Advanced Materials and Concepts for Full Solar Spectrum Energy Harvesting

Kin Man Yu

Collaborators: Wladek Walukiewicz (LBNL), Z. Liliental-Weber, Oscar Dubon (UCB), S. V. Novikov and S. T. Foxon (Nottingham), W. Sarney and S. Svensson (ARL), R. Martin (Strathclyde), C. W. Tu (UCSD), Y. Okada (Tokyo U.), T. Tanaka (Saga U.)

Solar Cell Losses

1. Thermalization loss
2. Transparency loss
3. Recombination loss
4. Junction loss
5. Contact loss

Our research focuses on new materials and concepts to overcome these losses.

Highly Mismatched Alloys

- Highly mismatched alloys (HMAs)—novel alloys formed by the substitution of isoelectronic elements with very different electronegativities/size.
- Developed a band anticrossing (BAC) model to describe the electronic structures of HMAs (1000 citations).
- Utilized the unique properties of HMAs to develop new concepts and materials for energy conversion devices.

InGaN: Full spectrum PV

- The direct energy gap of In$_{1-x}$Ga$_x$N covers most of the solar spectrum.
- Advantages of using InGaN for solar cells:
  - Flexibility in choosing the number and the bandgaps of junctions to optimize the solar cell performance.
  - Fabrication process could be greatly simplified.
  - Superior radiation resistance—solar cells operated in outer space.

Highly Mismatched Oxides

- Single alloy system with band gap tunable from 0.8-3.4 eV
- High absorption coefficient
- Amorphous structure: grown on low cost substrate, e.g. glass

InGaN-Si hybrid tandem cell

- No tunnel junction needed
- Built on well-established Si solar cell technology

Intermediate band solar cell using GaNAs HMA

- An intermediate band solar cell using dilute GaNAs (~2% N) HMA demonstrates an optical activity of three energy bands that absorb and convert into electrical current the crucial part of the solar spectrum.
- The narrow intermediate band acts only as a "stepping stone" enabling efficient use of low energy solar photons.

CdO as High Mobility Transparent Conductor

- Ideal uncompensated materials with extremely high mobilities of 300 cm$^2$/Vs with electron concentration of $4 \times 10^{20}$/cm$^3$ have been achieved with Ga doping with a maximum conductivity of 20,000 S/cm (or $\rho = 5 \times 10^{-5}$Ω·cm).
- CdO can be used for Si and CZTS instead of metal grids.
- Transmittance of CdO-In compatible with MJ PV.

Structurally Mismatched CdO-ZnO

- Two distinct phase regimes: RS phase with high electron mobility.
- Optical gap of WZ phase decreases from 3.3 eV (ZnO) to 1.9 eV (x=0.67).
- Near band gap edge emission decreases from 3.3 eV (ZnO) to 1.7 eV (x=0.69).