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Epitaxial preparation of germanium cells for photovoltaic and thermophotovoltaic applications

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Germanium is widely used in the advanced III-V photovoltaic technology based on arsenides and phosphides to realise triple junction (TJ) solar cells for space application and in thermophotovoltaic (TPV) devices.

Nowadays, Ge cells are realised by diffusion and the cell conversion efficiency is partially limited by the broad doping profile thus obtained. Better performances could be achieved by means of homo-epitaxy of Ge on the Ge substrate, as improved thickness and doping profile control can be obtained with the epitaxial process.

TJ cells, made of a InGaP/InGaAs/Ge monolithic array, have reached an efficiency value over 40% under concentration. The AM1.5 current density of the TJ cells are in the range of 15 mA/cm^2 and the limiting subcell is the GaAs one: theoretical models suggest that the Ge subcell could produce a current density up to 40 mA/cm^2, so that a large amount of the Ge potential is not fulfilled in the TJ cell. Epitaxial deposition of Ge would permit novel cell design (e.g. stacking 2 Ge cells) in order to obtain higher open circuit voltage.

Ge cells are also employed in TPV devices to produce electricity from a heating source, thus fulfilling all the energetic content of a particular fuel and obtaining both heat and power from a single source. In this application, the advantages of Ge compared to the more common GaSb are a larger wafer size and a cheaper price.

Ge epitaxial layers were deposited on both Ge and GaAs substrates by means of a home made Metal-Organic Vapor Phase (MOVPE) reactor using isobutylgermane (iBuGe). The samples were characterised by X-Ray Diffraction (XRD), Atomic Force Microscopy (AFM) and Transmission Electron Microscopy (TEM). Ohmic contacts were deposited on the samples in order to perform electrical characterization and to realise a simple p-n junction which showed photovoltaic effect.

This work analyses the epitaxial growth of Germanium and the effect of the growth parameters (iBuGe partial pressure, temperature) on growth rate, surface morphology and material quality.

In the temperature interval between 500 and 600°C a mass transport controlled regime was observed. Surface morphology showed a dependence on both the growth rate and on the substrate orientation: by using a low iBuGe partial pressure, a large density of holes were observed both by TEM and AFM. The holes almost disappeared by increasing the growth rate up to a limit of about 1µm/h, after which the surface roughness increases, degrading sample quality. XRD showed a nearly perfect crystallographic structure for the samples deposited on exaclty oriented (001) Ge substrates, while a larger diffraction peak was obtained for samples grown on (001) Ge substrated 6°off toward (110) direction. On the latter, a rougher and wave-like surface was observed by AFM while on exaclty oriented the surface was mirrorlike.

n/p junctions were characterised by means of I-V and C-V techniques, and an optimal rectifying behaviour was obtained. The illuminated Ge n/p junctions reported a V_{OC} of about 170 mV.