

High-Speed Composition Analysis of High-Z Metal Alloys in DualEELS™ Mode

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Introduction

As the size of III-V devices decreases, ohmic contacts and their performance becomes increasingly significant. In addition to low resistance, these contacts must be reproducible, show good lateral and depth uniformity and be thermally stable. AuGeNi ohmic contacts are widely used as they show a low contact resistivity and are typically compatible with the fabrication of III-V MOSFET devices [1]. However, they have the drawback of poor uniformity due to the diffusion of the Au into the III-V substrate. This diffusion is dependent on the temperature used during the annealing process after deposition of Au, Ge and Ni. It is clear that the performance of this type of contact will be influenced by both the material present and the degree of roughness at the interface with the III-V substrate; methods to analyze these materials at the sub-nanometer level are required.

To study these interfaces, it is critical to use techniques that can probe a broad range of structural, compositional and chemical properties on real world devices with high-throughput. Modern HAADF-STEM instruments combined with EELS spectrum imaging forms a compelling tool. HAADF-STEM provides structural information and qualitative compositional information while EELS provides sensitive quantitative compositional data along with true chemical state data from a range of elements all with sub-nanometer resolution. The introduction of fast EELS spectrometers such as the GIF Quantum® [2] and the Enfinium® has dramatically changed the rate that information can be recorded via EELS spectrum imaging. The detectors in these next generation systems allow EELS chemical maps to be acquired at over 1000 spectra per second allowing the full advantage of the increased brightness available in a probe corrected STEM microscope to be realized. In addition to speed, these detectors support both higher dynamic range and duty-cycle acquisition. These advances allow fast EELS spectra with excellent signal-to-noise ratio to be acquired from the high-energy region of the EELS spectrum for heavy elements such as Au and Pt with exposure times below 1ms in some cases.

Methods and Materials

The AuGeNi ohmic contact stack of this study was deposited by electron beam evaporation onto a AlInAs layer previously grown using molecular beam epitaxy (MBE), which is shown schematically in Figure 1. After deposition, the sample underwent a rapid thermal annealing process. Sample was grown using the facilities available at Electrical & Electronics Department at the University of Glasgow, UK. The TEM cross-section was prepared using the FIB situated at the Department of Physics and Astronomy at the University of Glasgow, UK. As a result of the FIB preparation process, this TEM cross-section shows the presence of the electron and ion beam deposited PtC protective layers. A SiN capping layer was also deposited in order to prevent the sample from the damage that might occur during the TEM specimen preparation. Data was acquired using a probe corrected JEOL ARM 200 equipped with Schottky FEG and Gatan Enfinium® ER EELS system at Arizona State University. EELS SI analysis was carried out in DualEELS™ mode and the regions of the EELS spectrum from 0eV to 2000eV and from 600eV to 2600eV were simultaneously acquired using exposure times as low as of 0.006ms and 0.99ms respectively. Taking advantage of the fast acquisition available in the Enfinium® and the increased probe current, nearly 315000 spectra (512x307x2) were acquired in just 420 seconds with a spectral rate of nearly 800 spectra per second from a wide region of the sample as shown in the ADF STEM image in Figure 2. Figures 3a-f show the EELS elemental maps of the sample composition extracted from the Ni L_{2,3}-edges at 855eV, the Ge L_{2,3}-edges at 1217eV, the As L_{2,3}-edges at 1323eV, the Si K-edge at 1839eV, the Pt M_{4,5}-edges at 2122eV and the Au M_{4,5}-edges at 2206eV. Figure 3g shows the EELS colored elemental map of Ni, Ge, As, Si, Pt and Au. Despite the high-energy of some edges involved such as the Si K-edge at 1839eV and the Pt and Au M_{4,5}-edges at 2122eV and 2206eV the contrast shown in those elemental maps is very high and clearly shows where all the elements are located and distributed across the whole investigated region of the sample. It is quite interesting to note that the Ge seems to diffuse more strongly towards the upper Au region whereas the Ni towards the lower. The Au diffuses into the III-V substrate making the interface rough and affecting the electrical performance of the resulting device. The amount of Au diffusing into the substrate depends on the conditions employed during the annealing process and can be quantified using EELS as shown in the following section in the poster.

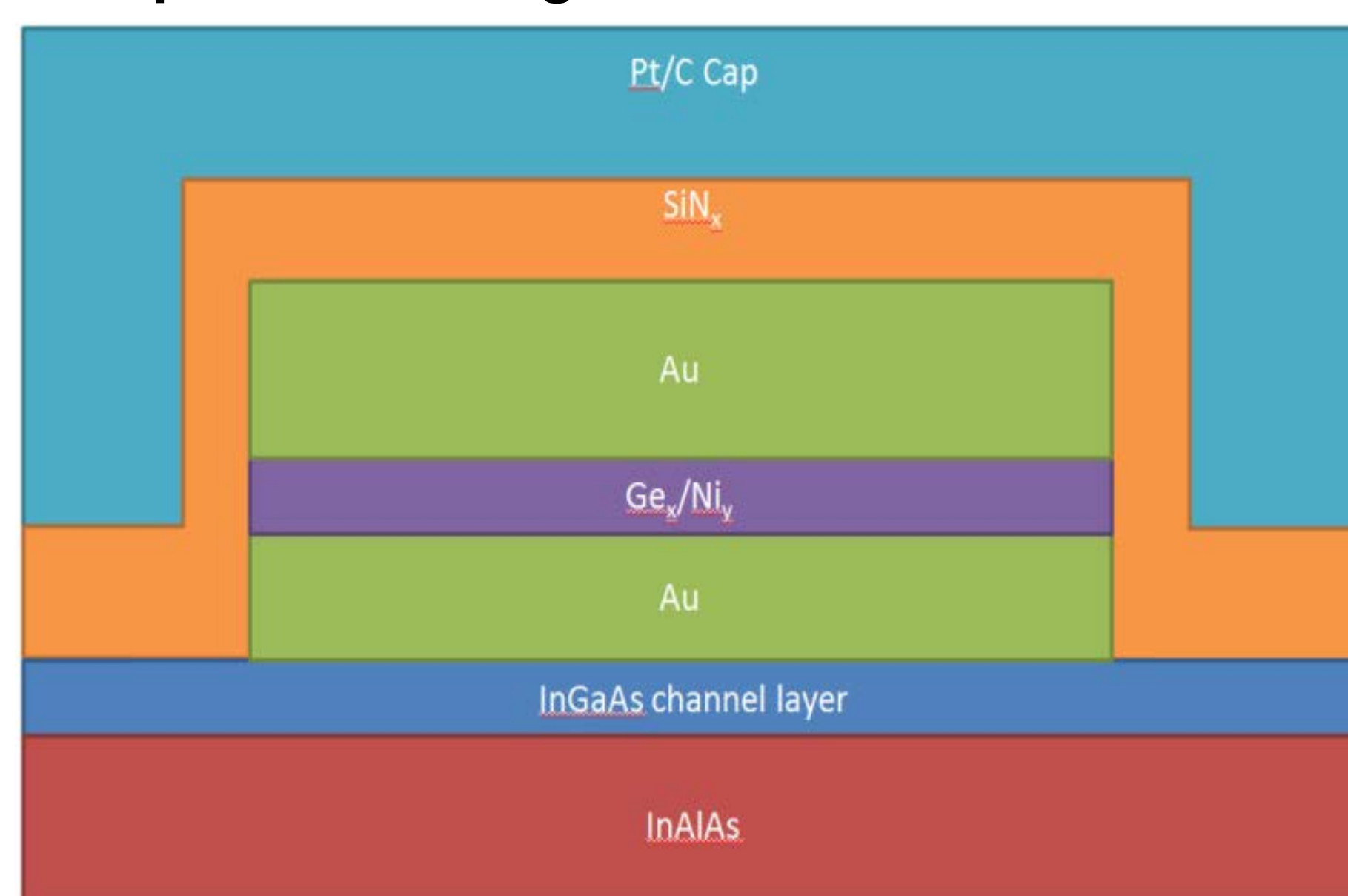


Figure 1: As grown structure. The SiN_x and Pt/C cap layers are added after processing to protect the structure during FIB specimen preparation.

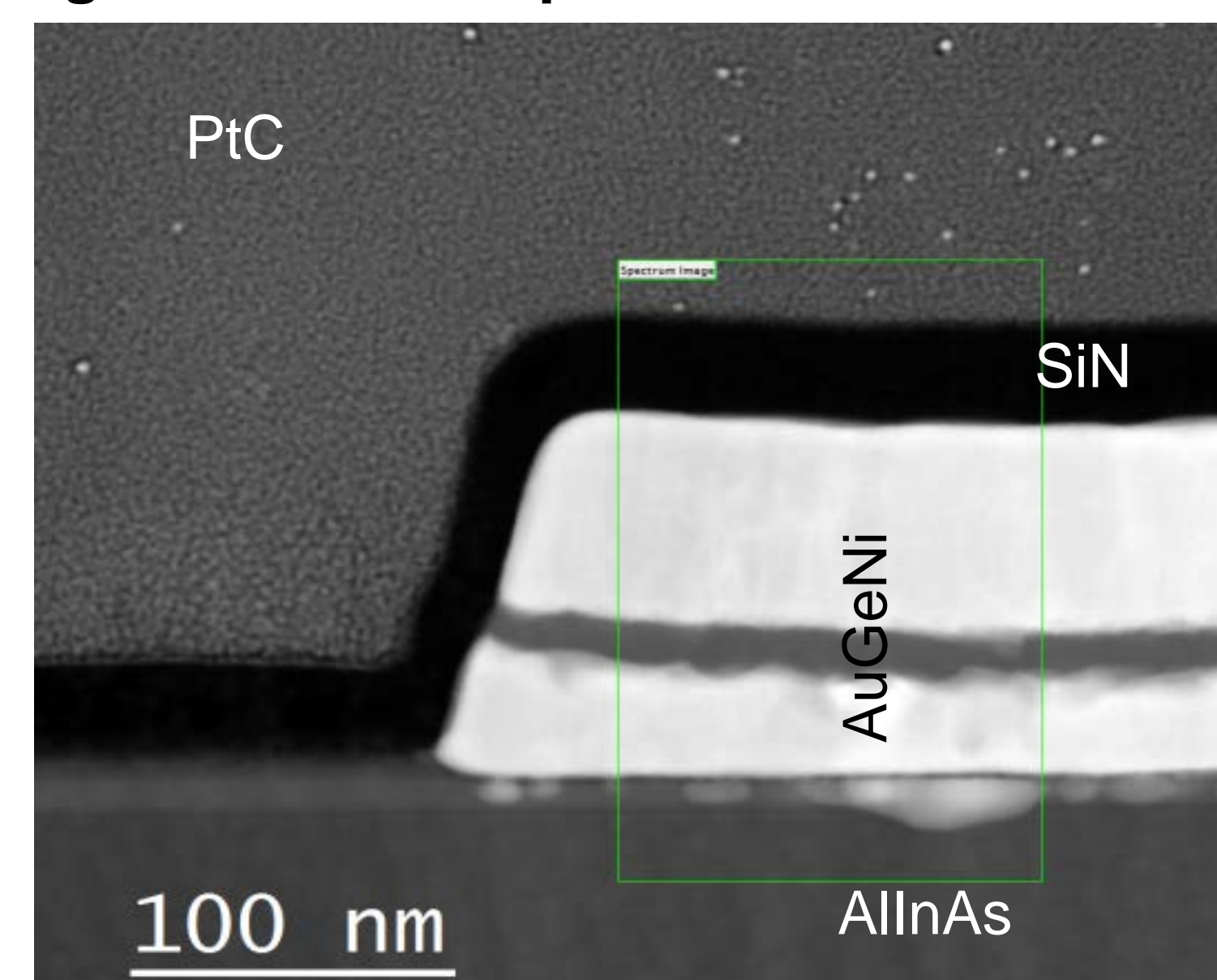
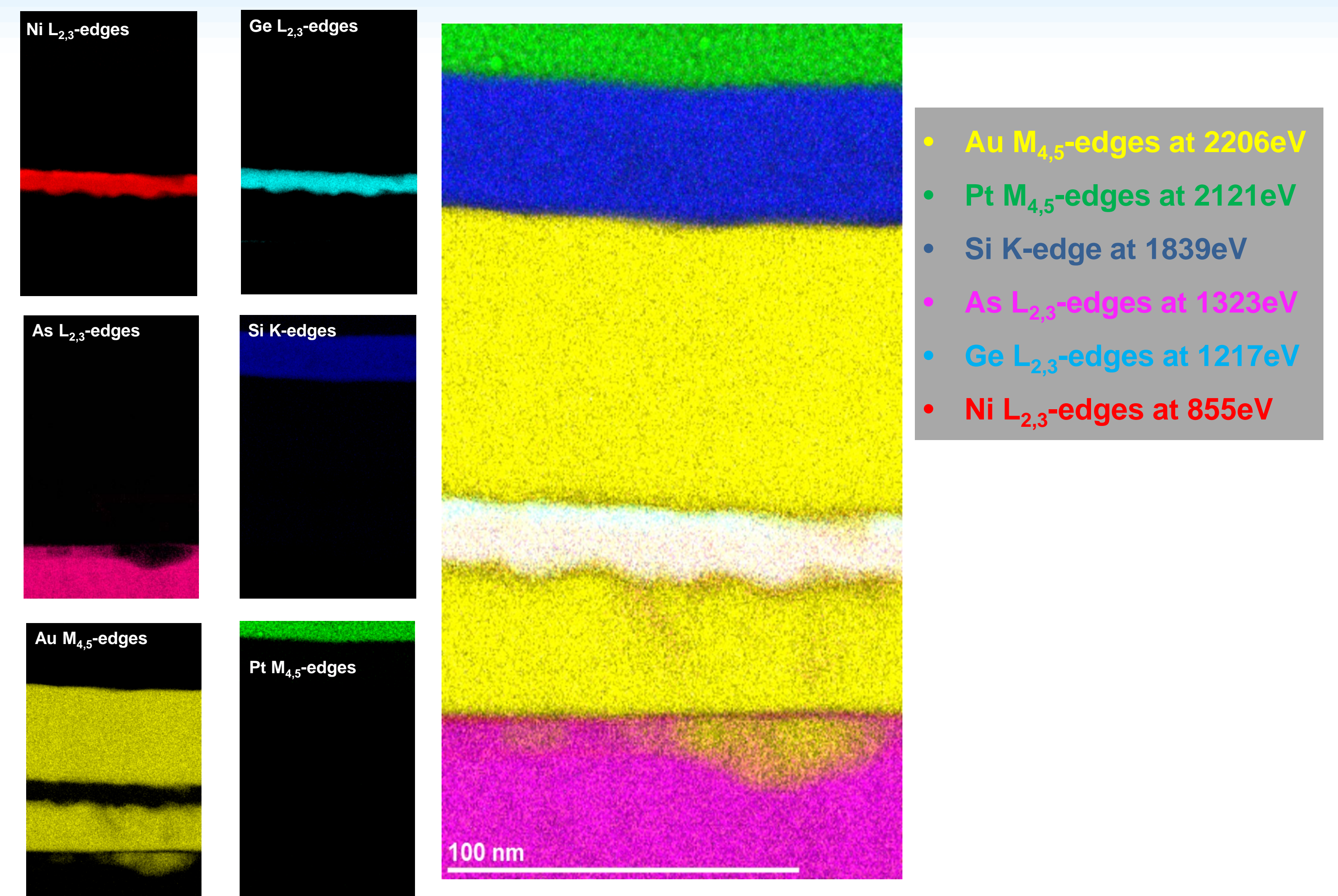


Figure 2: ADF STEM survey image. The green box is the area where the EELS SI were taken



Figures 3a-f. EELS elemental maps of Ni L_{2,3}-edges at 855eV in red, Ge L_{2,3}-edges at 1217eV in light blue, As L_{2,3}-edges at 1323eV in purple, Si K-edge at 1839eV in blue, Pt M_{4,5}-edges at 2121eV in green and Au M_{4,5}-edges at 2206eV in yellow. Figure 3g. EELS colored elemental map of Ni, Ge, As, Si, Pt and Au.

Acquiring the data in DualEELS™ mode.

Acquiring the data in DualEELS™ [3] mode allows the user to have the information from the low-loss region together with the core-loss data. Figure 4 shows an EELS spectrum extracted from the Au region in the sample after splicing the two datasets at high and low energy. The dynamic range has been clearly increased and the resultant EELS spectrum extends from 0eV to 2600eV. Given the presence of the low-loss region in the same dataset under identical experimental conditions provides information on the thickness which can be easily measured as shown in Figure 5. The sample seems quite thick as the thickness ranges from 0.8 to 1.72 relative to the main free path (λ). However having the low-loss in the same dataset under the same experimental conditions allows the plural scattering to be deconvolved recovering the single scattering distribution. In this way, the effects of plural scattering, which are bigger as the thickness increases, can be accounted and the EELS spectra can be deconvolved to single scattering distribution. Another advantage of acquiring data in DualEELS™ mode is that the compositional analysis becomes more accurate, due to the fact that core-loss signals can be readily normalized with the low-loss allowing non-compositional intensity artifacts in the elemental map to be completely removed. Thus, measuring the absolute composition (atoms per unit area rather than simple composition ratios) requires the presence of the low-loss region acquired under the same experimental conditions. Figure 6 shows the absolute number of atoms of Au, Ge and Ni extracted from the metal ohmic contact region. The measured value of 66 Au-atoms/nm³ agrees well with the typical value of 59 atoms/nm³ for bulk gold. In this case, for the Au, the accuracy of the measurements is within 7atoms/nm³

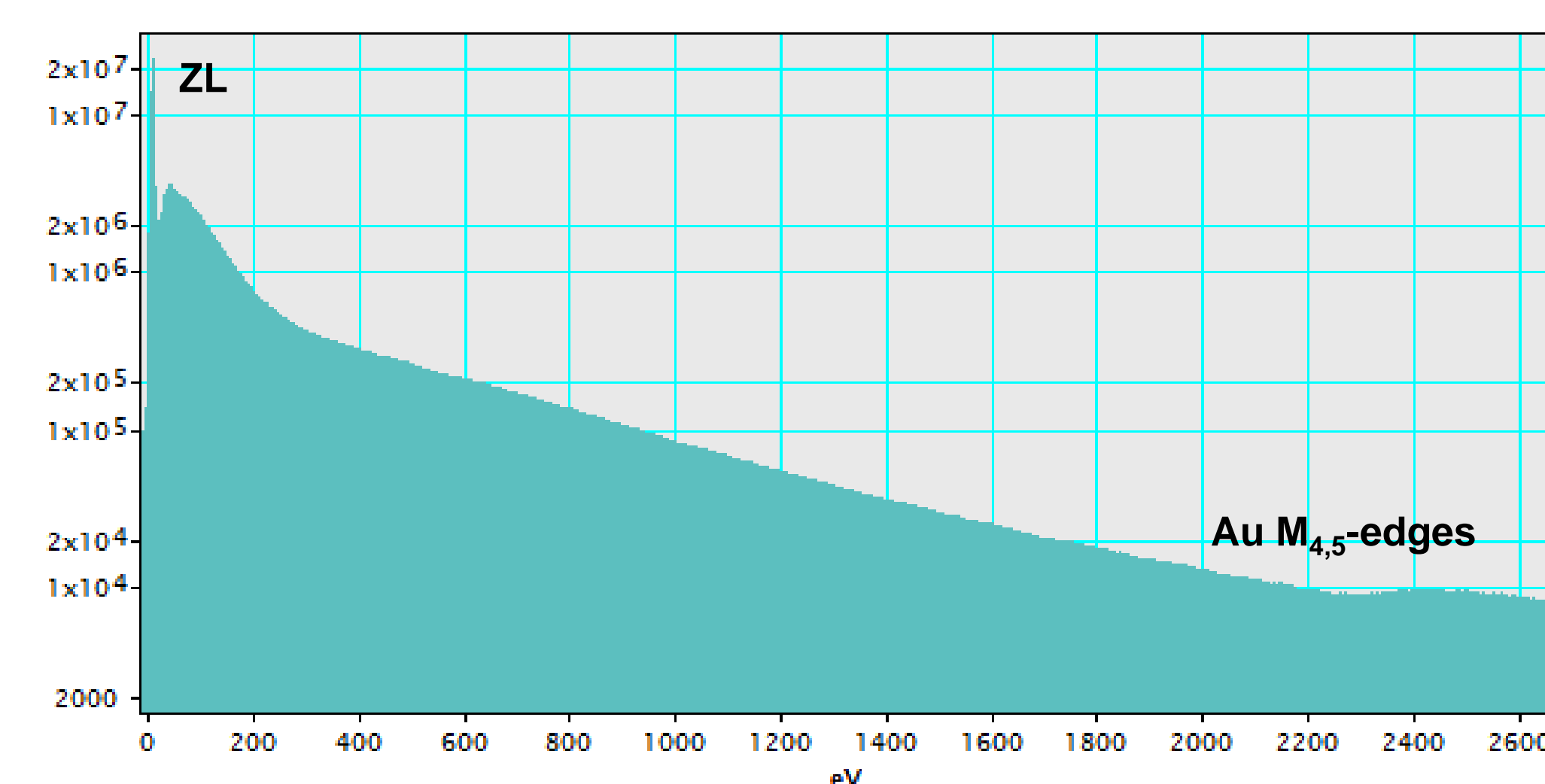


Figure 4: Extracted EELS spectrum in log-view from the spliced SI in the Au region of the sample.

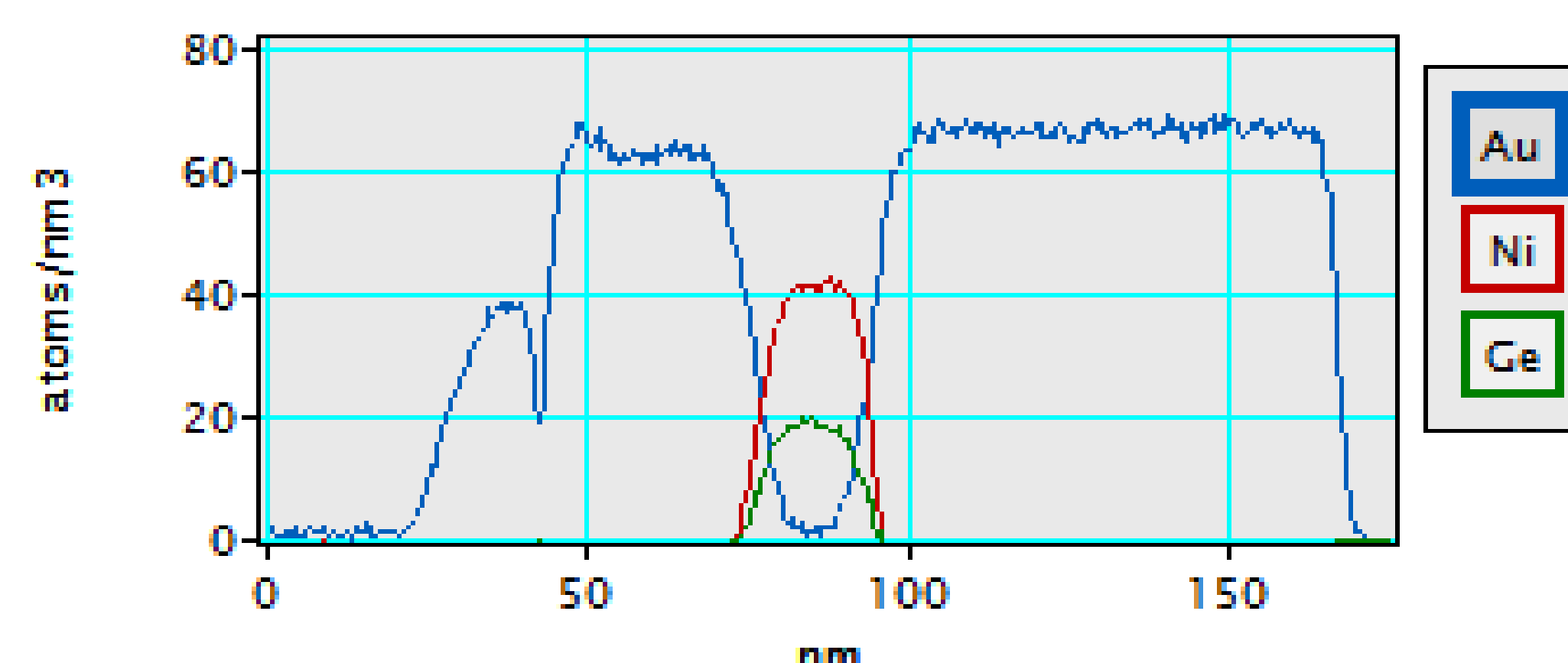


Figure 6: Absolute composition of Au, Ge and Ni across the AuGeNi ohmic contact region.

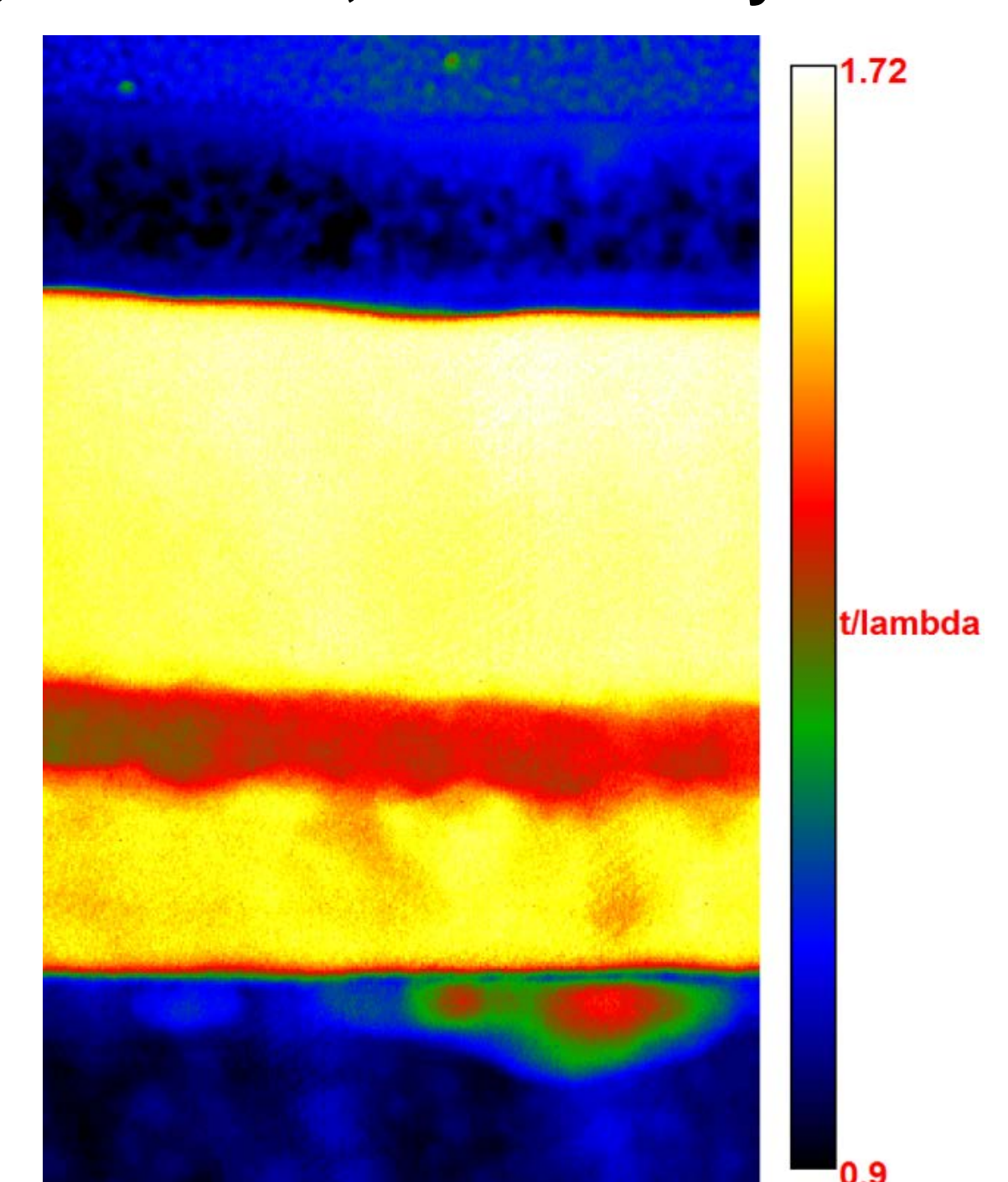


Figure 5: Relative thickness map obtained using the low-loss region of the spectrum available under the same conditions in the same dataset.

Conclusions

We have shown that high-speed atomic EELS elemental maps with high contrast and high signal-to-noise ratios can be acquired routinely from high-energy edges. In addition, using the DualEELS™ capability, which is available in both the GIF Quantum® and the Enfinium®, it is possible to record simultaneously two different regions of the EELS spectrum under the same experimental conditions. Some applications and advantages of the acquisition in DualEELS™ mode are reported in this poster.

References

- [1] R.J.W. Hill, D.A.J. Moran, X. Li, H. Zhou, D. Macintyre, S. Thoms, A. Asenov, P. Zurcher, J. Abrokwhah, R. Droopad, M. Passlack and I.G. Thayne, IEEE Electron Devices Letters, 28, 2007, 12
- [2] AJ Gubbens, M Barfels, C Trevor, R Twesten, P Thomas, N Menon, B Kraus, C Mao and B McGinn, Ultramicroscopy, vol. 110, pp. 962-970, 2010
- [3] J. Scott, P.J. Thomas, M. Mackenzie, S. Mcfadzean, A.J. Craven and W.A.P. Nicholson, Ultramicroscopy, 108, 1586-1594, 2008

