especially due to the thinning of the Ge wafers after epitaxy to reduce weight and thus launch cost. The second part was exploring an alternative low Ge low cost triple junction which is not based on a Ge wafer (low Ge alternative triple junction) and thus reduces the Ge consumption by at least an order of magnitude.

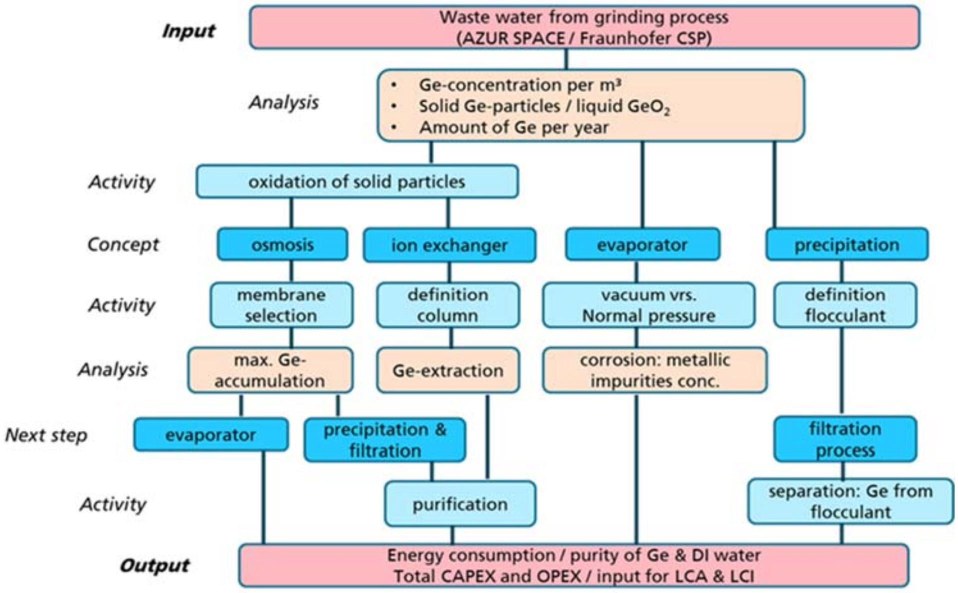

Figure 1: Recycling concepts for Germanium grinding water

The first route investigated the several strategies to recover Ge from a grinding slurry (see Figure 1). This grinding slurry occurs, when Ge wafers are thinned after the III-V epitaxy process step, to reduce the weight of the Ge based triple or quadruple junctions. Here two routes were selected and successfully demonstrated in pilot-scale. Both processes considered of two main steps. The recovery routes are a) the recovery via a combination of ion exchange to increase the Ge concentration followed by an evaporation process and b) an initial process based on osmosis followed by an evaporation step. In conclusion, the recovery of germanium from grinding wastewater is relatively easy and can be done in an economical way. The most preferable options are osmosis and ion exchange followed by evaporation. A recovery rate of >95 % germanium can be achieved, while the deionized water collected with the evaporator can be reused in the grinding process once again. The CAPEX for an implementation of an ion exchange recycling concept would be <10,000€, while the OPEX is around 600€ for a low concentrated wastewater stream (0.2 g/l, 2,000 l/h) and 100 l ion exchange resin with a capacity of 6 kg Ge. Regarding environmental considerations it is found that 29.7 kg CO_2-Eq. is associated to the production of 1 kg $GeCl_4$ from secondary Ge sourced from the ion-exchange followed by evaporation route. This is about 8 times lower than the $GeCl_4$ production from primary Ge sourced from coal ashes.

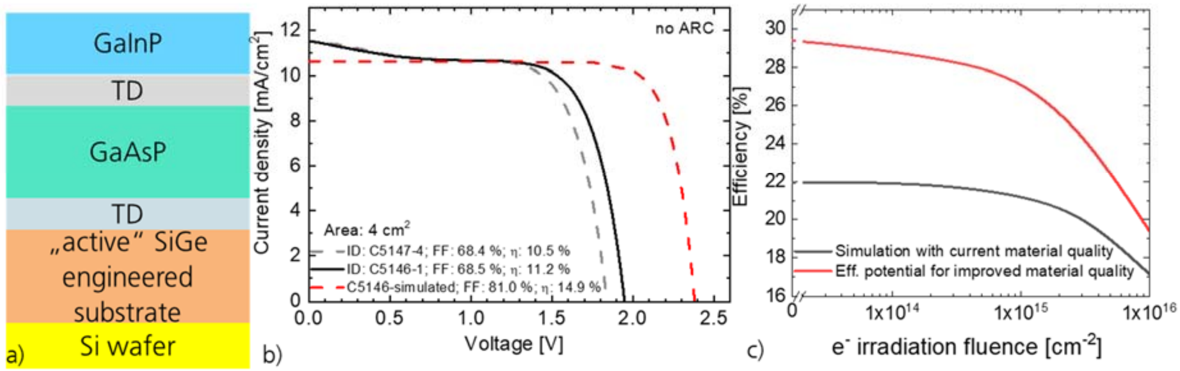

Figure 2: a) Schematic of the functional structure of proposed triple-junction. The GaInP, GaAsP and SiGe absorbers are in series connected through tunnel diodes (TD). b) I-V curve under AM0 illumination of the current status of the GeSiR triple junction (black dashed) in comparison to the simulation with the current absorber lifetimes (red dashed). Note that about 30% in J_{SC} could directly be gained by applying an anti-reflection coating. c) Calculated efficiency potential at room temperature of the "low Ge triple junction" solar cell on Si as function of 1 MeV electron irradiation is shown (red). Black depicts the expected the performance with the current absorber materials lifetimes reached.

As an even more drastic reduction in Ge consumption a low Ge consumption and low cost alternative triple junction solar cell was suggested and realized for the first time (see Figure 2). Here the Ge wafer of today's GaInP/GaAs/Ge triple junction is replaced by a SiGe engineered substrate, where the SiGe absorber material is deposited on a metamorphic SiGe buffer on a Si wafer. Initial devices suffer from a high threading dislocations density in the order of 10^7 cm^{-2} originating from the SiGe metamorphic buffer in the engineered substrate as offered by a commercial vendor. However, threading dislocation densities in the low 10^6 cm^{-2} have been reported in literature already for such metamorphic materials. Further after the III-V growth also a high density of large epitaxy defects is found causing localized shunts and thus limiting the performance. Since also the SiGe subcells suffers from local shunts it is suspected that also these defects originate in this particular not ideal growth conditions of the SiGe metamorphic buffer which was available. As de-risking test 5 successive temperature shocks by dipping the cells in liquid nitrogen followed by a slow heating to 50°C were survived without performance degradation by such 4 cm^2 cells. Further 1 MeV electron irradiation suggests a slightly higher radiation hardness than GaAs. Thus, a fully developed product based on this approach is expected to reach an efficiency of 29.4% under AM0 irradiation and 27.1% after 1 MeV electron irradiation with a fluence of $1*10^{15}$ cm^{-2}. The use of the SiGe engineered substrate would lower the global warming potential by 2.4 times when replacing a 200 µm Ge wafer mostly due to a reduced Ge consumption by a factor of 18.

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