**Triode Plasma Approach to Low-Damage TCO Deposition for Silicon Heterojunction Solar Cells**

J.-H. An1,2, J.-E. Hong1, S.-I. Mo1,2, Y. Jo1, S, Choi1, S. J. Oh2, K. T. Jeong3, H.-e. Song3, J.-H. Oh1, K.-H. Kim4

*1 Korea Institute of Energy Research, Ulsan, South Korea*

*2 Korea University, Seoul, South Korea*

*3 Korea Institute of Energy Research, Daejeon, South Korea*

*4 Chungbuk National University, Cheongju, South Korea*

Transparent conducting oxides (TCOs) are essential in various optoelectronic applications, including carrier-selective passivating contact solar cells, due to their excellent transparency and electrical conductivity. However, conventional diode-configured sputtering methods often introduce significant sputter damage, which degrades the surface passivation quality of a-Si:H/c-Si silicon heterojunction (SHJ) solar cells. This degradation is primarily caused by the bombardment of highly energetic oxygen ions, resulting in partially irreversible damage even after thermal annealing. In this presentation, we propose a triode plasma sputtering configuration that integrates a negatively biased mesh electrode into the conventional diode system. Measurements showed that sputter damage in SHJ devices can be assessed by observing the evolution of implied open-circuit voltage (i*V*oc), effective carrier lifetime (*τ*eff), and low-temperature hydrogen exodiffusion in SHJ precursor structures. Our triode plasma approach suppresses oxygen ion bombardment, reducing *τ*eff degradation from 96% (diode) to just 7% (triode). We also observed that triode-configured plasma not only reduced sputter damage but also altered the properties of as-deposited ITO films, which serve as indicators of this reduction. The triode configuration not only minimizes oxygen ion damage but also yields ITO films with enhanced carrier mobility, higher refractive indices, and lower extinction coefficients. Furthermore, the reduction in ion bombardment is reflected in a shift in the preferred crystal orientation of the ITO films from the (400) to the (222) plane.