NANO III-V/SI PV
HETEROGENEOUS INTEGRATION OF NIR III-V NANOSTRUCTURES IN CRYSTALLINE SILICON THIN FILM SOLAR CELLS

KTH · Mohammed Saad
IMEC · Ounsi el Daif
Obducat Technologies AB · Lee Kidong

Motivation:

Si continues to be an important semiconductor material of choice for PV. Although, best performances are obtained with traditional wafer based c-Si cells, the cost factor has driven the development of thin film cells using a-Si, poly or micro-crystalline Si with SoA cell efficiencies in the range 10-11%. Besides material development, approaches (e.g. by plasmonics) to enhance absorption in these thin films are being explored. However, utilizing the full solar spectrum is still a major challenge with thin film solar cells and also with c-Si. In contrast, with III-V materials advanced epitaxial solutions have made it possible to obtain multi-junction solar cells pushing efficiencies to record levels of ~45%.

The solutions that exist to integrate different band-gap materials on Si include wafer-bonding and hetero-epitaxy. One major problem is the lattice mismatch between the III-V materials and Si, resulting in a high density of crystalline defects and the quality of the III-V/Si interface. Hetero-epitaxy is still at an early stage and requires substantial development to obtain defect-free III-V layers. The wafer-bonding approach, on the other hand, is investigated extensively and several optoelectronic/photonic devices on Si have been demonstrated. Important advantages with wafer bonding include low-temperature processing and the mature epitaxial growth technology for the III-Vs. However, wafer bonding usually involves removal of the III-V substrate, constituting a substantial wastage of material. Finally, the electronic properties including energy band discontinuities of the III-V/Si system are less known.

The theme of this project was to explore bonding of direct band-gap semiconductor nanostructures, separately generated by dry etching of designed III-V epitaxial layers, on to Si and subsequent solar cell fabrication using this composit material. However, such an approach is far from obvious and has several challenges ranging from fabrication of high optical quality III-V nanostructures, bonding to Si, III-V/Si interface control etc. Below is a brief summary of the main results and conclusions.

Summary of results and achievements:

Dry etching process was optimized to generate high optical quality InP-based multi-layer nanopillar arrays. Subsequently, material selective etching was used to fabricate nanodisks from the nanopillars. The nanodisks could then be transferred to Si substrates by transfer printing using a polymer stamp. The limitations were on the yield of the transfer process which affects the desired spatial density of the nanodisks on the Si surface. The transfer process has to be further developed for high yield. Colloidal lithography and nano-imprint lithography are attractive for low-cost pattern generation. More work investigating different conditions for wafer bonding and characterization of the III-V/Si interfaces including energy-band discontinuity is necessary.