5th IUVSTA School on Photovoltaic Materials and Devices

Sponsored by the Electronic Materials and Processing Division
Final Report from the MVS

The 5th IUVSTA School on Photovoltaic Materials and Devices was held in Huatulco, Oaxaca, Mexico from September 29th to October 3rd, 2003. The school was organized in conjunction with the 23rd National Congress of the Mexican Vacuum Society.
The aim of this school was to provide an intense forum on photovoltaic materials and devices. This school brought together scientists from academic institutions, national laboratories and research centers, to exchange their views on new developments and strategies as well as to form new collaborations. An additional important issue was to provide contacts for young researchers and students with experienced researchers on thin film solar cells.
The school included tutorials by 4 invited speakers and spammed through the four days of the event. All courses were of excellent scientific and technical quality and got great comments from the attendees. The topics of the tutorials were the following:

Monday, September 29

Science Issues and Technological Applications of TCO Films

Dr. Gregory J. Exarhos, Laboratory Fellow
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Abstract
Development of dielectric materials that exhibit both electrical conductivity and transparency continues to attract considerable attention within the technical community since they comprise an integral component of photonic devices including photovoltaic cells, optical limiters, advanced displays (OLEDs), and white light emitting panels for next generation lighting applications. Both chemical and structural defects, intentionally induced during processing, generate charge carriers in otherwise transparent materials and it is these charge carriers that promote conductivity. The number of charge carriers formed and their mobility through the material, then, control the magnitude of the overall conductivity. Among the resident charge carriers in different materials are included electrons, holes, and even a localized charge state known as the polaron that locally distorts chemical bonding in the material. The mechanisms for free carrier migration and polaron hopping will be discussed in terms of a harmonic oscillator formalism that can be used to relate the conductivity to the long wavelength optical response of

the material. Approaches to forming TCO films and post deposition modification of their properties will be reviewed along with the methods used to characterize the films. Issues regarding film interactions at the buried film-substrate interface also will be addressed along with film properties stability in ambient environments. The incorporation of TCO films in devices is highlighted for the several examples listed previously. Challenges in film deposition, properties stability, and device integration also will be discussed.

Outline

I. Describe phenomena responsible for charge transport in dielectrics

A. How does light interact with matter –SHO picture
B. What is the dielectric constant – SHO relationships
C. How is the dielectric constant related to the complex refractive index
D. How are the optical properties related to conductivity
E. Mutually exclusive properties; eg. Conductivity is proportional to both n and k which are frequency dependent; high conductivity usually means high k which means low transparency; how do we overcome this problem
F. Examples of free carrier conductors (review paper)

II. Representative TCO's

A. n-type ITO and doped n- and p-type ZnO films (crystal structures) (trap states near the conduction band; trap states near the valence band)
B. p-type TCO's as seen in Dellafosites – nature of the charge carrier
C. p-type polaron conductors (mixed transition metal oxides)

III. Thin Film Deposition Techniques (relate processing parameters to properties)

A. Magnetron sputtering
B. Solution-cast films
C. Pulsed laser deposition
D. CVD approaches
E. Post deposition modification

IV. Characterization Methods (relate resident defect structure to properties)

A. Electrical Property Measurements (van der Pauw, Hall, Seebeck)
B. Optical (UV/Vis/NIR, FTIR, Raman Spectroscopy, Ellipsometry)
C. Electron spectroscopies (XPS, UPS) depth profiling, interface characterization

D. X-ray diffraction of thin films
E. Microstructure and interface morphology (SEM, TEM, AFM, STM)

V. Applications

A. Active and passive actuators for optical limiting
B. Photovoltaic materials (silicon, CIS), materials integration issues
C. Generation of light - OLED’s, display technology, large area lighting
D. Passive heat reflecting windows and innovative wall insulation material
E. Advanced thermoelectric materials for power generation

Tuesday, September 30

Manufacturing Solar Cells

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Abstract
This talk considers the primary solar cell technologies and the techniques and primary issues of their production. The primary objective of the talk is to give an overview to those interested in possibly establishing manufacturing of solar cells of the options and questions that should be considered. Manufacture of solar cells by almost all technologies requires a large facility including, in most cases, sophisticated vacuum apparatuses. The capital cost of such a facility can be a limitation to product price. In addition, the materials and assembly of the package and wiring of the devices can dominate the cost. These issues should be carefully considered before selecting technologies and building plants. The actual cost of the solar cell itself must be minimized due to the costs of the remainder of the devices and the production facility. The most effective means to achieve this reduction is through reliable processes with high yields. These issues will be discussed in detail. Once one has understood the basic issues of manufacturing a low-margin product, one may consider which technology to produce. Crystalline silicon solar cells are the most common worldwide. Their manufacture is by the Czochralski process or by casting large-grained polycrystals. Major issues include electronic grade Si feedstock or purification of lower-quality material, sawing to minimize material loss, and the effective collection of the electric current produced by the cell. Single-crystal compound semiconductor cells based on GaAs and related materials have the highest overall performance but are very expensive to produce and are nearly impossible to make in large areas. These devices work best under high solar concentration. These factors combine to make such cells primarily useful for space-based applications. The thin film technologies include

amorphous silicon, CdTe, and CuInSe2 and related materials. The thin film deposition methods are more complex but more easily scaled to large areas. Most thin film methods are relatively easily automated, making thin film devices attractive where labor costs are high. Amorphous silicon has suffered from low overall performances. For these devices the cost per unit power output is limited by the glass and other components. CdTe and CuInSe2 are more complex to produce and are less well understood. Alternate low-technology approaches are under development for many solar cell materials but generally have resulted in poor performances, insufficient by comparison with existing technologies. The conclusion is that reliable models of the manufacture of crystalline Si solar cells can be developed. By these one could decide the potential for profit before building a manufacturing plant. Other technologies are much more of a gamble and reliable processes are still to be developed. Details of these issues will be examined and questions concerning specific approaches will be welcome.

Outline

I. Manufacturing Photovoltaics

A. First principles
B. Technologies
C. Generic Solar Cell Structures
D. Concentrators
E. Multijunction Cells
F. One-sun Devices
G. Record Laboratory Thin Film Solar Cell Efficiencies
H. Energy Payback Time

II. Current Manufacturing Status

A. World PV Cell/Module Production
B. Capacity Cost
C. Price History and Forecast

III. Raw Material Supply

A. Speciality Materials
  a. Crystalline Silicon
  b. Thin Film Cu(In,Ga)Se_2-alloys
  c. Thin Film CdTe
  d. Thin Film Silicon

IV. Materials Processing

A. Production Process Overview
B. Crystalline Si by Czochralsky Method
C. Crystalline Si by Casting
D. Crystalline Si by other methods
E. Crystalline GaAs by MBE
F. Crystalline GaAs by CVD

V. Manufacturing Amorphous Silicon Solar Cells

A. a-Si: H Solar Cell Structure
B. PECVD of a-Si
C. a-Si:H Energy Gap Control
D. PECVD of a-Si
E. Sputtering of a-Si:H
F. Amorphous Si Manufacturing Process
G. Example Cost Analysis
H. Performance Over Time

VI. CdTe Solar Cell Structure

A. CdTe by CSS
B. CdTe Treatment with CdCl
C. CdTe by Chemical Bath Deposition
D. CdTe Device Contacts

VII. $Cu(In_{1-x}Ga)Se_2$ Solar Cells

A. Depositing $Cu(In,Ga)(S,Se)_2$
B. CIGS Roll-Roll Coater
C. Case in Study in Manufacturing

VIII. Expected Yield Improvements
IX. Future Plans for Cost Reductions
X. Manufacturing: Where do we stand?
XI. The Future of Photovoltaics
XII. Opportunities

Wednesday, October 1

Chemical Bath Deposition

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Abstract
Chemical bath deposition (CBD), also known as chemical solution deposition, is a technique which has been used to deposit semiconductors for more than 130 years. Yet only in the last decade or two has it seen a resurgence of growth, largely due to its success in thin film photovoltaic cells.
This course aims to provide a reasonably comprehensive overview of the main issues and accomplishments of the technique.We will start with a historical overview of the technique. Following this, a brief review of some basic chemistry and physics most relevant will be given. The various mechanisms of CBD will then be treated in some detail. Attention will be paid to the substrate on which the film is to be deposited. Some recipes for CBD films will be elaborated, with emphasis on how variations in the various parameters are expected to affect the resulting films.

The different groups of semiconductors - sulphides, selenides, oxides and miscellaneous materials will be covered, with examples from each group. Examples of properties of specific interest to particular CBD films, such as nanostructure and optoelectronic properties, will be Finally, some applications - actual and potential - are discussed.

Outline

I. Chemistry and physics basics
   A. Solution Chemistry
   B. Nucleation and Growth
   C. Forces Between Particles

II. Characterization of Films

III. II-VI Semiconductors
   A. CdS
   B. CdeSe
   C. CdTe
   D. ZnS
   E. HgS

IV. Binary and Ternary Materials Deposited by CBD

V. Milestones in the history of CBD

VI. Substrate

VII. Other Sulphides and Selenides

VIII. Epitaxy

IX. Mechanisms

X. Future Prospects for CBD

XI. Photovoltaic Cells

XII. Quantum Size Effects/Nanocrystallinity

XIII. Deposition of Ternary Semiconductors

XIV. Formation of (Hydr)oxides

Thursday, October 2

Surface characterization techniques for solar cell manufacturing

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Abstract

Manufacturing in high technology areas is now basically a combination of sequential depositions and removals of thin films. Complex patterned stacks are built up this way in, e.g. semi-conductor devices, magnetic recording heads and

media, solar devices, etc. It is critical in the devopment of these processes to be able to obtain detailed film characterization information (thickness, composition, effects at interfaces, gradients as a function of depths, etc). In manufacturing it may be necessary to control these parameters very tightly. The thickness of films and film stacks needing to be handled can vary from less than 10 Å to tens of 1000's of Å. Owing to this wide range many different analytical techniques may have to be used to characterize them. This course reviews the major techniques used in industry for thin film and ultra-thin film characterization and metrology, with an emphasis on the ultra thin film end and the more recently emerging techniques needed there.

Outline

I. Ultra Thin Films Characterization & Metrology
II. Angle Resolved XPS and Parallel ARXPS
III. Why is XPS now important to the industry
IV. What is ARXPS?
V. What is PARXPS?
VI. Potential Advantages of PARXPS
VII. The Theta 3000
VIII. Key wafer processing areas addressable
IX. Ultra-thin film depth profiling by PARXPS: status and applications
X. Comparison of the Theta 300 lab too (PARXPS) with the Phi fab tool

The attendance to the 5th IUVSTA School on Photovoltaic Materials and Devices was around 50 people, with a large participation from students. Participants from other countries were: Colombia (3) , Cuba (1), Peru (1), Spain (1), Russia (1), Slovakia (1).

MVS Organizing Committee

Some pictures from the 5^{th} *IUVSTA School on Photovoltaic Materials and Devices*