Why is Depth Profiling of Electrical Properties using DHEM Important?

Carrier concentration and mobility are semiconductor properties that greatly affect device performance. The commonly used techniques to determine these properties are 4-point probe and Hall effect/Van der Pauw measurements, which yield Hall mobility (μ_H) and carrier concentration (n) values for the full film under study. The measured bulk values can be used for correlating process conditions and film attributes ***only if*** the mobility and carrier concentration are uniform through the thickness of the film. If the mobility and/or the carrier concentration vary through the film, as is often the case, then the bulk measurements yield effective mobility and carrier concentration values that can be represented by the relationships:

$$\mu_{H\,eff} = [\int n(z)\,\mu(z)^2\,dz] / [\int n(z)\,\mu(z)\,dz] \qquad n_{eff} = [\int n(z)\,\mu(z)\,dz] / [\int dz][\mu_{H\,eff}]$$

As one may expect from the above equations, depending on how the mobility and the carrier concentration may vary through the thickness of a film (in “z” direction), the effective values obtained from the bulk measurements cannot define the true characteristics of the film, and therefore, can be very misleading. Differential Hall Effect Metrology (DHEM) measures and delivers high resolution depth profiles of mobility and carrier concentration through a film providing the details necessary to reach the right conclusion.

Example

Two Si samples were P-doped under two different conditions (Process A and Process B). Bulk measurements yielded lower sheet resistance value and higher carrier concentration (assuming 12 nm thickness) for Process B compared to process A, as shown in the table below. The goal in this study was to improve dopant activation at the surface region of the film for low-resistance contact fabrication. If the bulk data was relied upon for process development in this example, one would ***wrongly*** conclude that Process B was better than Process A, because it yielded lower sheet resistance and higher effective carrier concentration values. The DHEM depth profiles obtained from the two samples, however, clearly demonstrated that the sample subjected to Process A actually had a higher near-surface dopant activation compared to Process B. This is a correct determination that the standard bulk measurements could not reach.

	Process A	Process B
Rs (Ω/□)	835.86	494.09
$\mu_{H\,eff}$ (cm^2/V-s)	58.15	40.41
n_{eff} (cm^{-3})	1.07×10^{20}	2.6×10^{20}