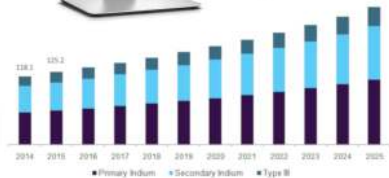
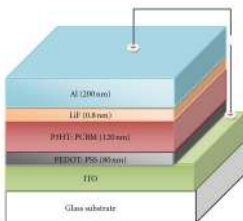


Improved TCO Process Stability Using In Situ 4-Point Probe Sheet Resistance Monitoring

J. H. Gurian
November 27, 2018

Increasing TCO Market



Grand View Research GVR-1-68038-820-6
 Etan J. Tal
 Ashley Pomeroy

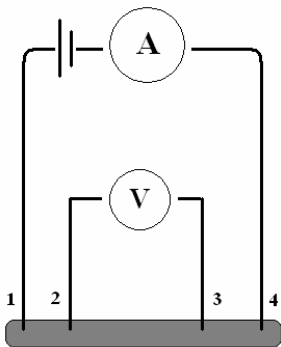
In-Situ Sheet Resistance Monitoring

- 4-point probe technique
- 200 k Ω to 0.2 Ω range
- $\pm 0.5\%$ accuracy
- FR4-based sensor card

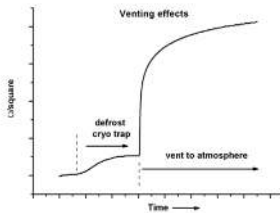
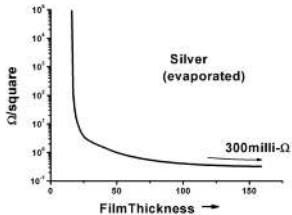
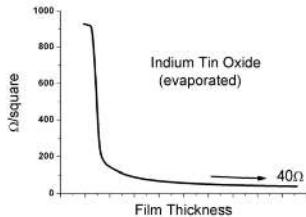
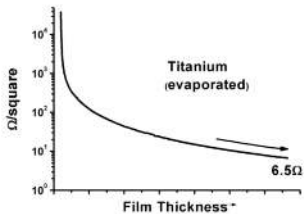


4-Point Sensing

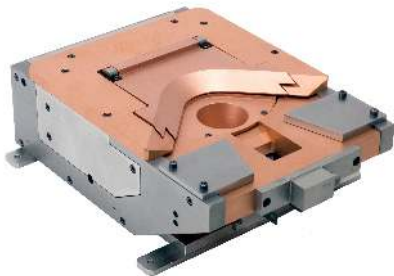
- Outer electrodes supply current I
- Inner electrodes sense voltage V
- Ohm's Law $\Omega = \frac{V}{I}$ provides accurate film resistance
- Eliminates wire lead and contact resistance from measurement



SRM Examples



Electron Beam Advantages

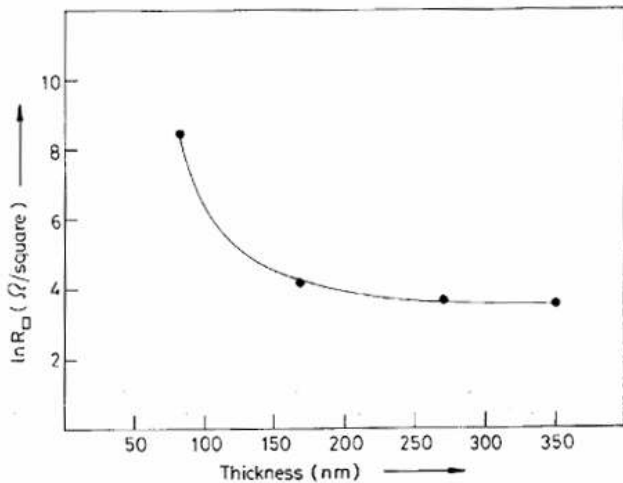


- High Deposition Rates
- Excellent Material Utilization
- Easily incorporate multiple materials for multilayer coatings

Electron Beam ITO Difficulties



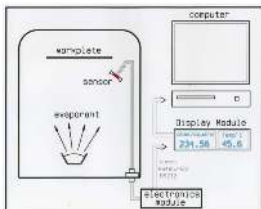
- Difficult ITO stoichiometry control
- In_2O_3 & SnO_2 evaporate at individual vapor pressures
- Post-deposition 250-400 °C air bake recommended

ITO Ω/\square vs Thickness

Benoy, M.D. et al Braz. J. Phys. (2009)

Deposition Equipment

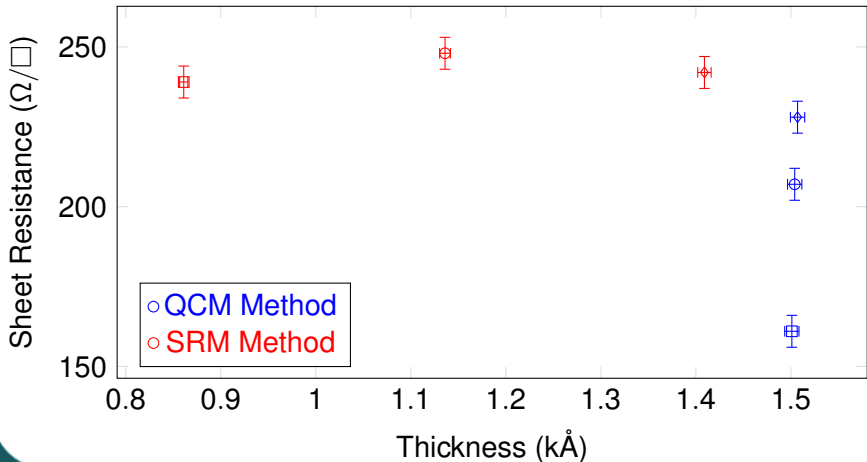
- CCS CA-50
- Telemark Model 274 4x40cc
- Telemark 861 Dep Controller
- 6MHz Quartz Crystal Sensor
- Sheet Resistance Monitor



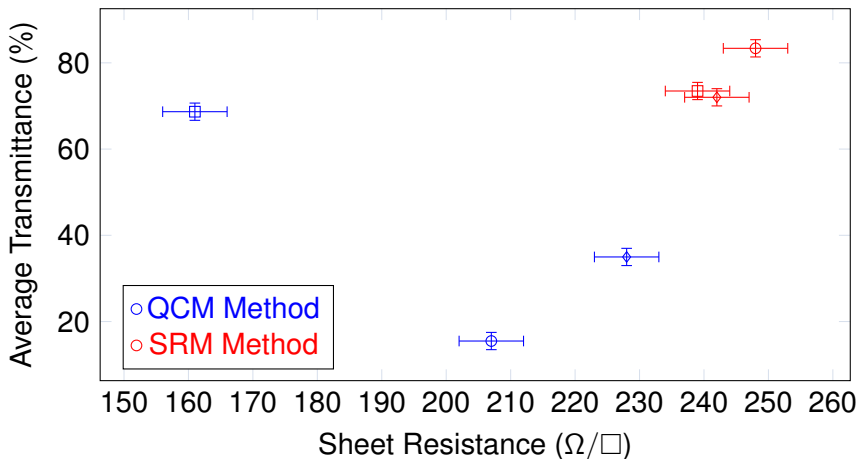
Experimental Approach

- Evaporate ITO ($\text{In}_2\text{O}_3/\text{SnO}_2$ 90/10 WT%) at 5 \AA s^{-1}
- Stop via QCM at 1.5 k\AA
- 5×10^{-5} Torr O_2 partial pressure
- 1 h in-air post-deposition bake at $300 \text{ }^\circ\text{C}$
- Measure sheet resistance & optical transparency
- Repeat for (3) runs to establish run-to-run variation
- Repeat procedure using Sheet Resistance Monitor as stop criteria

Resistivity Results



380-780 nm Optical Transmittance Results



Measuring using a Telemark Model 833 Optical Monitor

Conclusions

- In-situ sheet resistance monitoring improved resistance run-to-run variation from 20% to 5%
- Currently developing high temperature SRM sensor cards for $>150\text{ }^{\circ}\text{C}$
- Exhibit Booth 1125

