RF-Sputtered Ge-ITO Nanocomposite Thin Films for Photovoltaic Applications

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Objectives and Motivation

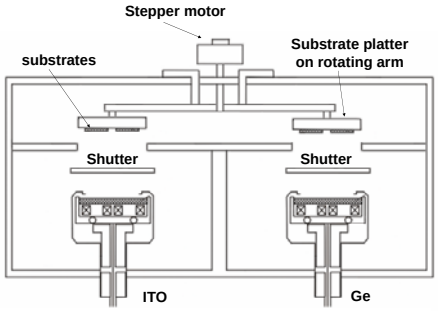
Nanophase photovoltaic (PV) cell architectures containing distinct absorption and carrier transport phases offer new opportunities to individually tailor the spectral capture and carrier collection functions necessary for efficient PV energy conversion.

The current effort focuses on the development of inorganic nanocomposite structures in which a semiconductor quantum dot (QD) "sensitizer" phase is introduced at a thin film PV heterojunction. In this context, quantum dots are of increasing interest for nanostructured photovoltaics as their absorption characteristics can be tuned through both composition and quantum size effects for more effective matching to the solar spectrum.

A dual-source, sequential RF-sputtering technique that allows the simultaneous formation of heterojunction structure and QD-phase is employed. The approach provides the opportunity to control QD ensemble characteristics that can significantly influence the optical and electronic performance of the nanocomposite (e.g. average QD size, local volume fraction, distribution within the junction region, and interfacial chemistry).

An initial investigation of Ge (QD)-ITO nanocomposite thin films produced using the sequential RF-sputtering technique is pursued. Nanostructural development and the resulting optical, photoconductive, and electronic response of these materials is examined.

Sequential RF-Magnetron Sputter Deposition



Dual-source deposition chamber schematic

Approach:

✓ Alternating exposure to Ge and ITO sputter sources. Control exposure time over each source to define: relative volume fraction of each phase in nanocomposite, distribution of phases along film growth direction, phase assemblage (e.g. discontinuous vs. continuous layers)

** T.J. Bukowski, Ph.D. Dissertation, Univ. of Florida, 2002*

Post-deposition thermal anneal:

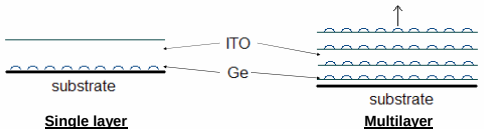
✓ 600 C, 30 minutes in air for initial evaluation.*

Nanocomposite Design:

✓ **Multilayer Ge (QD)-ITO:** allows nanostructural development and optical behavior for Ge QD ensemble to be examined.

- Layer designs examined:
  0.4 nm Ge:15 nm ITO; 1.5 nm Ge:15 nm ITO

✓ **Single layer Ge (QD) with ITO overlayer:** evaluation of QD contribution in the context of a heterojunction structure. (0.4 nm Ge and 1.5 nm Ge)

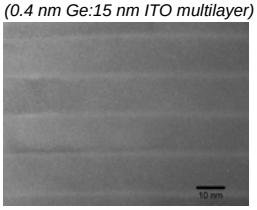


Substrates:

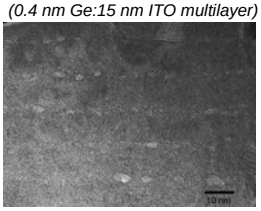
✓ Silica (optical and photoconductivity analysis) and Si (ITO-Si heterojunction).

Microstructural Analysis (Cross-section TEM)

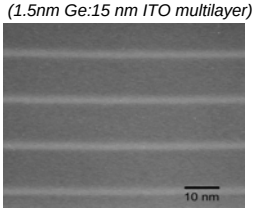
As-deposited (0.4 nm Ge:15 nm ITO multilayer)



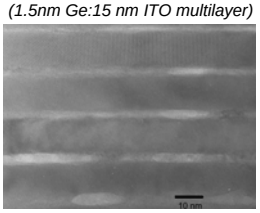
Annealed (600 C, 30 min.) (0.4 nm Ge:15 nm ITO multilayer)



As-deposited (1.5nm Ge:15 nm ITO multilayer)



Annealed (600 C, 30 min.) (1.5nm Ge:15 nm ITO multilayer)



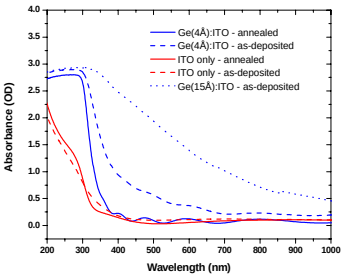
✓ Microstructure of as-deposited composite confirms deposition of alternative Ge-ITO layer system.

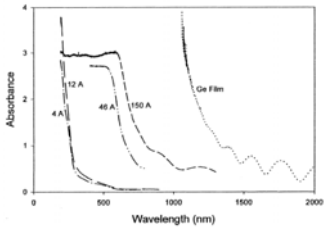
✓ Post-deposition thermal treatment produces equiaxed Ge nanocrystals (diameters approximately 2 – 8 nm).

✓ Higher aspect ratio nanocrystals produced in 1.5 nm Ge: 15 nm ITO multilayer structures.

✓ Quantum dot number density varies along film deposition direction with a periodicity determined by the initial alternating layer structure.

Optical Absorption: Multilayer Structure





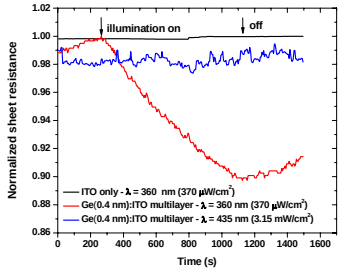
*Ge quantum dots in silica matrix***

✓ Absorption behavior of annealed multilayer nanocomposite confirms quantum shift in Ge absorption edge. Comparison with analogous absorption data for Ge in silica indicates similar quantum shift for Ge in ITO.

✓ Sample with lower Ge exposure time exhibits higher energy as-deposited absorption edge: support for the presence of a discontinuous Ge layer in as-deposited structure (nanostructure now under study).

*** T.J. Bukowski et al., J. Non-cryst. Sol. 274, 87 (2000)*

Photoconductivity (4-point probe)



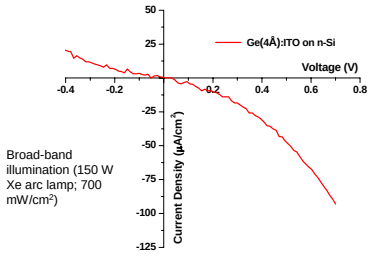
✓ Photoconductivity measured for samples on fused silica to eliminate substrate optical absorption at photon energies near Ge quantum dot absorption edge.

✓ Photoresponse probed as a function of wavelength using LED sources (10 nm FWHM) operating at 360 nm ($E > E_g$) and 435 nm ($E < E_g$)

✓ Increased conductivity under 360 nm illumination confirm participation of Ge QD phase in carrier generation. ITO (n-type) carrier transport phase.

Heterojunction Characterization (J-V)

Single layer ITO-Ge sample (115 nm ITO:0.4 nm Ge (single layer) on n-Si)



✓ Rectifying ITO/n-Si heterojunction containing Ge quantum dots confirmed.

✓ Photovoltaic response now under study.

Summary

✓ Ge-ITO nanocomposite thin films produced via sequential RF-magnetron sputtering. Electronic and optical behavior examined in the context of nanostructured photovoltaic objectives.

✓ Successful production of Ge quantum dots (2 - 8 nm) in ITO confirmed in an multilayer nanolayer sample design. Control of deposition conditions can be used to tailor Ge-phase distribution within matrix and the starting point for phase development through post-deposition thermal treatment.

✓ Optical absorption and photoconductivity confirm optical behavior of Ge QD ensemble and Ge photocarrier production and transport in ITO (multilayer). J-V characterization under illumination confirms rectifying ITO-Si junction with photomodified behavior.

✓ Future Efforts: increased nanostructural control through alternative multilayer designs, deposition conditions and thermal anneal schedules. Photovoltaic performance measurement.

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