Notes from Spring MRS 2011 - *Nanowires*

***Tuesday***

**8am**: Harry Atwater – **Si NWs for PV**

Require thin and flexible PV – specifically for building integrated PV

$/Wp; c-Si ~ $2.20 (η = 18-21%)

CdTe ~ $1.00 (η = 13%)

CIGS ~ $1.00 (η = 18%)

Wire array Si ~ $1.00 (η = 18-21%)

Main driver: Cost

- Able to grow vertical wire arrays on 150 mm diameter wafers.

- Able to peel off 100 cm2 flexible polymer that has wire arrays embedded.

Optics: Using very smooth wires, can effectively create waveguides

Simulation of L ~ 100 μm, d ~ 5 μm, Diffusion Length ~ 10 μm >> η ~ 17%

**Initial results; VOC = 500 mV, FF ~ 65%, JSC ~ 24.5 mAcm-2 >> η ~ 7%**

Moving on to GaP/Si and GaNxP1-x tandem cells. VLS grown Si wires, MOCVD to coat with GaP, Si wire had hexagonal cross section and defects appear within GaP shell at points at which facets meet.

**8.30am:** J. Connell (Northwestern University) – **Ge Nanowires from Au-Cu catalysts**

Cu is less O2-sensitive than Al.

Solid and liquid growth at temperature compatible with GaH4

Can tune nanoparticle diameters by varying Au:Cu ratios.

Start with Au-Cu2O shell, but annealing results in homogenous alloy.

Growth rates from: Au ~ 1.5 μm/min

Cu ~ 0.1 μm/min

Au-Cu ~ 0.2 – 0.6 μm/min

**8.45**: – S. Hu (Stanford University) - **Stability of Ge-core/SiGe shell NWs**

Drivers: - Ge NWs – higher electron and hole mobilities

- Direct band-gap, telecommunication wavelengths

- Valence band offsets Ge/SiGe system may confine holes to the core

Initially, Si shells highly defected, however when using lower Si concentration, smooth defect-free shells form.

Synthesis:

GeH4 precursor + H2 carrier gas (growth at 300°C)

Post growth thermal treatments may lead to stress relaxation mechanisms.

Anneal at 700°C promotes interdiffusion

**9am**: - Yi-Chia Chou (Purdue University) - **In situ TEM observations of NW growth**

Solid catalysts are better when making abrupt Si-Ge heterojunction nanowires

Ag is completely miscible with Au: Ag more resistant to oxidation than Al.

Ag: VSS growth – Ag particles remain solid during Si nucleation. However, Ag diffuses rapidly so use Ag-Au alloys.

Some particles grow by VLS, some by CSS

Si nanowire growth rate from solid Ag2Au below 520°C is too slow. Growth rate of VLS ~ 4x that of VSS

- VLS used to grow longer segments

- VSS used to grow Si/Ge heterostructure

**9.30am**: - Shruti Thombane (Stanford University) – **Size effects in Ni catalysed NW growth**

Growth rate for Ni catalyst ~ 8nm/min

Growth rate for Au catalyst ~ 100nm/min

**9.45am**: - Michael Filler (Georgia State Univeristy) - **In-situ study of H2-influence of Si NW crystal orientation**

In thin film, H desorption is the rate limiting step of Si film growth.

Two step growth: – Nucleation step: 1 x 10-5 Torr, 600°C, 15 min

- Elongation step: 5 x 10-5 Torr, 500°C, 120 min

Grow along <111> direction, but at low T or high P, changes to <112>. (This transition is not growth rate dependent). Can change growth direction mid-growth by adding/removing H.

**11am**: - Adele Tamboli (California Institute of Technology) – **Wafer scale growth of Si microwire arrays**

Diffusion lengths ~ 30 μm

NW array > Polymer embedding > Film removal > Re-use substrate!

Tube furnace: Samples located in hot zone, Si deposits on all hot surfaces

Large area microwire array growth: - Use RF induction-heated, cold wall growth process (minimises gas depletion).

- Deposit uniform arrays on 6in wafers

Analysis: Use confocal microscopy to assess structural quality of wire arrays

Wire height distribution was very tight: 53 – 65 μm

Photoelectrochemical analysis:

Use methyl viologen as a liquid junction with p-Si wires to test energy conversion properties.

Wires grown over small areas: η = 8%

Over large area: η = 1.6% (wires too short, doping too high)

**11.15am**: - Andrey Polateyev – **Optical absorption in Si heterojunction wires**

Majority of absorption is in c-Si (as opposed to a-Si shell). Envelope amorphous layer with reflecting contact to trap light.

Jph increases with wire diameter and front surface texturing. Improvement is due to NIR response. Axial junction devices are limited by recombination in c-Si

**11.30am**: - Emily Warren (California Institute of Technology) – **Radial junction Si microwire photocathodes**

- Use lithography to pattern an array of holes on Si <111> substrate coated with a thermal oxide.

- Evaporate Cu into holes

- Remove oxide with H thermal oxide

- Grow wires

**11.45**: Aditye Mohite (Los Alamos, New Mexico) – **Direct measurement of minority carrier diffusion lengths in VLS growth p-n junction Si NWs**

Au catalysed – surface recombination kills diffusion LP

Diffusion lengths roughly constant with applied bias.

Photocurrent plotted as function of distance along wire. The peak shows junction region. Wider peaks suggest longer diffusion length.

Shorter diffusion lengths at lower T

**4.30pm**: - Lopez (Northwestern University) – **Silicon NW polytypes: A Raman spectroscopy study of crystal structure**

Polytypes a result of variations in the stacking sequence.

Rama n spectrpscopy can probe phonons with very low wavenumber. More Raman peaks are seen as k-space period is reduced.

Polytypes can be confused with Moire fringes in TEM imaging. Raman spectroscopy used as confirmation.

Polytypes exhibit new optoelectronic properties – Silicon EG reduces a hexagonality % increases.

However – experimental variables that also effect results;

- Crystallographic selection rules

- Electromagnetic resonance

- Electronic resonance

In plane lattice constant depends linearly on hexagonality

ωpolytype (phonon frequency) = ωZF + ωlattice constant

**4.45pm**: - Greil (Vienna) - **Raman and electronic characterisation of ultra-strained Si/Ge nanowires**

Strain engineering – band gap, effective mass, mobility, thermal conductivity, band structure. Use cantilever to strain wires (wires grown on cantilever)

Single crystalline Si (also Ge, GaAs, ZnO) – defect free

High resolution Raman spectroscopy of a Ge nanowire

First order peak shifts both in tensile and compressive strain.

Piezoresistive effect – 10 fold increase in conductivity for 3.5% elongation.