High Resolution X-Ray Microanalysis

Introduction
Advanced materials analysis in high tech industries, such as semiconductors and microelectronics, nanotechnology, and life sciences, requires ever increasing high resolution analytical performance to allow the analyst to understand the subtle differences in the characteristics of the samples.

The term resolution is used in two distinctly different aspects of SEM based microanalysis. In general, resolution defines the ability of the system to resolve, or separate, two aspects of the analysis that are very close together. In imaging and mapping, spatial resolution will affect the analyst’s ability to visibly separate two physically closely spaced items. In a spectrum, improved energy resolution enables differentiation between two elements whose peaks fall at closely spaced energies, as with light element peak separation. One of the benefits of a truly superior microanalysis system is the ability to deliver high resolution in both areas with one detector. This can be demonstrated by the analysis of a semiconductor device using the TEAM™ EDS Analysis System with an Octane Silicon Drift Detector (SDD).

Materials Challenge
As the size of the features to be analyzed continues to move to the nanoscale, the probe size of the electron beam needs to shrink to meet the spatial resolution required for successful analysis. This is done by reducing the beam accelerating voltage (kV) and beam current, resulting in a smaller interaction volume in the sample. Unfortunately, this also results in lower x-ray signal intensity, and smaller spectral energy range with fewer peak options. Successful analysis must therefore maximize the collection efficiency of the x-ray signal with a larger detector sensor and thinnest possible detector window. Additionally, energy resolution at the low end of the spectrum to becomes critical to resolve closely spaced element peaks.

Analytical Results
Mega-Resolution Phase Maps
Figure 1 shows a phase map from the cross section of a semiconductor device acquired with an electron beam energy of 5 keV with an TEAM™ EDS System with Octane SDD. The data collection shows a gold bond wire connected to an aluminum bond pad with the device structure underneath. While the low beam energy leads to a higher spatial resolution due to limited penetration depth and volume from which x-rays are generated, the significant peak overlaps between the light element K-lines and the heavier element L- and M-lines make elemental mapping and correct spectral deconvolution highly challenging from an energy resolution standpoint.

The phase map in Figure 1 shows areas with similar chemical composition rather than the pure elemental maps. This feature, unique to the TEAM™ EDS System, allows the user to rapidly identify differences between areas without having to overlay multiple elements. As an example, the Si elemental map is shown in Figure 2. This map shows all areas where Si is present, but does not reveal the differences between the areas. By extracting the Si maps from the distinct phases automatically identified by the TEAM™ software during phase map acquisition, the user can easily identify the glass particles found in the device encapsulation material and the silicon oxide dielectric layer in the device (Figure 3), the silicon nitride barrier layer (Figure 4), and the pure silicon substrate (Figure 5).
An interesting feature of the sample is revealed by examining the gold and aluminum rich phases. The pure gold phase in Figure 6 clearly shows the gold bond wire while Figure 7 shows the aluminum bond pad and metal layers. However, the TEAM™ software also identifies a gold/aluminum intermetallic phase as shown in Figure 8. Quantification of the x-ray spectra from intermetallic phase shows the composition to be 40 atomic percent gold and 60 atomic percent aluminum. The intermixing of gold and aluminum is caused by the junction being exposed to high temperatures. This is a well-known failure mechanism in integrated circuits as the growth of intermetallic phases causes a volume reduction which leads to voiding at the gold-aluminum interface. The intermetallic itself is also a poor conductor, leading to increased electrical resistance in the bond connection.

By examining the high magnification map of the device structure shown in Figure 9, the excellent light element sensitivity and resolution of the Octane detector at low acceleration voltages becomes even more apparent. The size of the yellow aluminum metal structures are 1 micron (upper) and 750 nm (lower) and the nitrogen rich passivation layers around the structures are clearly resolved.

High Resolution Imaging with Line Scan
While mapping provides a detailed picture of the sample and great insight into the elemental distribution and phases, the x-ray line scan is an invaluable tool when very rapid acquisition is desired, as is often the case with beam sensitive samples. Figure 10 shows the nitrogen signal from a line scan across an aluminum layer in the device. The upper passivation layer has a width of 150 nm and with a step size of 20 nm, the total acquisition time of the line scan was less than 30 seconds. The short acquisition time emphasizes the capability of a large area detector to rapidly record high quality spectra without losing information and shows the excellent light element sensitivity even at very fast acquisition times. This is possible due to the resolution stability and superior detector electronics of the Octane SDD series, which has the fastest processing times on the market and guarantees high quality data at all acquisition speeds.

Recommended EDAX Solution
A larger area SDD with <50 nm silicon nitride window, such as the EDAX Octane Elite, is ideally suited for high resolution semiconductor microanalysis. The well-engineered geometrical design maximizes proximity with superior solid angle, as compared with detectors of similar size. The thin window provides the highest level of transmission for low keV X-rays, while still preventing damage to the detector, which is not the case with a windowless detector. These features allow the SEM operating conditions required for optimal imaging resolution. The resolution quality of the low energy spectrum, paired with the unique software functionality of TEAM™ EDS, delivers light element performance results never before possible with large area detector systems. Combining these two performance attributes, Octane SDDs maximize both spatial and energy resolution, providing the ultimate analytical results on highly demanding samples.