University and Exploratory Research Funding Opportunities Workshop

Breakout Group IV: III-V Multijunction Cells and Organic PV Cells

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Purpose of Meeting and Ground Rules

"…to identify and prioritize lists of potential PV research topics for inclusion in two proposed funding opportunity announcements (FOAs) directed primarily towards U.S. universities."

Research Priorities: CPV and Multijunction*

- Materials 7
  - Lattice Mismatch/Understanding of defects 5
  - Improved Transparent Conducting Materials 5
  - Novel materials – 3
    - Polycrystalline III-V Thin Films, possible synergy with II-VI research
  - Quantum Dots 1
  - Nano-wires
- Optics (Top-Down Design Approaches) 6
  - Materials for Lenses and Mirrors 8
  - Novel Cell/Optics Integration 7
- Advances in Semiconductor Growth 4
  - Faster 6
    - MOCVD advances and CVD advances, etc…
  - Novel Materials 3
  - Epitaxial Liftoff 1
  - New Precursors
  - Synergies with semiconductor manufacturing industries – foundries, amplifier production…..
- Systems 2
  - Evaluating Performance at the system level

*The breakout group first prioritized the major headings, and then the subheadings within each major heading. Numbers show the number of votes for each item. However, all items on the list are of research interest.

Breakout Group IV: III-V Multijunction Cells and Organic PV Cells

Research Priorities: CPV and Multijunction*

- Reliability Research: Fundamental Understanding of Failure Mechanisms 1
  - Thermal Modeling, Cycling, Contacts 4
  - Encapsulation 3
  - Interconnects and Packaging 2
- Understanding Transport 1
  - Experiment and modeling of transport mechanism 2
  - Developing Characterization Tools
- Device Architecture 1
  - Synergies with semiconductor manufacturing industries – foundries, amplifier production…. 2.
  - Understanding of Luminescence and Photon Recycling and Implications for Device Architecture 1
  - Tunnel Junctions
  - Devices for up and down conversion
  - Wafer bonding/epitaxial liftoff

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Breakout Group IV: III-V Multijunction Cells and Organic PV Cells

Research Priorities: Organics*

- New Materials 5
  - Transparent electrodes 4
  - Enhance mobility and absorbers 3
  - High Electron Carriers 1
  - Quantum dot integration
- Reliability 3
  - Degradation Mechanisms 3
  - Reliability, weatherability
  - Packaging
- Fundamental Understanding/Device Physics 2
  - Understand Transport 2
  - Energy level matching 2
  - Scale Up In Larger Area Devices 1
- Morphology Control and Growth Techniques 1

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Research Topics Discussion

Background Material Developed in the Course of Establishing Priorities

Research Topics

- Risk/Payoff, Long-, Short-Term Aspects
- Parallels between power amplifiers and solar cells could be exploited
  - need for electroplating, reducing line resistance, a lot of volume at cost points (cell phones, military industry)
  - project using commercial foundry capabilities – materials and other issues, but latent mfg. volume that is begging to be put to work. (This may not concern universities, could be a development project with industry)
  - Solar could at least use subset of their processing lines, wafer capacity.
- III-V for lighting and optical refrigeration research underway at AZ state – very high-efficiency MJ, 3-junction, infrared and UV bandgap efficiencies.
- Within materials deal with mismatches.
- Beyond materials, tunnel junction issues and series resistance, type II structures. Novel structures that could solve issues. Fill factor problems, recycling photons, nanowires.
- Devices and materials are closely related -- keep device architecture in close coordination with materials.
- Some materials are very mature individually, but when they are combined it is a different problem, as well as new materials. Lattice mismatch, other issues….

Research Topics

- Are there ways to physically separate the layers, window materials and encapsulation, wafer bonding. Optics?
- Small and expensive cells, only useful under concentration. Need input from people making cells.
- Simple optics favor monolithic structures – complex optics could change the architecture issues. But even simple optics have challenges.
- Need research on what optics can do, instead of adapting to the optics that are available. Start with defining problems, natural limits, and design for what they can deliver. A change in way problem is approached.
- Materials for optics – cells spectrally demanding, some materials may not have right transmissivity – research needed.
- Richard King: In semiconductor research in defects for III-V, particularly lattice mismatch.
- Conversion/non-conversion.
- The way cells are grown is limiting – developing fundamentals of how to do MOVPE – getting away from batch to belt or other continuous processes, and its material usage.
- In CPV, packaging for receivers, for thermal rejection, getting light in and electricity out – all comes together at the receiver. Area gets little research attention.
- More research on relationship on angular acceptance of receptor and cost – or go to low-concentrator system. There is some cost tradeoff between high and low concentration.

Research Topics

- $\theta = (N(1.5)/\sqrt{C} = 3^{o}$ Equation discussion – we fall short by factor of four by having subdegree angle intolerance. Can be done, but takes research, universities are good at going from top down. They are less limited than industry by current patents and equipment commitments.
- Reliability issues. If it will be field-deployed for 25 years the interconnection (contacts) and other issues become critical. We don't understand failure mechanisms, specifically in concentrators. Electromigration that happens at concentration, thermal cycling, etc…
  - Reliability within cells – major problem is packaging rather than semiconductor.
  - Major issue is knowing the lifetime reliably in order to finance and build plants. Without it, can't develop projects in the field.
- MOCVD improvements
  - improved growth rates and material utilization
  - accelerating technologies,
  - hydrothermal technologies to accelerate growth,
  - for nitrides an ammonia replacement that works at low temp., cheap and safe,
  - a non-explosive hydrogen replacement, with decent growth rates.
  - Speed directly impacts cost – microns per hour now, bulk crystal does milimeters per hour. That would make straight throughput approaches feasible.

Research Topics

- Utilization of materials is more important than growth – ASU – developed precursors for GaAs, but process can't be compressed. The packaging is a problem for that process, could revolutionize III-V processing.
- Organics:
  - Bulk heterojunction cells,
  - control/characterization of morphology,
  - control size and distribution of domains, developing channel-like structures, a key item.
  - Related to molecular structure of materials in active layers.
- Control of bandgap of organics – hole and electron carrier.
  - Hole and Electron mobility.
- Organic reliability, weatherability. Typically have 5 or less year lifetime unless fluorinated.
  - Need work in making better fluoropolymers.
  - New materials are key to polymers. Ways to enhance mobility in new materials.
  - Organics don't like negative charges, the fullerene materials metalize. In polymers there aren't any good electron carriers. Find high-mobility electron carriers in polymers.
  - Packaging is a big issue. Fluoropolymers don't have stability.
- Small-molecules and polymers: understanding degradation mechanism. For example sealing out oxygen reduces efficiency and speeds degradation. Are O effects universal? Varies among materials. Device architecture, exciton blocking layers, ….. Understanding what causes the breakdowns
- Organics: Work on larger areas – efficiencies drop, internal resistance increase. Need better understanding of what will happen when scale-up. At 1 cm^2 now.

Research Topics

- Limiting factor is the TCO.
  - Limited conductivity, tradeoff between transmissivity and conductivity in the TCO.
  - Most expensive element.
  - Potential of carbon nano-tubes.
  - Getting around Indium (scarce material) Tin Oxide. Issue spans entire solar industry.
- Theory: III-V luminescence is a loss mechanism.
  - Need a model to handle that, do something to confine that light and reabsorb.
  - Theory and experimental work together.
  - European models that include photon recycling to build from.
- Implications for improving device architectures to deal with luminescence, photon recycling. Enhancing beneficial aspects of photon recycling.
- Silicon does not emit light – can use simple P/N junction model.
  - Emission/reabsorption is complex in III-V, real diffusion coefficient is very complex.
  - Is not well-represented in device models. No easy way to deal with that.
  - Need to develop useable models.
- Fundamentals\understanding of transports in the novel materials – GaAs understood, but slight changes make radical changes in transport. Need fundamental understanding of those in organic and III-V.

Research Topics

- New experimental tools to measure and characterize these transport mechanisms, relation to defects, morphology…
  - Transport very important, including across hetero-junctions. Empirical theory describes, but need more to understand in detail.
  - Consider transport under optical illumination – reabsorption impacts transport substantially. Fundamental understanding can lead to quicker product development.
- Possibility of designing structures to take advantage of integrated optics – splitting approaches…. Topic universities could address.

Research Topics

- Multi-Junction Devices
  - Epitaxial liftoff strategies for multi-junction devices.
  - Manufacturability at low costs.
  - Contacts and transport mechanisms.
  - Wafer bonding approaches to maintain electrical and optical transmissivity, tunnel junctions at the interface – metal is good, but it is not transparent.
  - Epitaxial liftoff – large area liftoff, while maintaining characteristics.
- Exotic Materials: Too far from application – nano-wire growth is not controllable yet, may be in post-2015. Lots of mechanical and growth issues.
- Quantum dot solar cells are implemented in III-V, appropriate for this group.
  - Could be nearer than we think.
  - Extension of quantum well ideas and quantum structures to 1-D wires, 0D wells, getting higher current absorption, reducing voltage loss, absorption characteristics.
- Quantum dots combined with organics, tuneable absorption spectrum can be an advantage.
- Better interaction between quantum dot and the matrix (organic) – electrical coupling, interface control, organics and electrodes. Interface between quantum dot and organic.
- How to get carriers out of quantum dots is a fundamental issue. May not be feasible.
  - Physics within dot understood, but not much on how to make a device.
  - P/N junctions and voltage issues within dots – how to get anything out of a device.

- polycrystalline Materials
  - polycrystalline III-V materials, thin films, recombination defect benefits, how to make multi-junction cells even less expensive.
  - Growing on polycrystalline substrates.
  - High-bandgap thin-film that can combine with a CIS or other low-bandgap material. polycrystalline III-V material that could work in tandem with a I-III-VI.
- Encapsulation technologies
  - Encapsulation for flat-plates are well-developed, but concentrating format has different issues, particularly if you are dealing with broad spectral systems.
  - Experience in devices that the encapsulation is thought of late in the process. Needs upfront focus.
  - Different responses under different concentration from thermal issues, yellowing, moisture and contacts.

Research Topics

- Theoretical modeling of heat on PN junctions, how that and other variables are distributed.
- Long-term testing and measurement on thermal and other stresses, beyond modeling. Multi-variable testing of heat, moisture, etc….
- Test lab for industry that all can access and compare them, and industry can share results that do not impact IP. Draw some generalities. Give feedback to all research teams. (NREL does that – could it be improved?) Testing research type devices.

Research Topics

- More standardization in testing and measurement – for organics in particular. Efficiency reports use different sun concentrations, wavelengths, other caveats….
- Materials for optics – lenses or mirrors – and their expense/performance tradeoffs. Is there an ideal material?
  - Reflective optics are more advanced – luminized polymers, flexible shapes. May not be efficient enough.
- Coating for mirrors that are highly efficient, long-lived, and work well with a broader spectrum into UV ranges.
  - Silver is not good with blue wavelengths and it is hard to protect silver.
  - Multilayer dielectric mirrors – principle is good, has potential, high reflectivity, broad spectrum.

Participants

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