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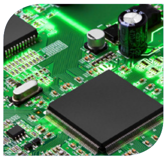


Plasmonics, Bandgap, Dielectric Function, and Chemical State Analysis Using High Energy Resolution Monochromated EELS

Improve energy resolution using advanced monochromated EELS.

Introduction

Electron Energy Loss Spectroscopy (EELS) is a powerful technique for probing chemical composition at high spatial resolution. Beyond elemental detection, EELS provides access to chemical bonding, bandgap, dielectric properties, and plasmonic behavior. However, the ability to extract this information is often limited by the ~1 eV energy spread of a standard field emission TEM source.

A monochromator narrows the energy spread of the electron beam by filtering and selecting only a small portion of emitted electrons. This dramatically improves energy resolution and enables analysis that is otherwise inaccessible.

This application note highlights Eurofins EAG's advanced monochromated EELS capabilities, including bandgap measurement, dielectric function extraction, plasmonic mode characterization, and high precision ELNES chemical state analysis.

Energy and Spatial Resolution with a Monochromated Beam

Several of our probe corrected AC-STEM tools are equipped with an integrated monochromator. As shown in Figure 1, the zero loss peak (ZLP) at 200 kV has a full width at half maximum (FWHM) of ~1 eV in unfiltered mode. After monochromation, the ZLP narrows to ~0.1 eV (100 meV) — a tenfold improvement. At 80 kV, even higher energy resolution is achieved, with measured ZLP widths of 65–75 meV.

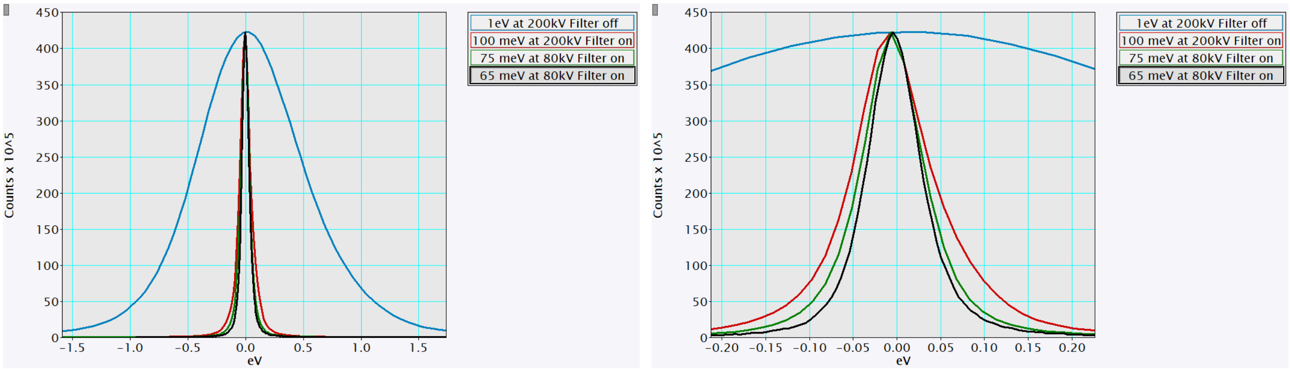


Figure 1. Zero loss peak collected at 200 and 80kV with monochromator filter off (lt. blue) and on (red, green, black). (b) is zoom in of the ZLP in (a).

Despite narrowing the energy spread, the monochromated beam maintains high spatial resolution. Figure 2 demonstrates that <110> silicon dumbbells (1.3 Å spacing) remain fully resolved at 80 kV using a 200 meV monochromated beam, confirming excellent probe quality.

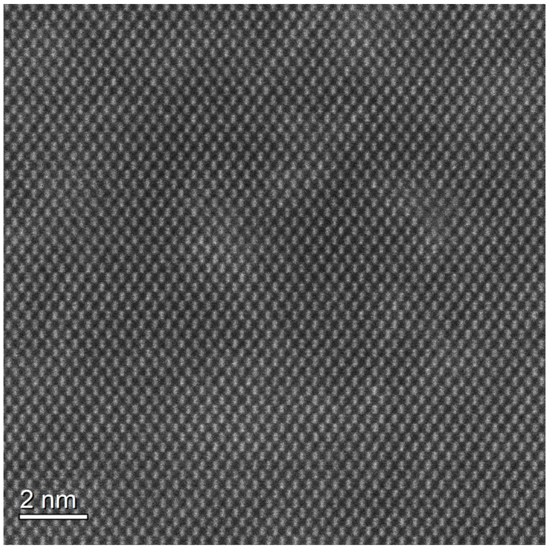


Figure 2. STEM HAADF image of Si along <110> direction collected at 80kV with monochromator filter on shows 1Å resolution.

This combination of high energy resolution and atomic spatial resolution enables analyses that were previously unattainable in industrial settings.

Plasmonic Analysis

Metal nanostructures support localized surface plasmon resonances whose energies and intensities depend on geometry and composition. Optical characterization lacks the spatial resolution needed to map plasmon distributions at the nanometer scale.

Monochromated STEM EELS overcomes this limitation. Figure 3 shows an Ag triangular prism where spectra collected at different positions reveal distinct plasmon modes:

- Corner: single mode at ~1.3 eV
- Edge midpoint: additional mode at ~2.0 eV
- Center: bulk like modes at ~2.9 and 3.8 eV

Energy filtered plasmon maps directly visualize these modes and their spatial localization, enabling true nanoscale plasmonic analysis.

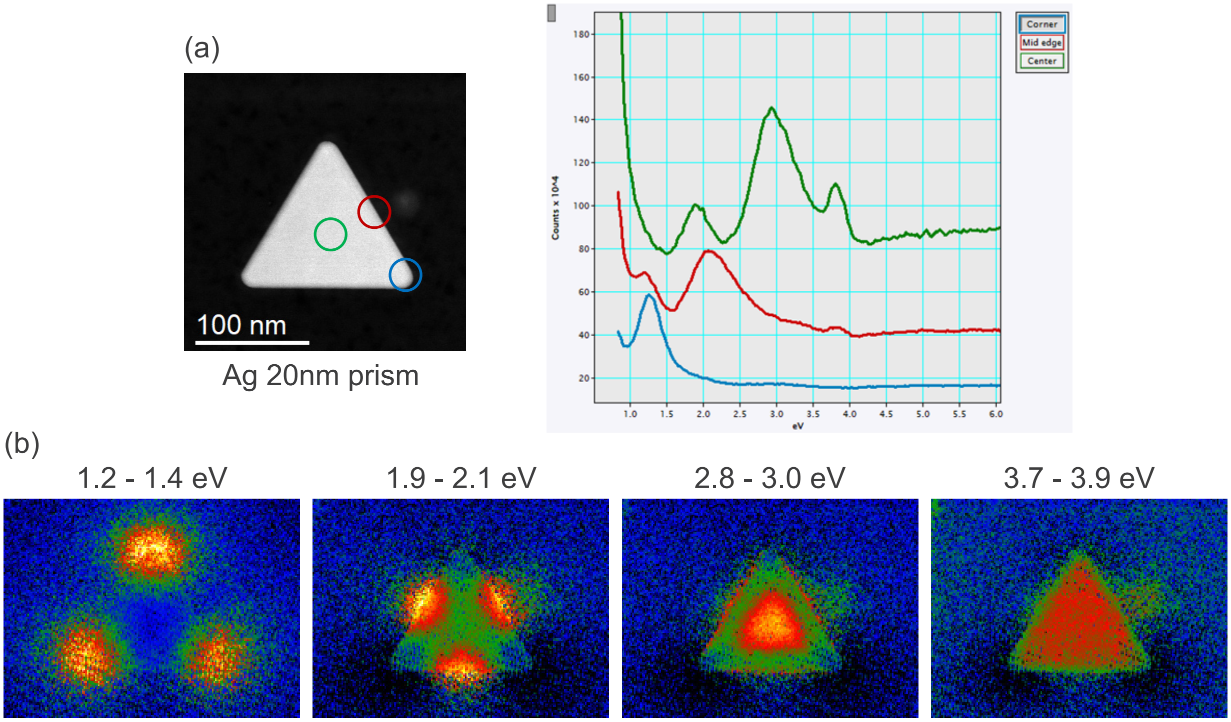


Figure 3. (a) STEM image of an Ag prism and three EELS spectra collected from center, edge middle and corner of the prism. (b) EELS maps with different energy loss to directly visualize the distribution of the plasmon modes.

Bandgap Measurement

Bandgap mapping at nanometer resolution is valuable for semiconductor materials, heterostructures, and interfaces. Historically, accurate bandgap extraction from EELS was hindered by the long tail of the ZLP in non monochromated spectra.

Using monochromated EELS, the bandgap onset becomes clearly visible, as demonstrated in Figure 4. After ZLP removal, materials such as GaN, AlGaN, Al_2O_3, and SiO_2 show well defined onset energies. Figure 5 shows a 2D bandgap map of a V-shape defect inside a commercial LED device. Small variance of bandgap in the level of 0.05-0.1eV was observed clearly at nm scale. This enables quantitative, spatially resolved bandgap measurements, even in complex device structures and defects.

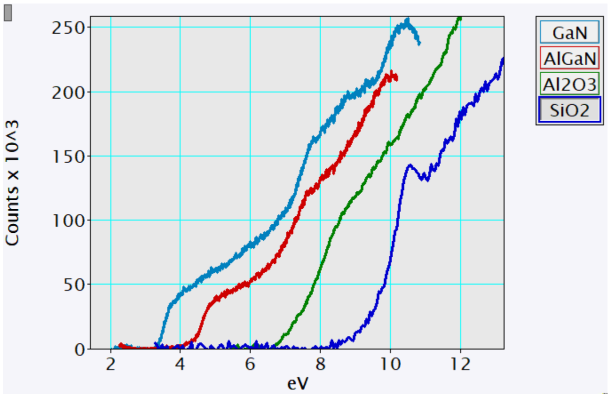
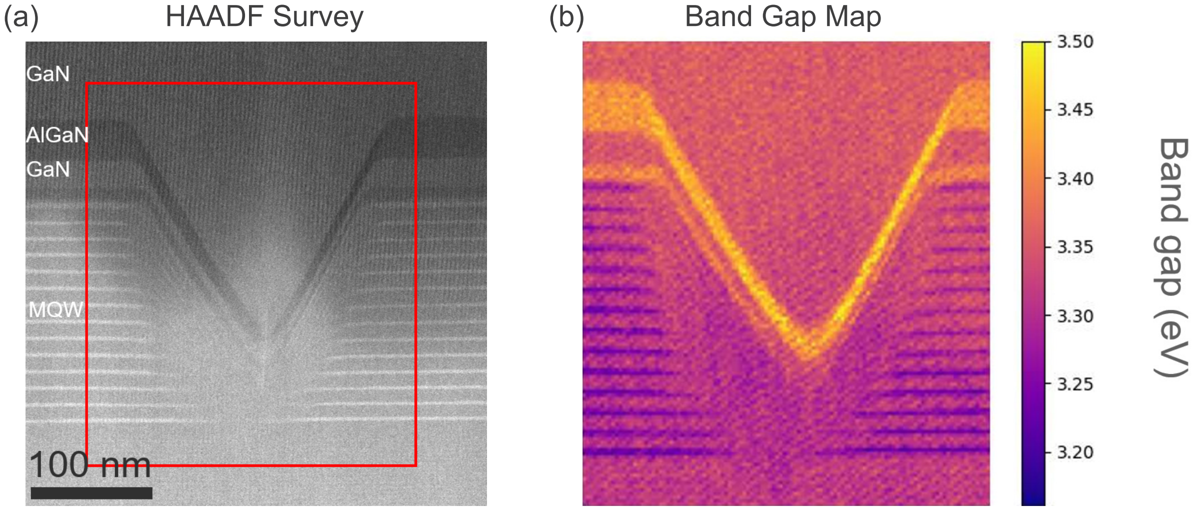


Figure 4. Low loss EELS of different materials, GaN, AlGaN, Al_2O_3 and SiO_2 after ZLP removal.


(a) HAADF Survey

(b) Band Gap Map

Figure 5. Bandgap maps from a commercial LED device show the variance of the bandgap at the V defect.

Dielectric Function Analysis

Low loss (valence) EELS encodes the optical response of a material. Compared to optical techniques such as ellipsometry, EELS offers:

- Higher spatial resolution
- Broader spectral coverage in a single acquisition
- Access to nanoscale variations in dielectric behavior

After ZLP subtraction and correction for surface/ retardation effects, Kramers–Kronig Analysis (KKA) yields the complex dielectric function. Figure 6 shows results for SiO_2, including:

- corrected loss function
- real and imaginary parts of the dielectric function
- refractive index n and extinction coefficient k

Thanks to high monochromated energy resolution, reliable dielectric information can be extracted down to a few electron volts, fully covering the visible regime.

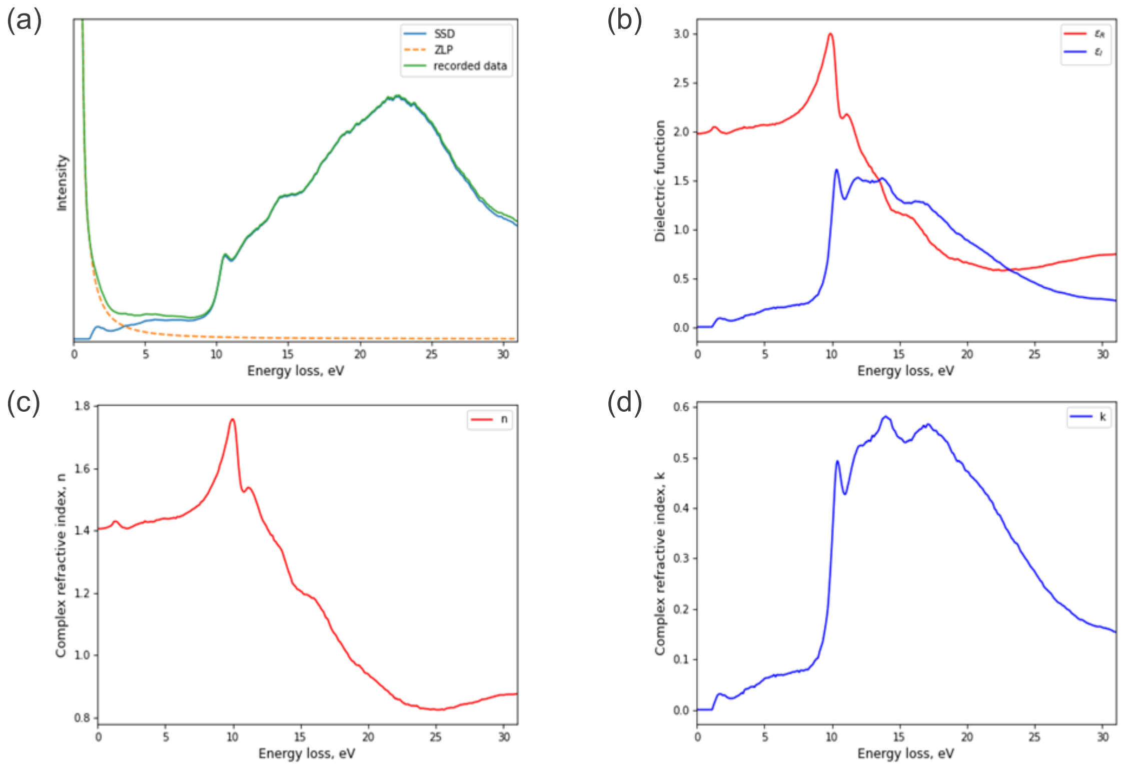


Figure 6. Low loss EELS of SiO2 (a), derived dielectric function (b) and refractive index n and k in (c,d).

Chemical State and ELNES Analysis

High loss (core loss) EELS provides elemental distribution maps at nanometer resolution. Figure 7 shows a 2D elemental map of a 3D NAND device, revealing a layer stack of:

W / AlTiN / SiO_2 / SiN / SiO_2 (SiON) / Si / SiO_2

However, conventional elemental maps lack chemical bonding sensitivity. Energy Loss Near Edge Structure (ELNES) analysis provides this capability.

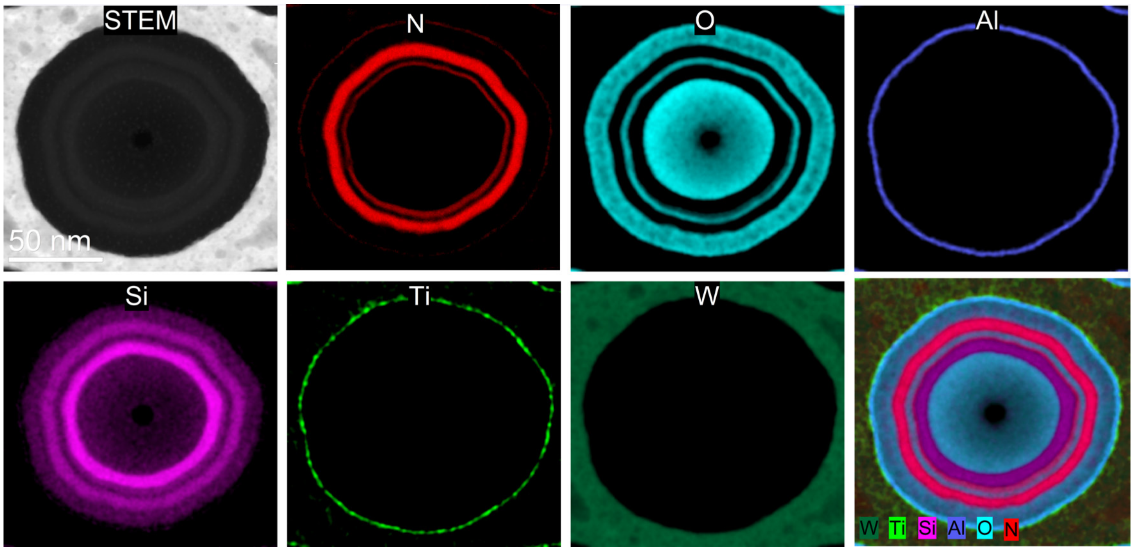


Figure 7. 2D elemental mapping by EELS of a planar view of 3D NAND structure.

Si L edge ELNES

Using monochromated EELS, subtle bonding related features become clearly resolved.

In SiO_2, a pre edge feature at 106 eV is observed (Fig. 8a), which further splits into two peaks separated by 0.4 eV (Fig. 8b) — a separation too small to detect with non monochromated EELS. The spectral shape closely matches that of quartz like Si–O bonding.

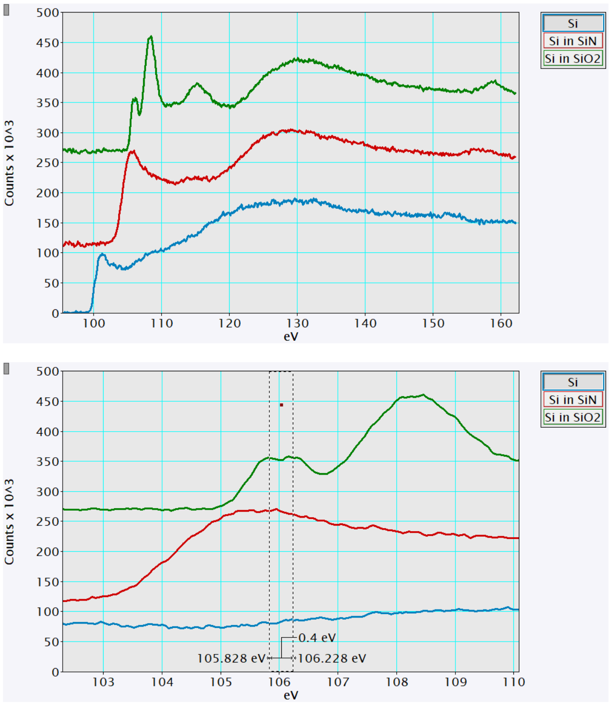


Figure 8. (a) Si L-edge in pure Si, SiN and SiO2 and it zoom in (b).

N K edge ELNES

The nitrogen K edge exhibits strong bonding sensitivity (Figure 9a):

- TiN: pronounced doublet from N 2p–Ti 3d hybrid states
- SiN and SiON: similar spectral shapes, indicating analogous bonding
- Interface (SiN/SiON): sharp 402 eV peak characteristic of N–N bonds, suggesting the presence of trapped N_2

Figure 9b shows a spatial map separating TiN like nitrogen, SiN/SiON nitrogen, and N_2 bubble accumulations with nanometer scale precision.

Although not every element shows obvious changes in ELNES under different chemical states, subtle chemical state resolution is only achievable with high dispersion, monochromated EELS.

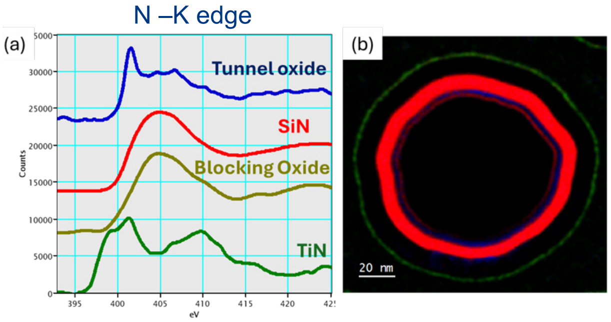


Figure 9. (a) N K-edge in TiN, blocking oxide, storage layer SiN, and tunnel oxide SiON. (b) the nitrogen maps in TiN, SiN, and at the tunnel oxide.

Conclusion

Eurofins EAG Laboratories provides industry leading monochromated EELS capabilities that deliver:

- Plasmonic mode mapping at nanometer resolution
- Accurate bandgap measurements and bandgap mapping
- Full optical dielectric function extraction via KKA
- High precision ELNES chemical state analysis
- Elemental mapping with nm level spatial resolution

EAG is among the very few industrial laboratories offering such advanced monochromated EELS analysis. Our state of the art instrumentation, combined with deep microscopy and spectroscopy expertise, enables customers to extract actionable insights from their most challenging materials problems.

Contact us today to learn how we can help you with your next project.