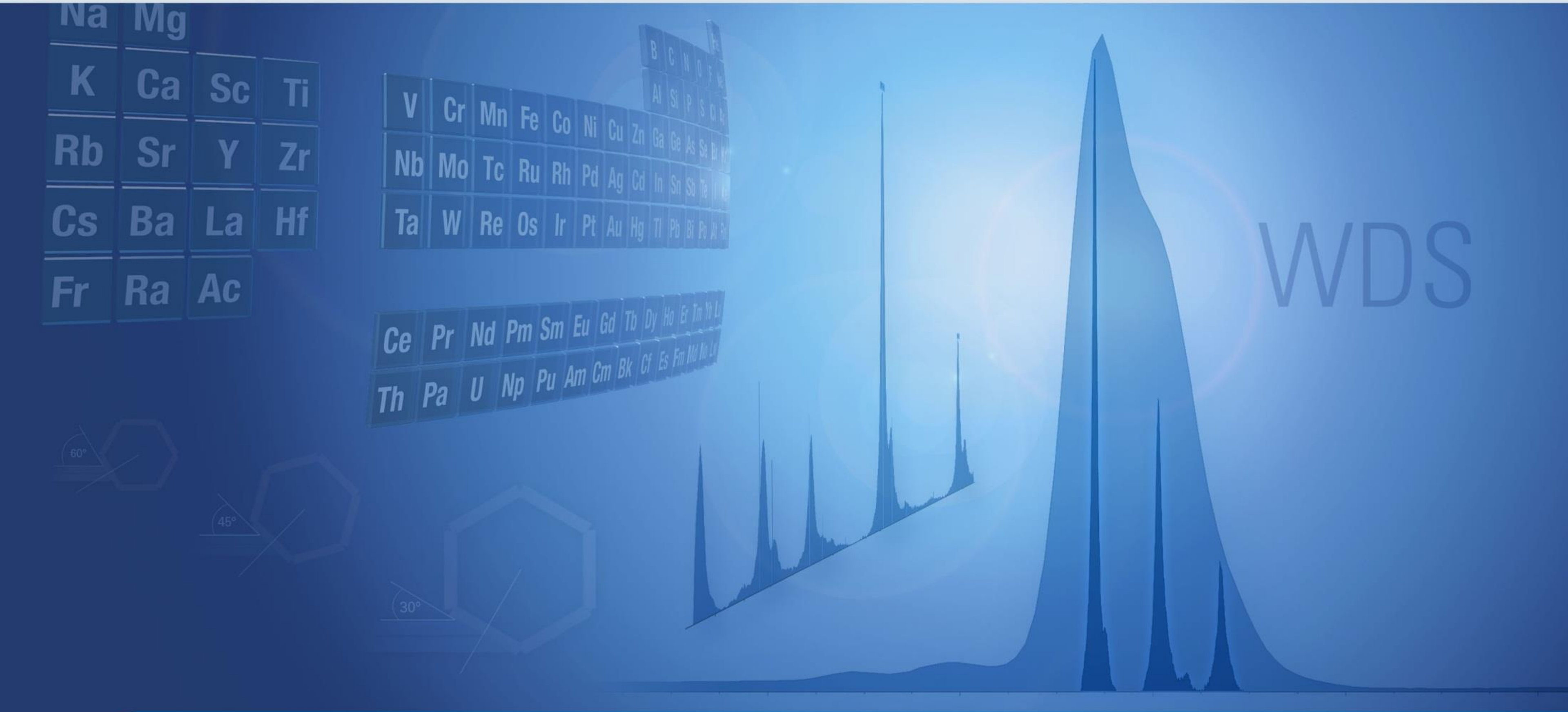
Advanced elemental analysis of semiconductors and microelectronics using QUANTAX WDS for SEM

Bruker Nano Analytics, Berlin, Germany
Webinar, July 16, 2020



Q&A

Are There Any Questions?

Please type in the questions you might have
in the Q&A box and press *Send*.

Presenters

Dr. Michael Abratis

Sr. Applications Scientist WDS,
Bruker Nano Analytics, Berlin, Germany

Dr. Max Buegler

Applications Specialist microXRF,
Bruker Nano Analytics, Berlin, Germany

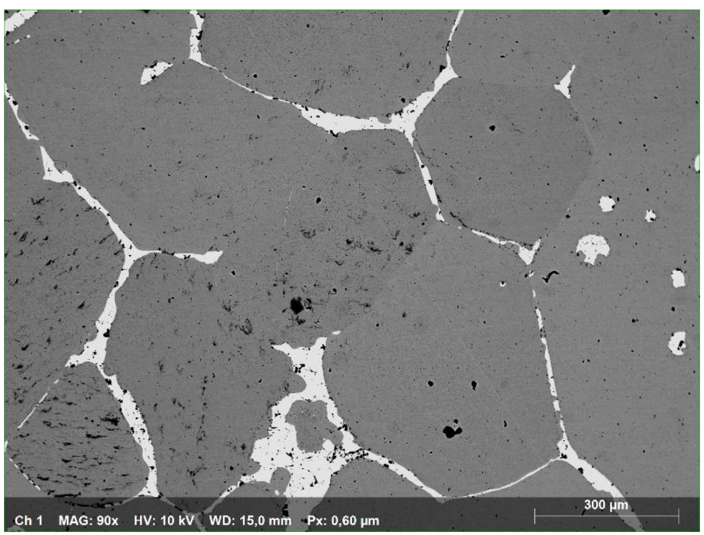
Introduction
Samples

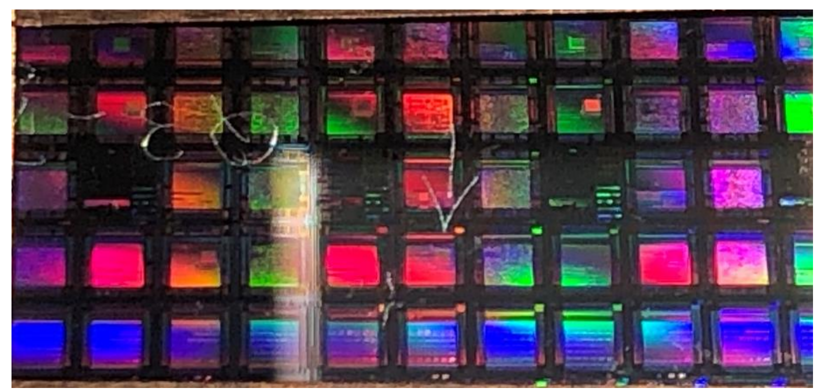
Semiconductors

- MoS_2
- WSi_2
- $TaSi_2$
- (Ag)PbTe – Bi

Microelectronics

- Layered sample (W–Ta–Si)
- Semiconductor microchip (SSD/CPU)





Introduction
Motivation for WDS application

Spectral overlaps in semiconductors

- Peak overlaps common in semiconductors
- EDS applies peak deconvolution
- WDS able to resolve peaks
- WDS requires no post-processing
- WDS can achieve higher precision in element identification

Small structures in semiconductors and microelectronics

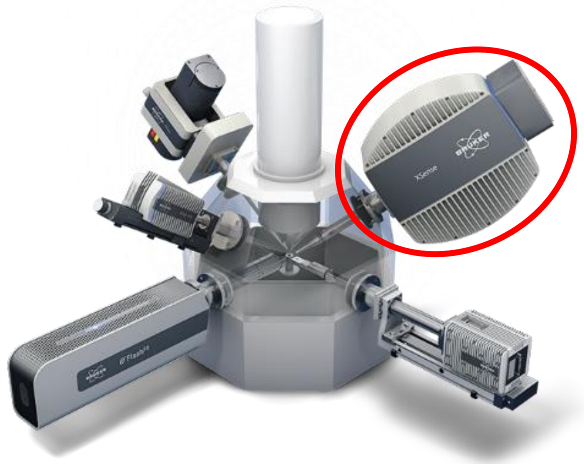
- High spatial resolution required
- Low voltage application required
- High spectral resolution at low energies required

Overview

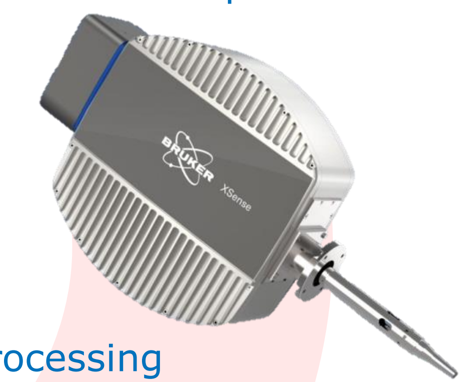
- Introduction to QUANTAX WDS
- What is a Semiconductor and what is it good for?
- Application on Semiconductors
- Application on Microelectronics
- Workflow for QUANTAX WDS analyses
- Summary and Conclusion

QUANTAX WDS
System Components

QUANTAX WDS: integral part of the QUANTAX family



XSense™ WD spectrometer



Signal processing unit SVE 6

ESPRIT 2

- Spectrum, P/B-acquisition in ‘Spectrum’ and ‘Objects’ mode
- Mapping and LineScan
- Quantification (SB, coupled quant possible)
- Device control

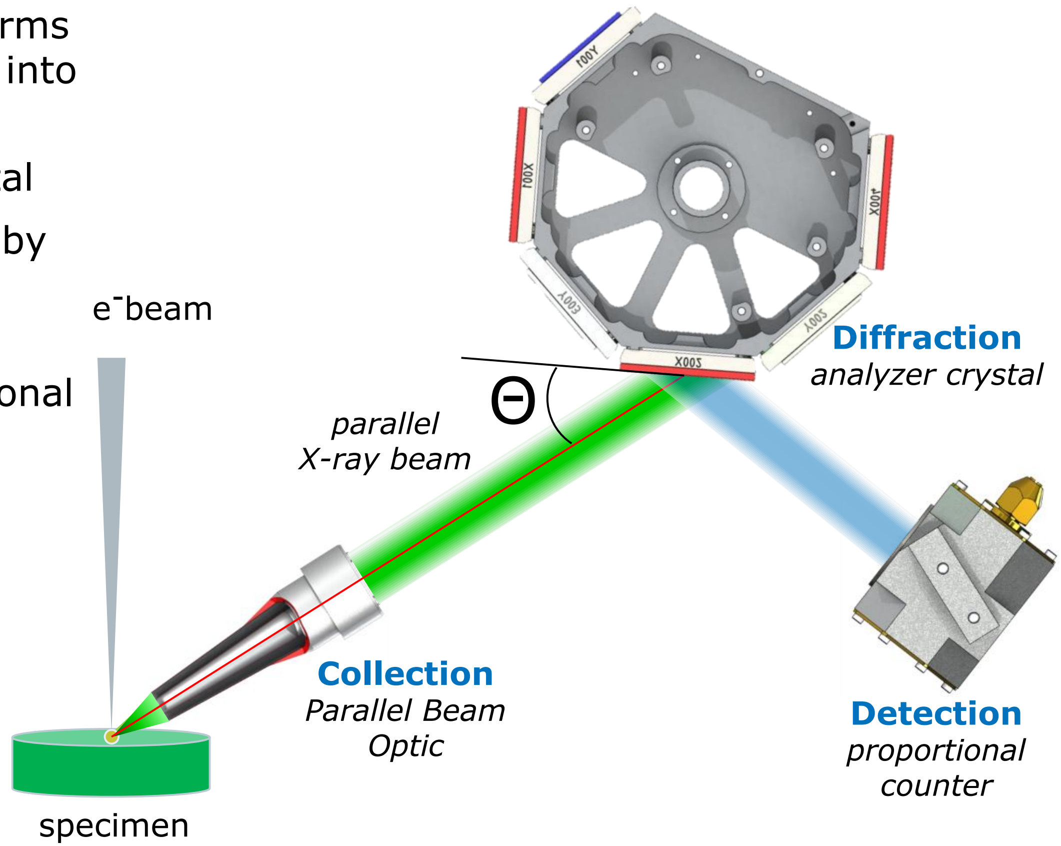
… all integrated in the Esprit GUI

XSense WD Spectrometer
Setup and Working Principle

- Parallel Beam Optic (PBO) transforms X-rays diverging from the sample into parallel beam
- Bragg diffraction at analyzer crystal
- Measurement energy determined by Bragg angle Θ and crystal lattice constant
- X-ray detection with flow proportional counter

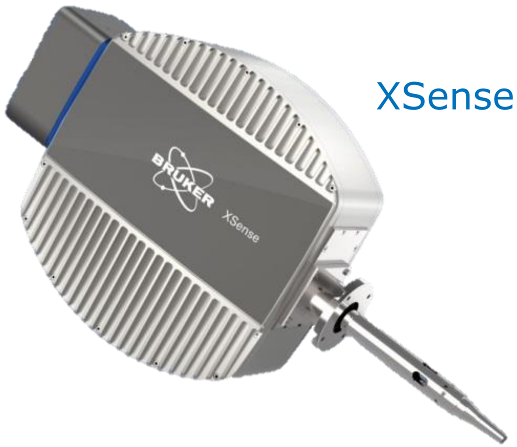
Benefit:

➡ very high sensitivity due to large solid angle

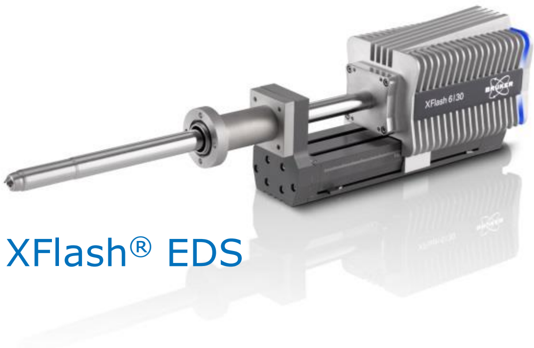


Bragg equation: $n\lambda = 2d\,\sin(\theta)$

Spectrometer comparison
Advantages of WDS over EDS



XSense WDS



XFlash® EDS

Compared with EDS the WDS shows:

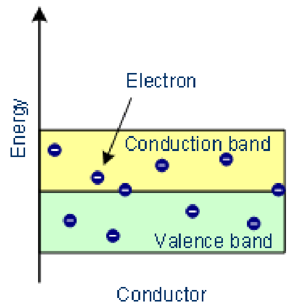
- substantially higher spectral resolution (typically 3 – 15 eV FWHM)
- enhanced P/B-ratios, i.e. lower detection limits
- outstanding sensitivity for light elements including Be, B

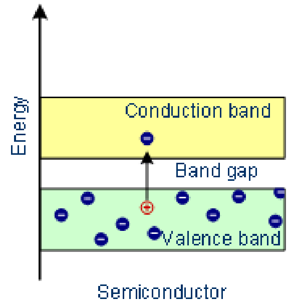
→ **WDS is an ideal technique to complement EDS in demanding applications**

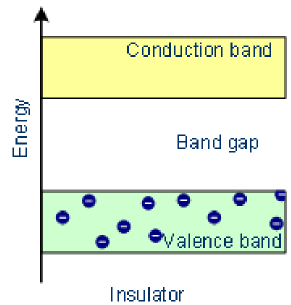
Semiconductors
What is a Semiconductor

"A **semiconductor** material has an electrical conductivity value falling between that of a conductor, such as metallic copper, and an insulator, such as glass." (Wikipedia)

This is described by the **band structure**. It describes the energetic position of the **valence band**, where tightly bound valence electrons are situated, and the **conduction band**, where electrons can potentially hop from one atom to another, and thus contribute to carrying a current, with respect to the **Fermi-level**.





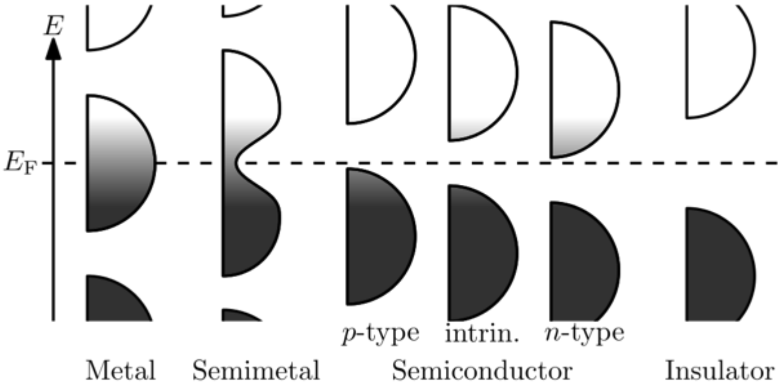


In a **conductor** those bands are in contact or overlap, there are always mobile electrons available.

In a **semiconductor** those bands are in proximity, electrons can be excited from the valence into the conduction band.

In an **insulator** there is a "large" band gap (> 6 eV), preventing electrons from becoming 'mobilized'.

Semiconductors
What does a Semiconductor do



The Fermi-level (E_F) describes the energy at which there is a 50 % probability of a virtual state to be occupied at the given conditions and at thermal equilibrium.

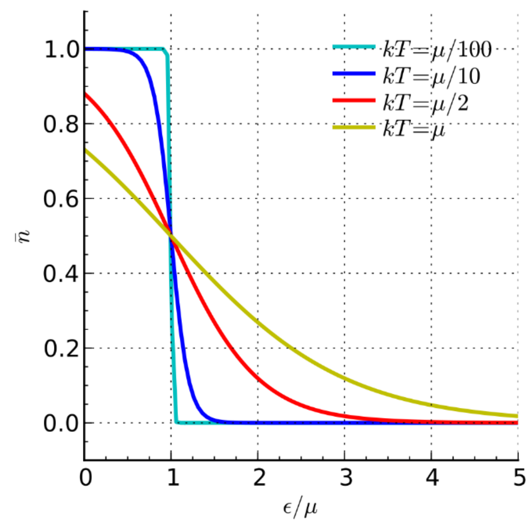
The probability of this occupation can be described by Fermi–Dirac distribution:

$$\bar{n}_i = \frac{1}{e^{(\varepsilon_i - \mu)/k_B T} + 1}$$

The Fermi level μ (also E_F) can be manipulated locally by introducing additional charges by incorporation of donor and acceptor states through doping.

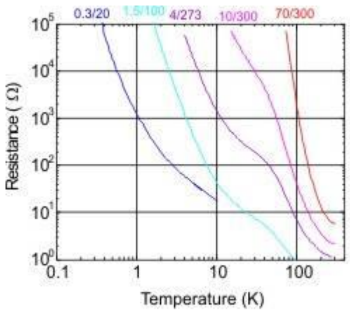
Also the number of available charge carriers depends on the temperature and other excitation sources, allowing for a multitude of different applications.

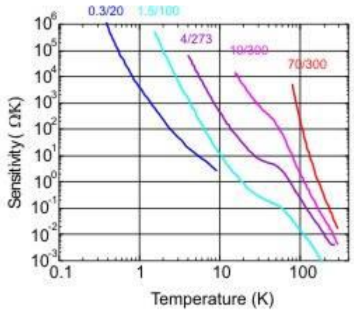
Fermi–Dirac distribution

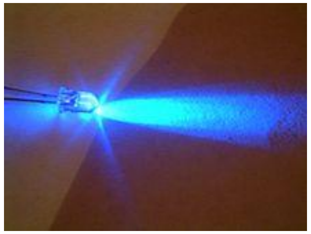


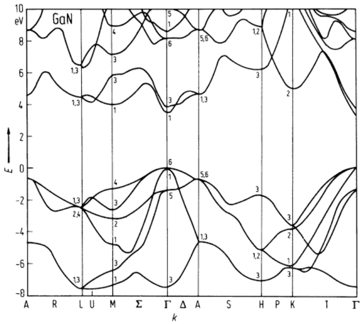
Semiconductors
What is it good for?

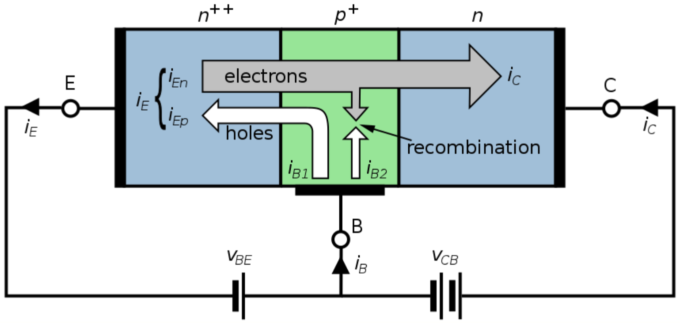
- Resulting from the temperature dependency of the conductivity, it allows for construction of thermocouples of high sensitivity in certain temperature ranges.
- As charge carriers can be generated by absorption of light of sufficient photon energy, they are used for photodetectors.
- In semiconductors with a suitable band structure (mostly direct band gap), the reverse effect as well is possible, they can emit light through the recombination of a hole (in valence band) and an electron (from conduction band).
- Combining different semiconductors or differently doped areas of semiconductors allows for building diodes (only allowing current in one direction) and transistors, to control a current, and build efficient and fast amplifiers.











Application 1
Molybdenite (MoS_2)

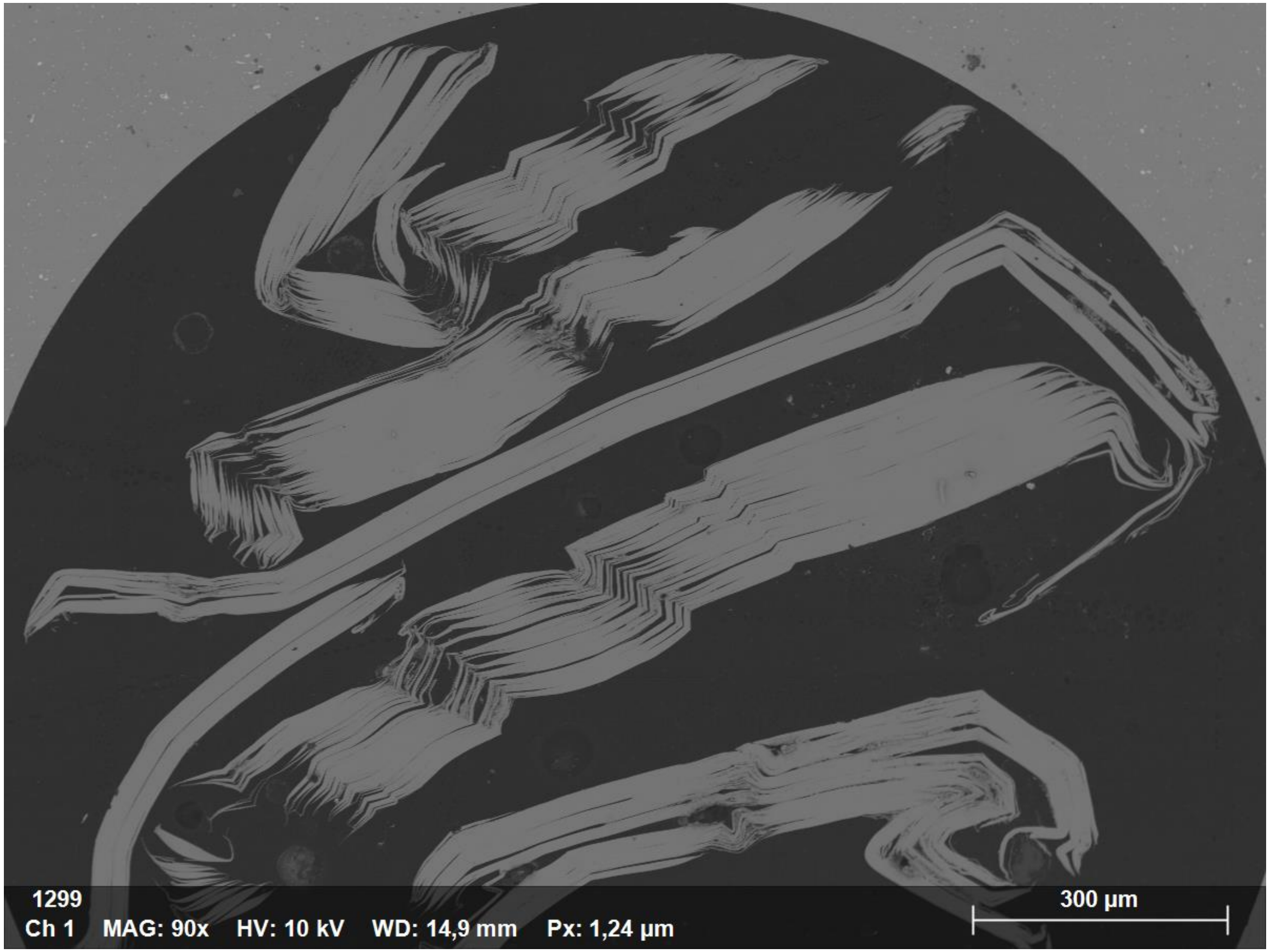
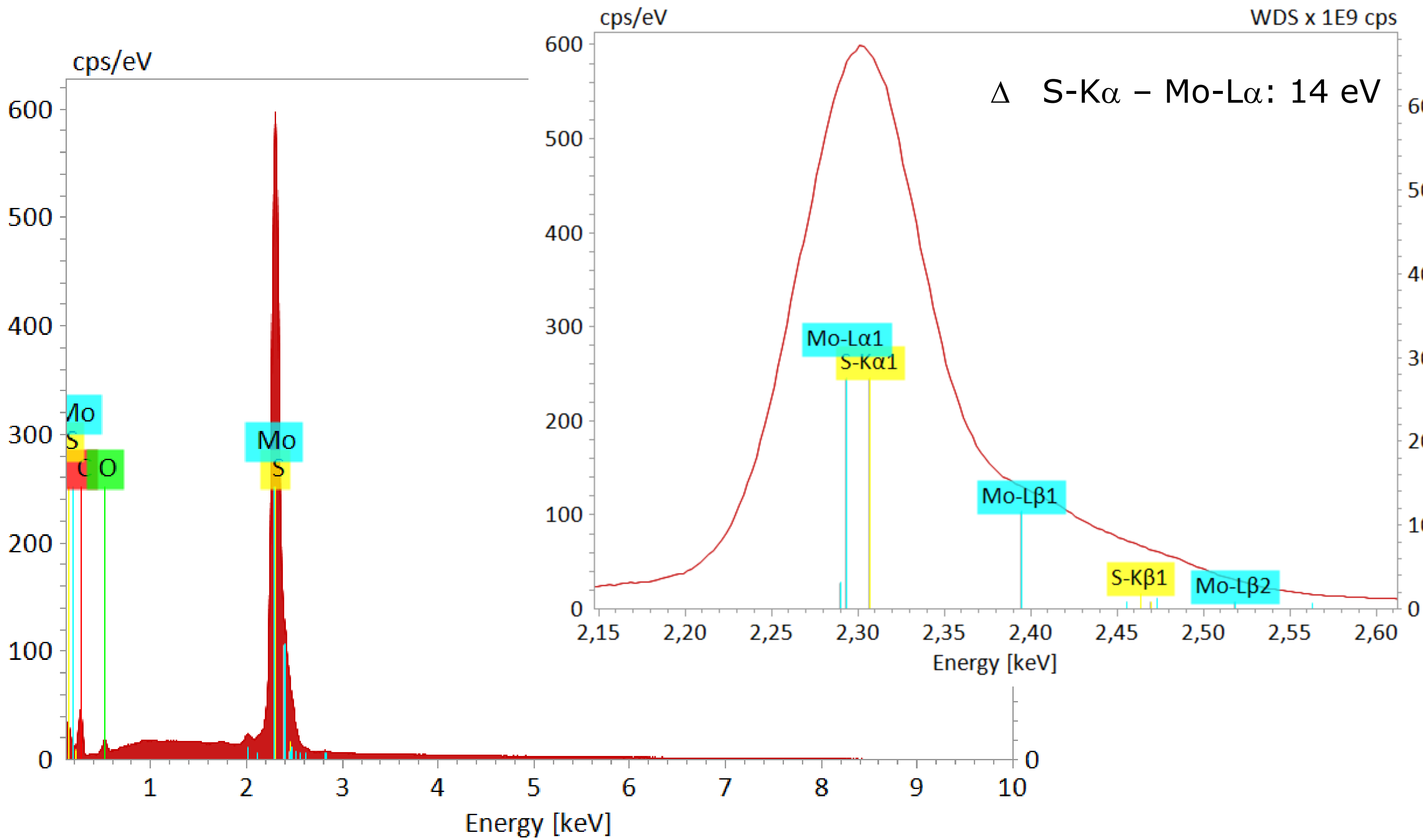


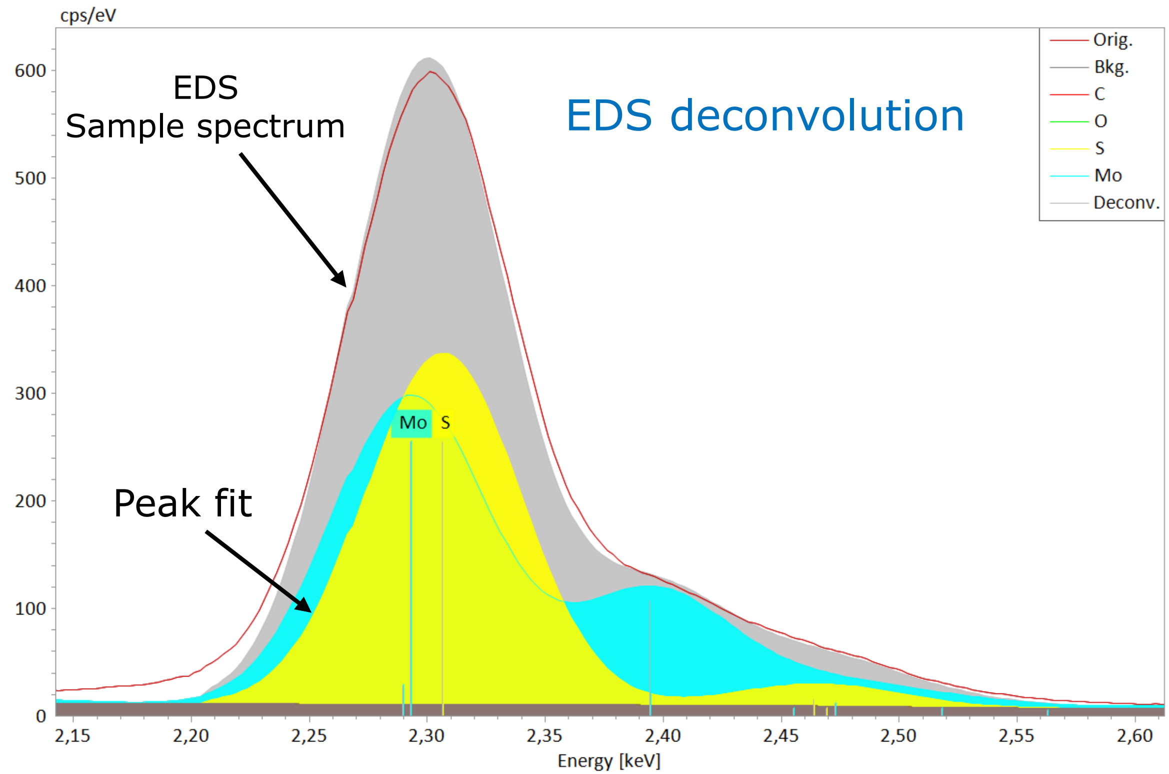
Image dimensions:

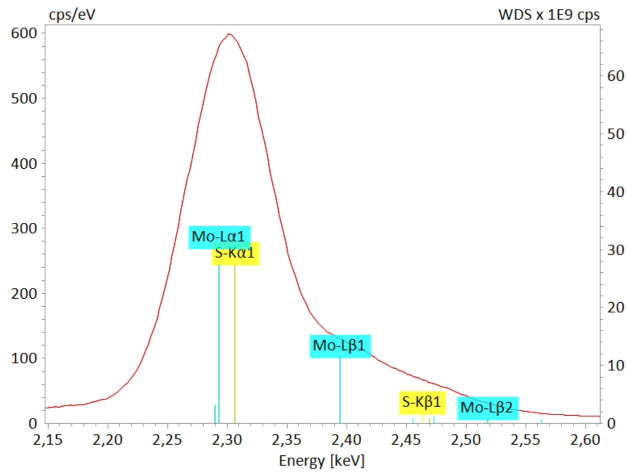
1.4 x 1.1 mm

Application 1
Molybdenite (MoS_2)



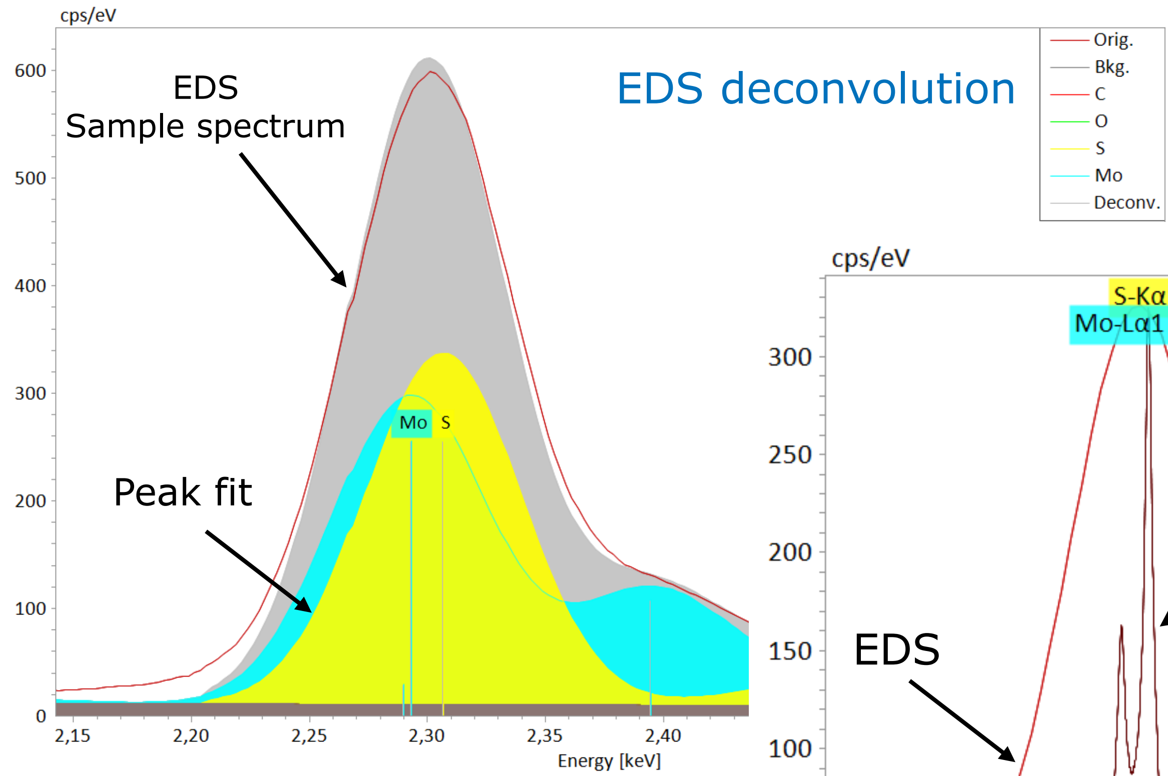
Application 1
Molybdenite (MoS_2)

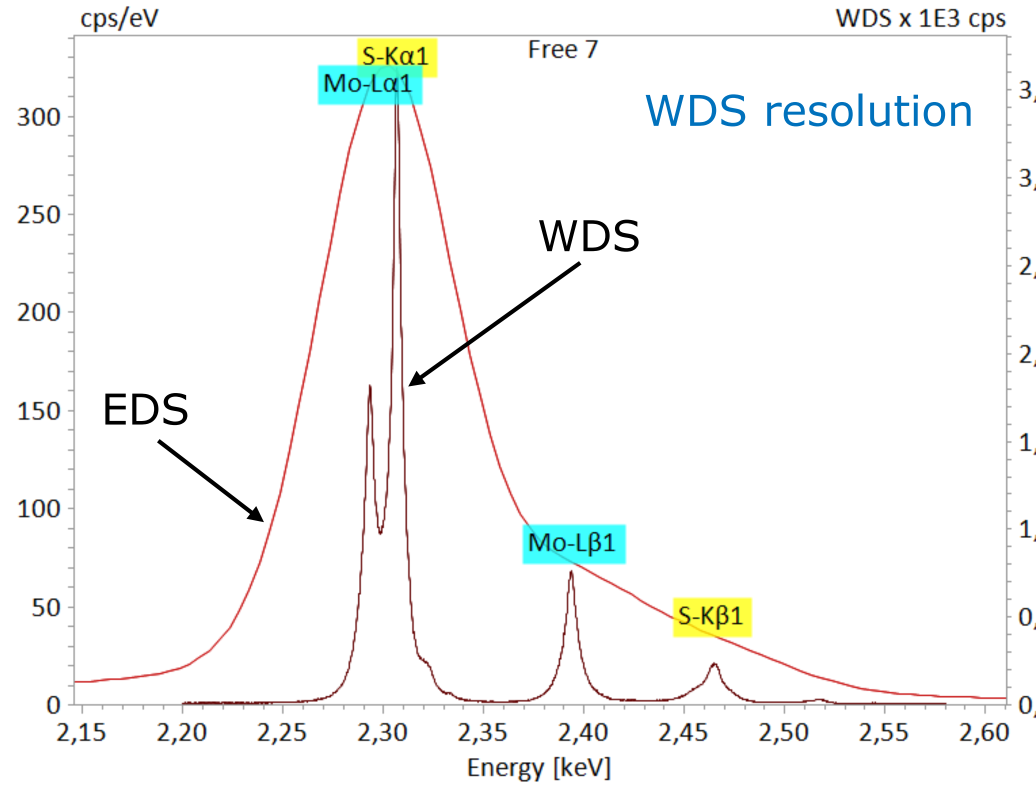




Spectrum modeling by fitting of theoretical or measured pure element peaks

Application 1
Molybdenite (MoS_2)





Δ S-Kα – Mo-Lα: 14 eV

$FWHM_{WDS}$: 6 eV

$FWHM_{EDS}$: 78 eV

Application 2
Tungsten silicide (WSi_2)

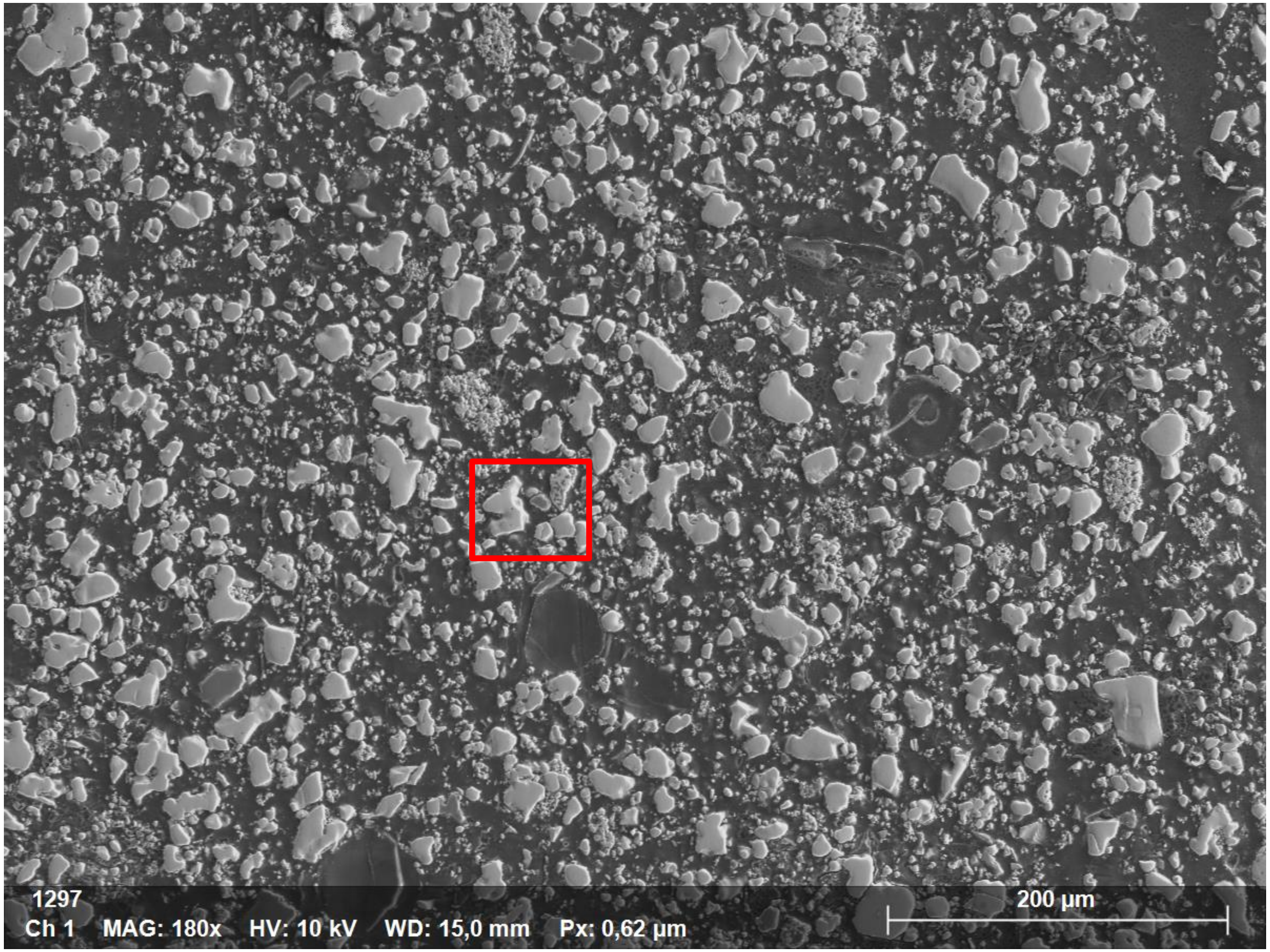
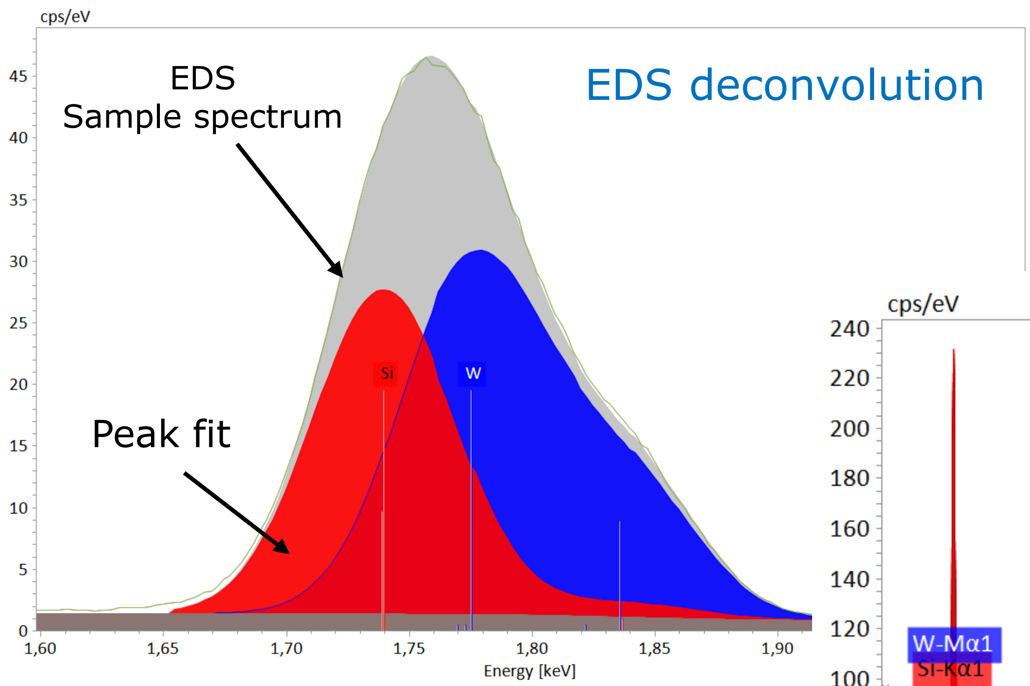
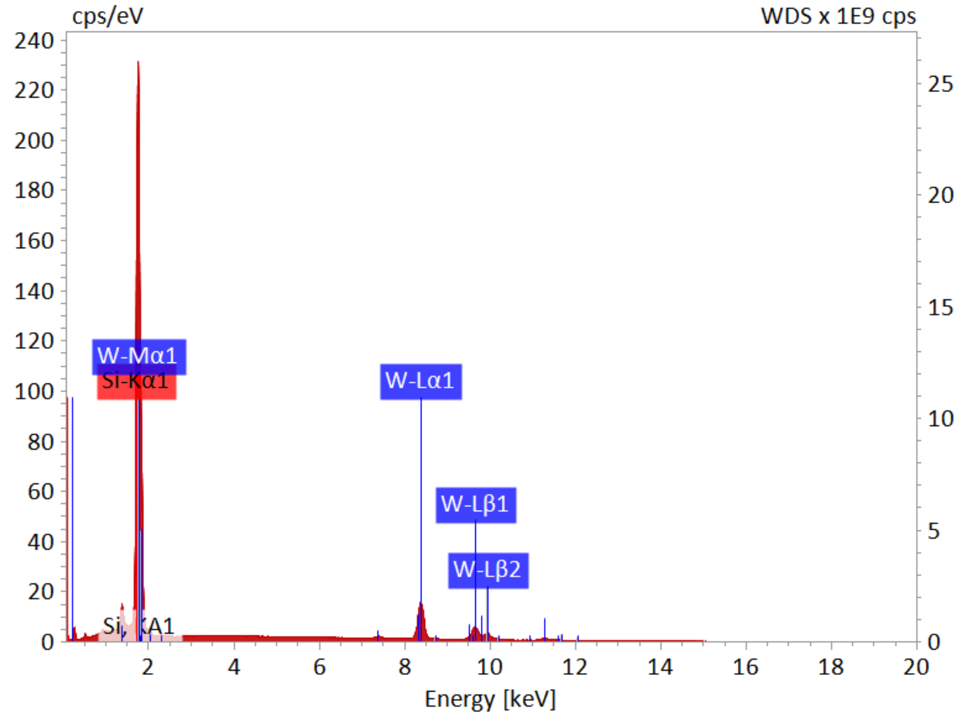


Image dimensions:

724 x 538 µm

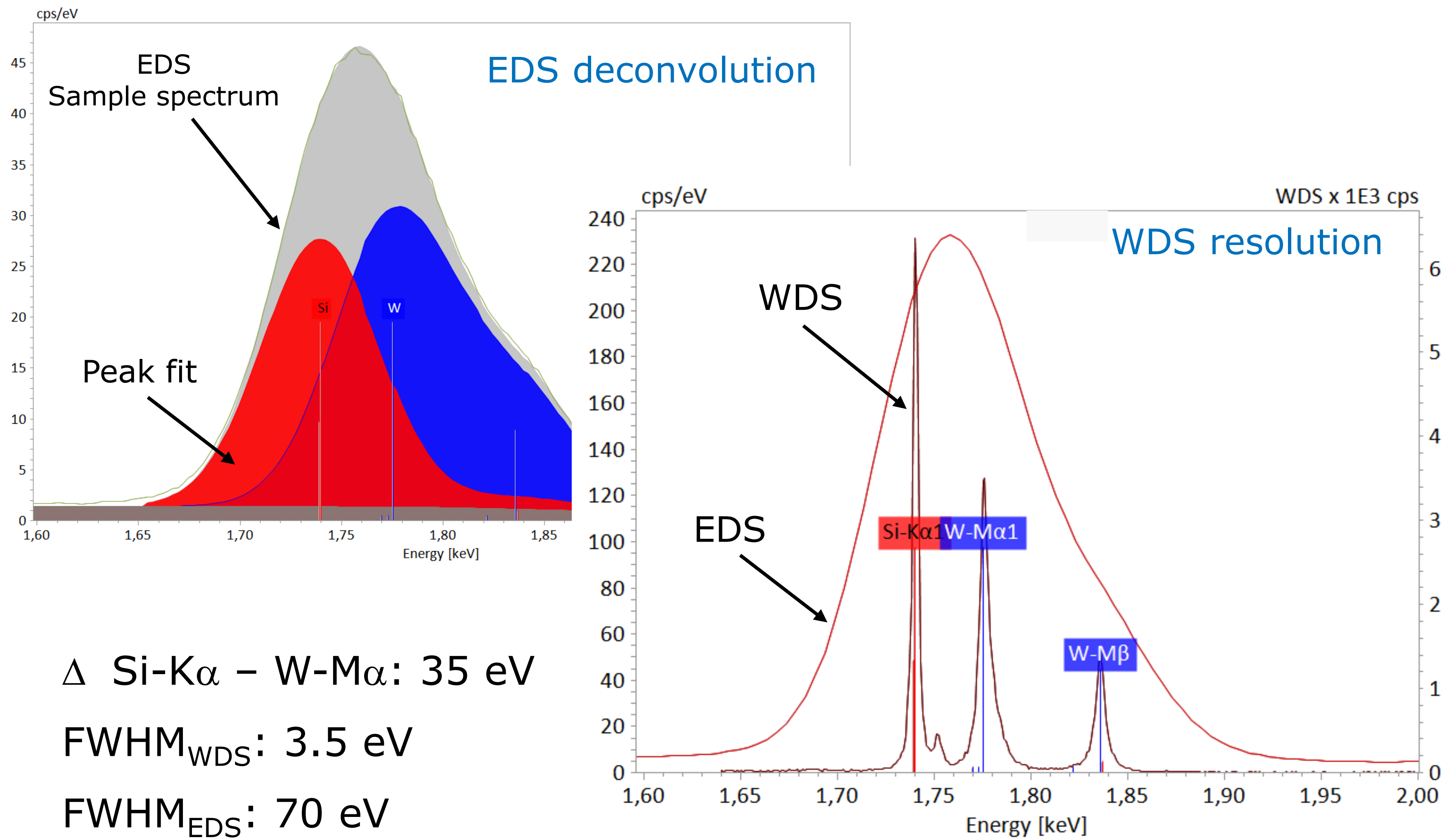
Application 2
Tungsten silicide (WSi_2)





Δ Si-Kα – W-Mα: 35 eV

Application 2
Tungsten silicide (WSi_2)

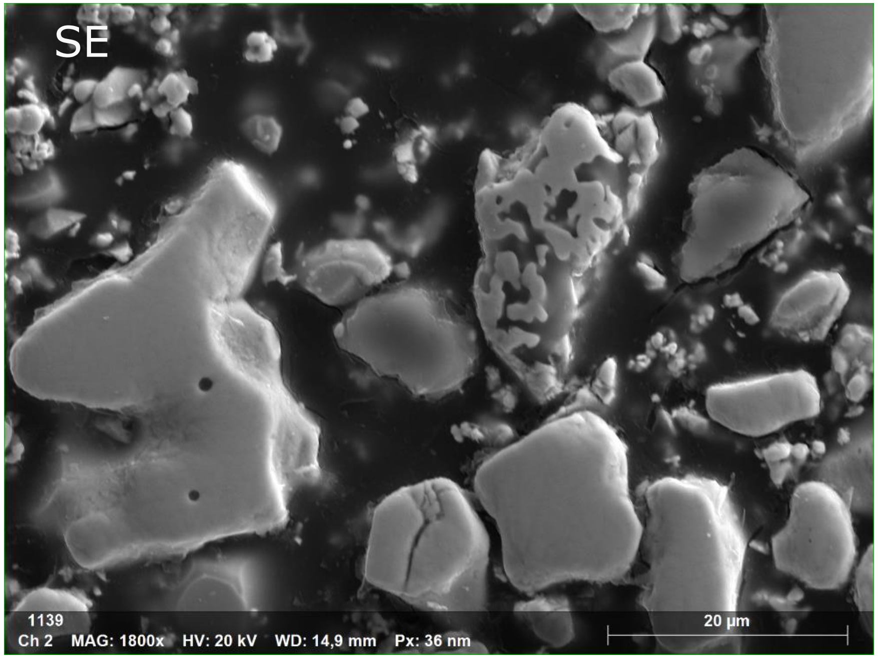


Δ Si-Kα – W-Mα: 35 eV

$FWHM_{WDS}$: 3.5 eV

$FWHM_{EDS}$: 70 eV

Application 2
Tungsten silicide (WSi_2) mapping



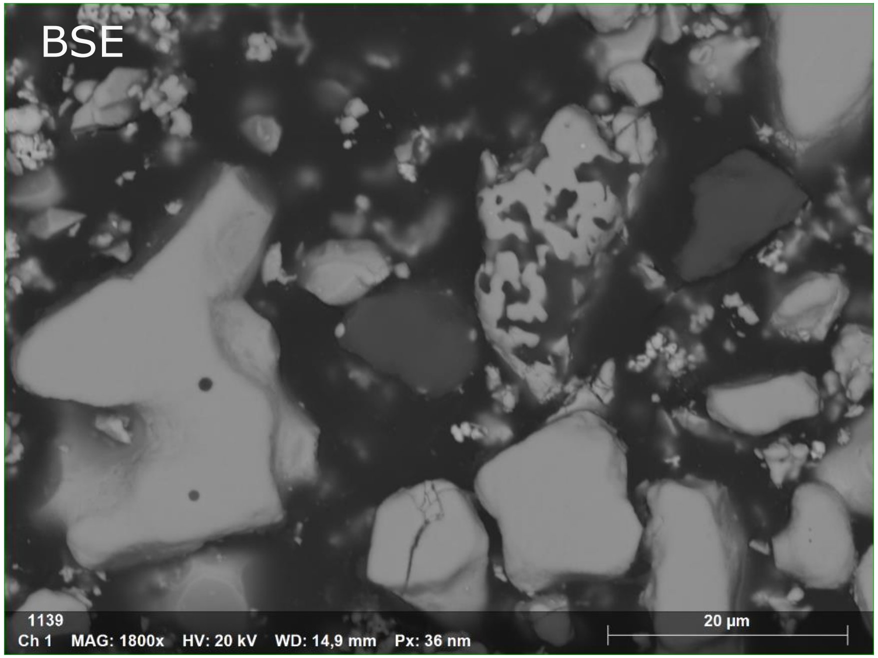
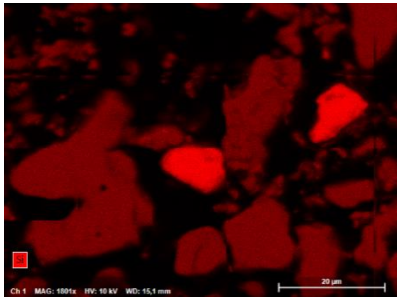
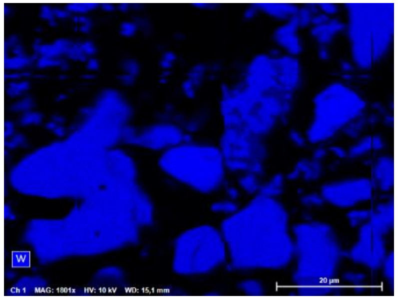
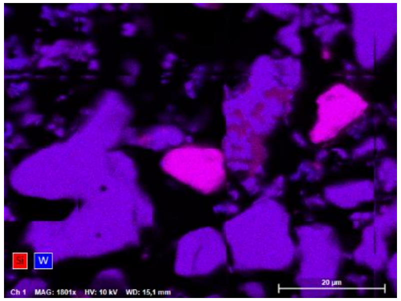
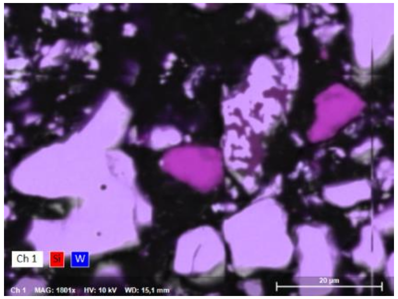


Image dimensions: 72 x 54 µm

Testing for sample homogeneity

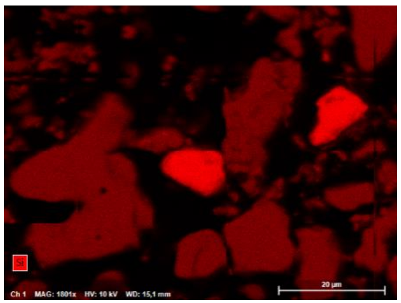
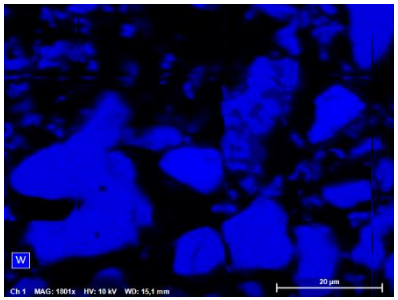
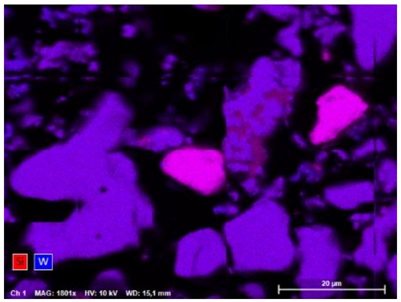
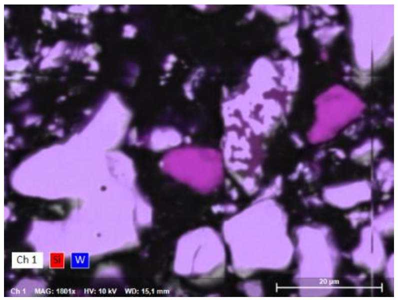
Application 2
Tungsten silicide (WSi_2) @10kV

	Si	W	Si+W	BSE+ Si+W
EDS				

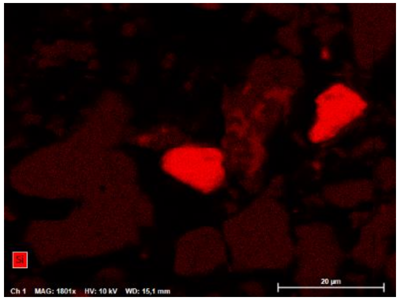
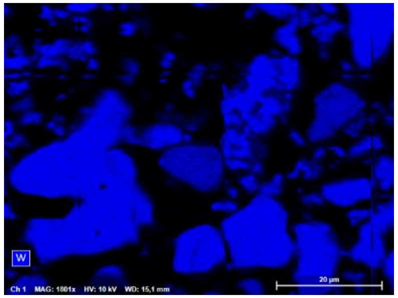
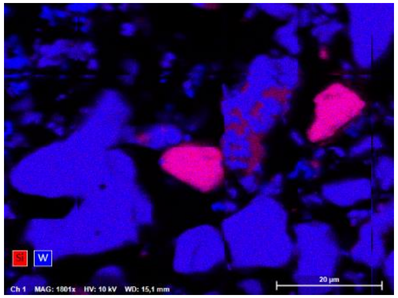
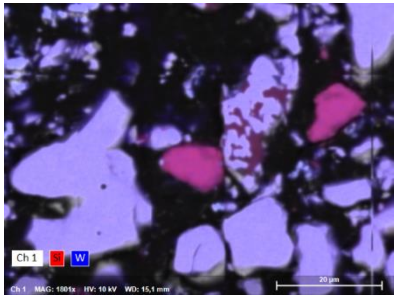
Application 2
Tungsten silicide (WSi_2) @10kV

Si | W | Si+W | BSE+ Si+W

EDS

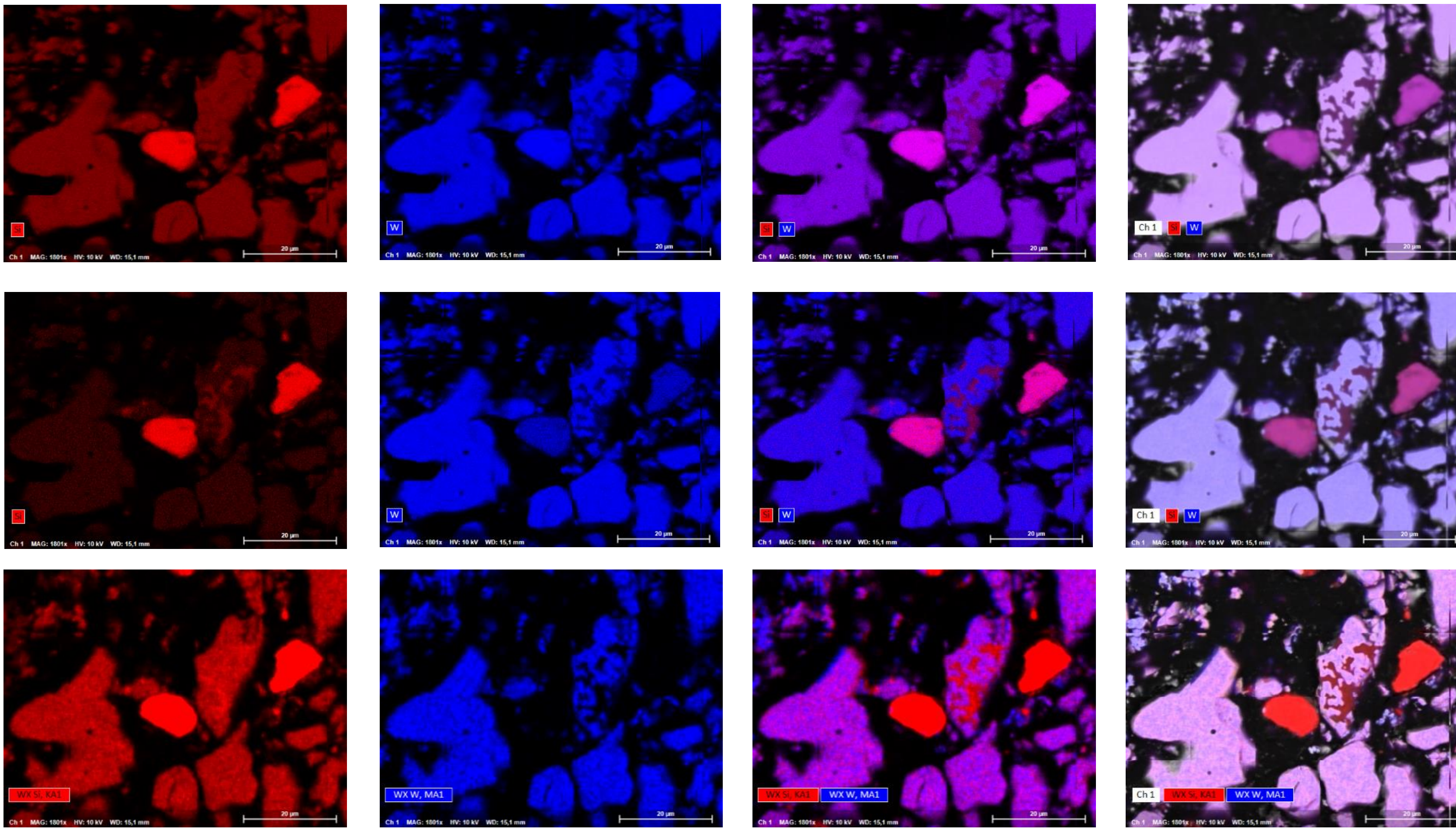





EDS decon

Application 2
Tungsten silicide (WSi_2) @10kV

BRUKER



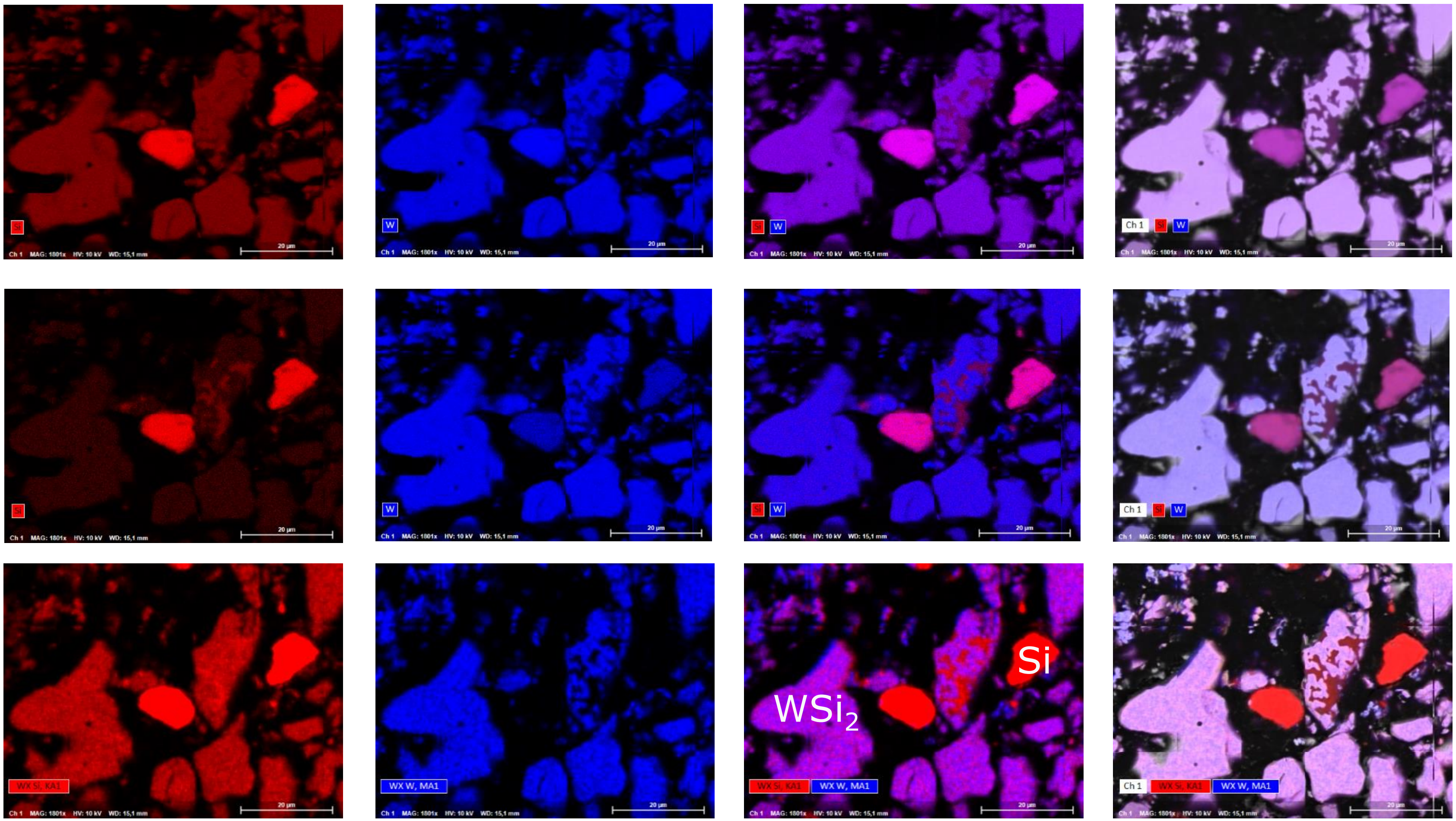
Application 2
Tungsten silicide (WSi_2) @10kV

Si | W | Si+W | BSE+ Si+W

EDS

EDS decon

WDS



Application 3
Tantalum silicide ($TaSi_2$)

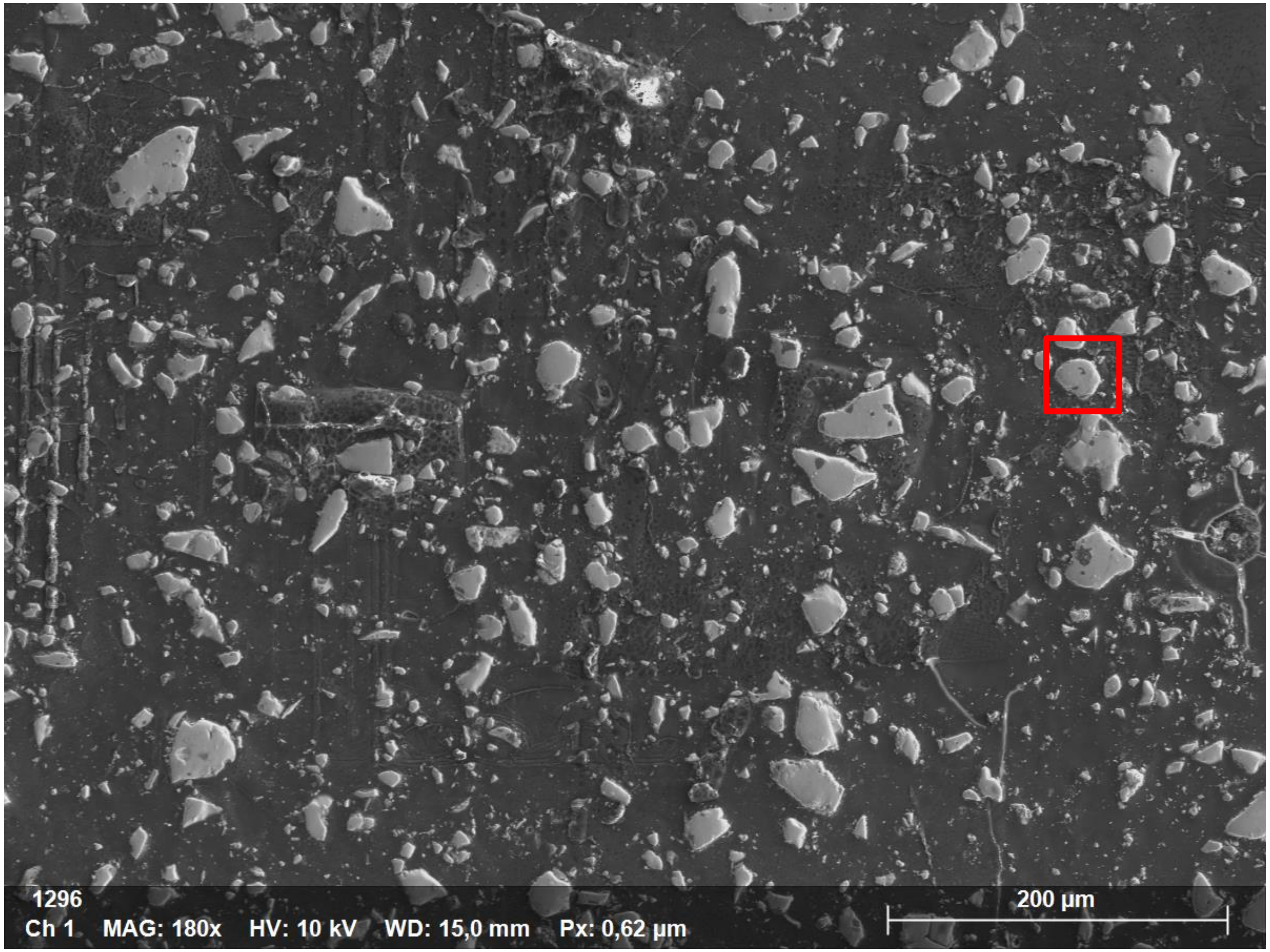
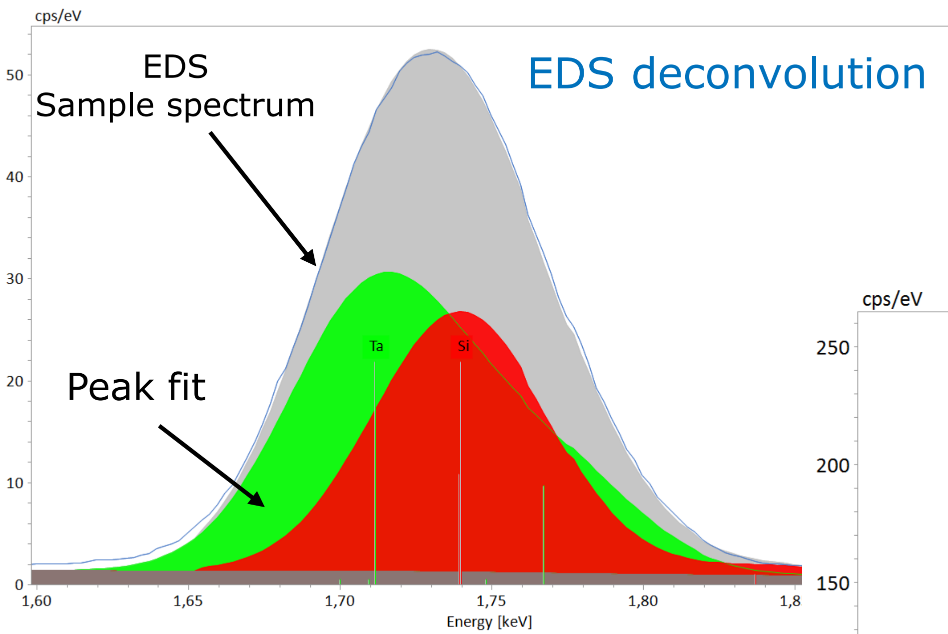
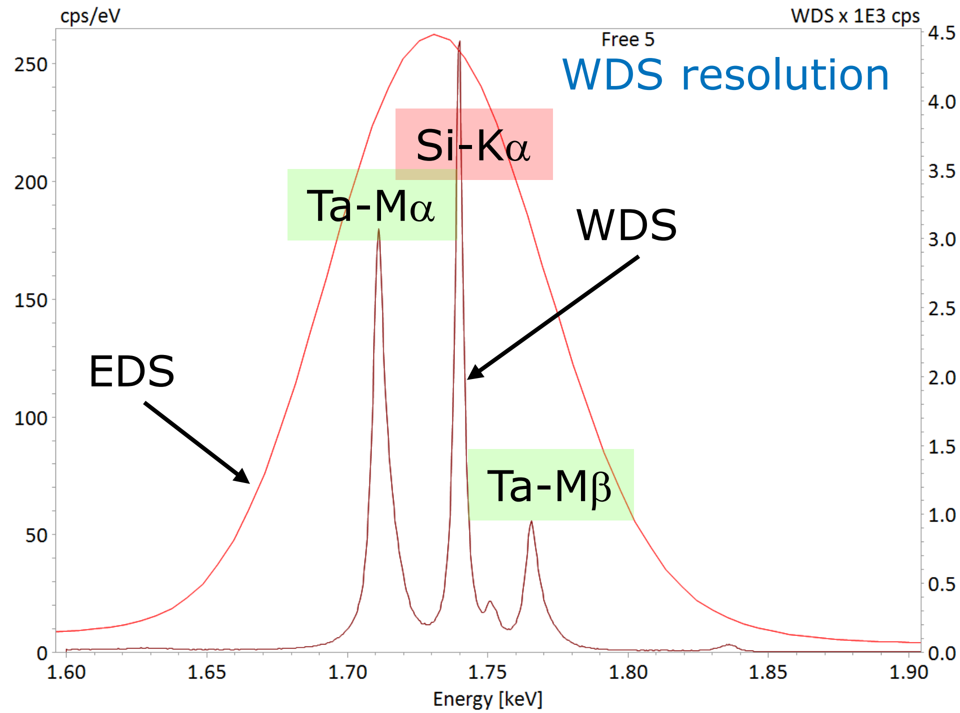


Image dimensions:

724 x 538 µm

Application 3
Tantalum silicide ($TaSi_2$)



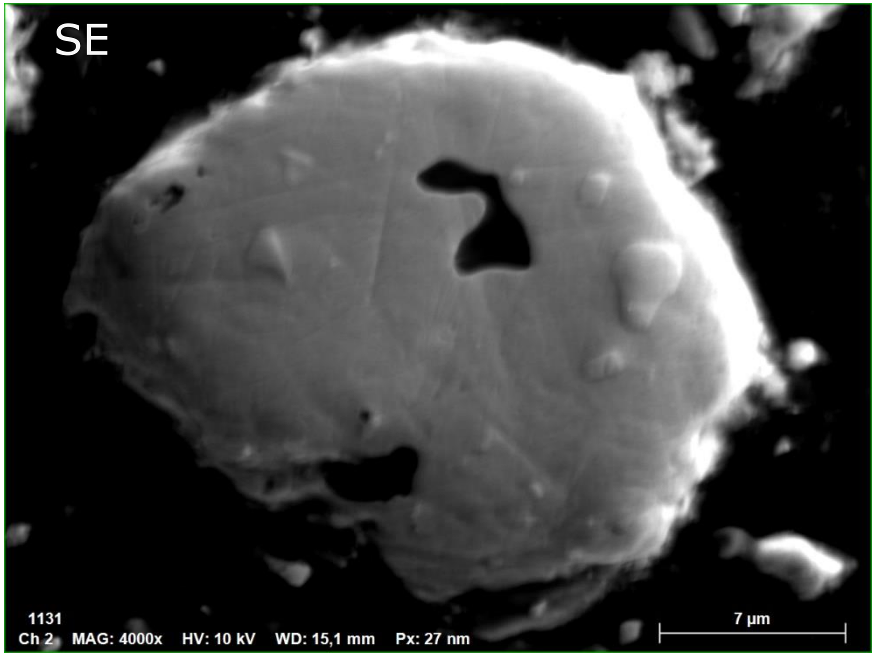


Δ Si-Kα – Ta-Mα: 27 eV

$FWHM_{WDS}$: 3.5 eV

$FWHM_{EDS}$: 70 eV

Application 3
Tantalum silicide ($TaSi_2$) single grain



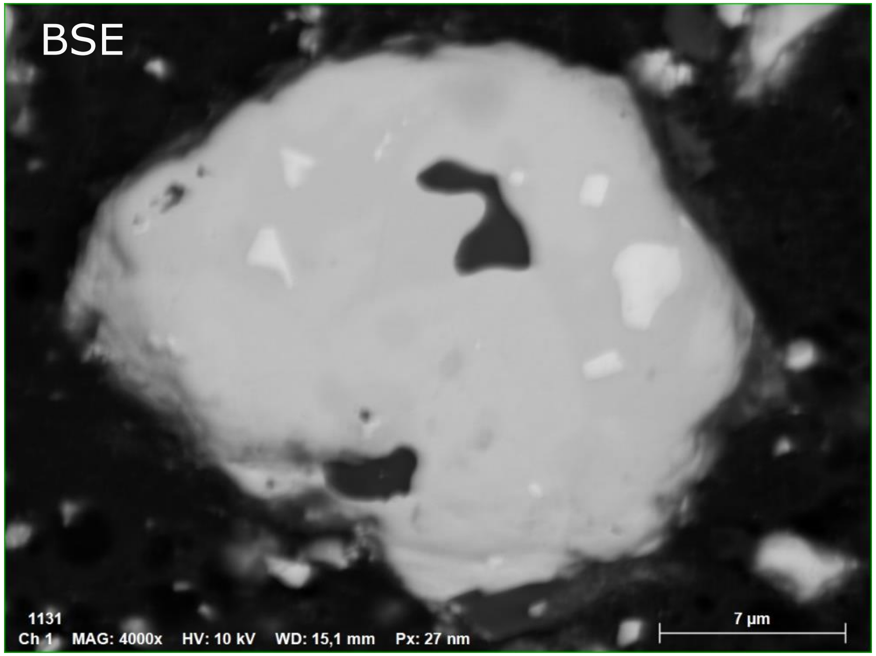


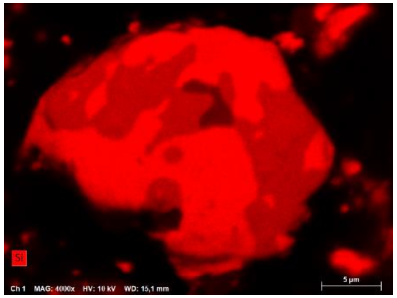
Image dimensions: 32 x 24 µm

Testing for sample homogeneity

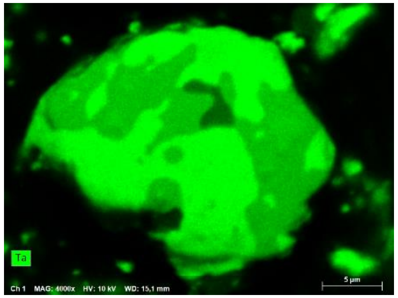
Application 3
Tantalum silicide ($TaSi_2$) @10kV

EDS

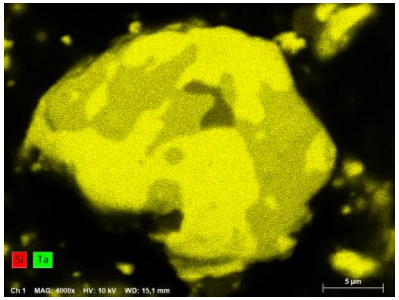
Si



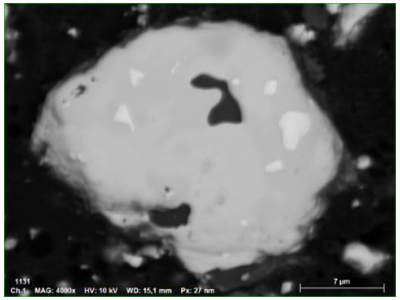
Ta



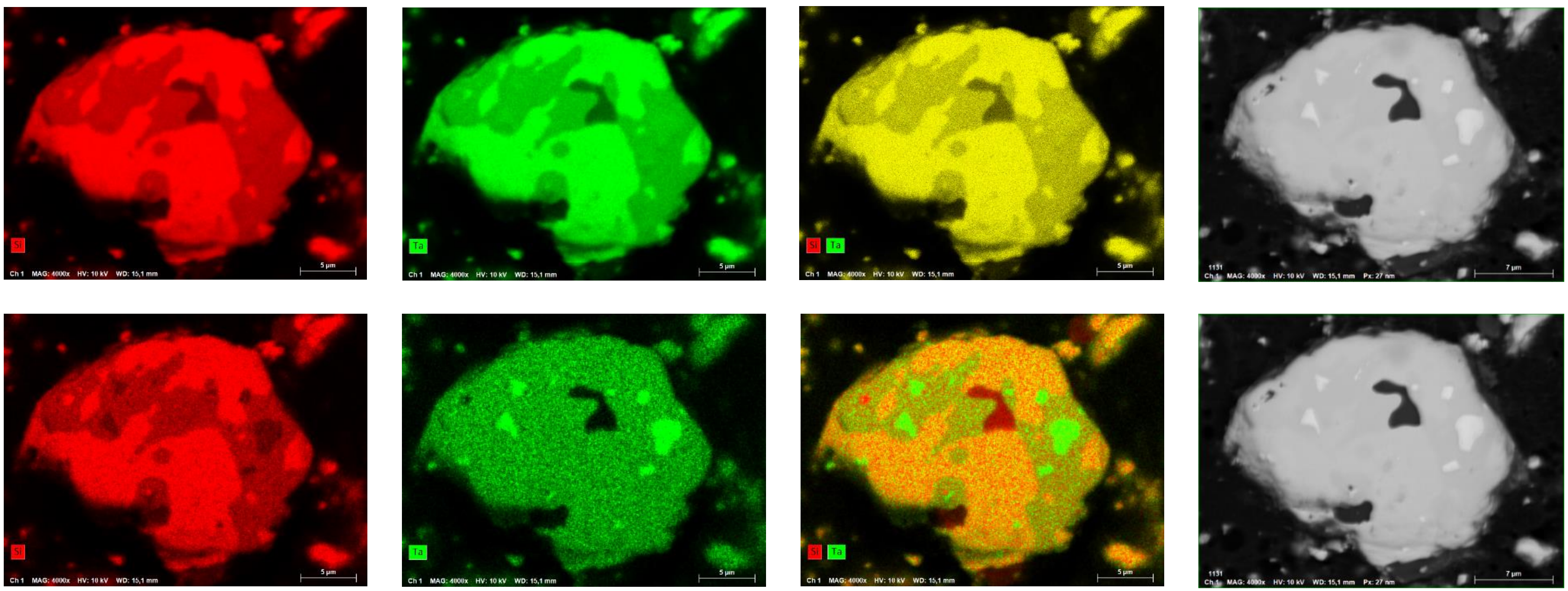
Si+Ta



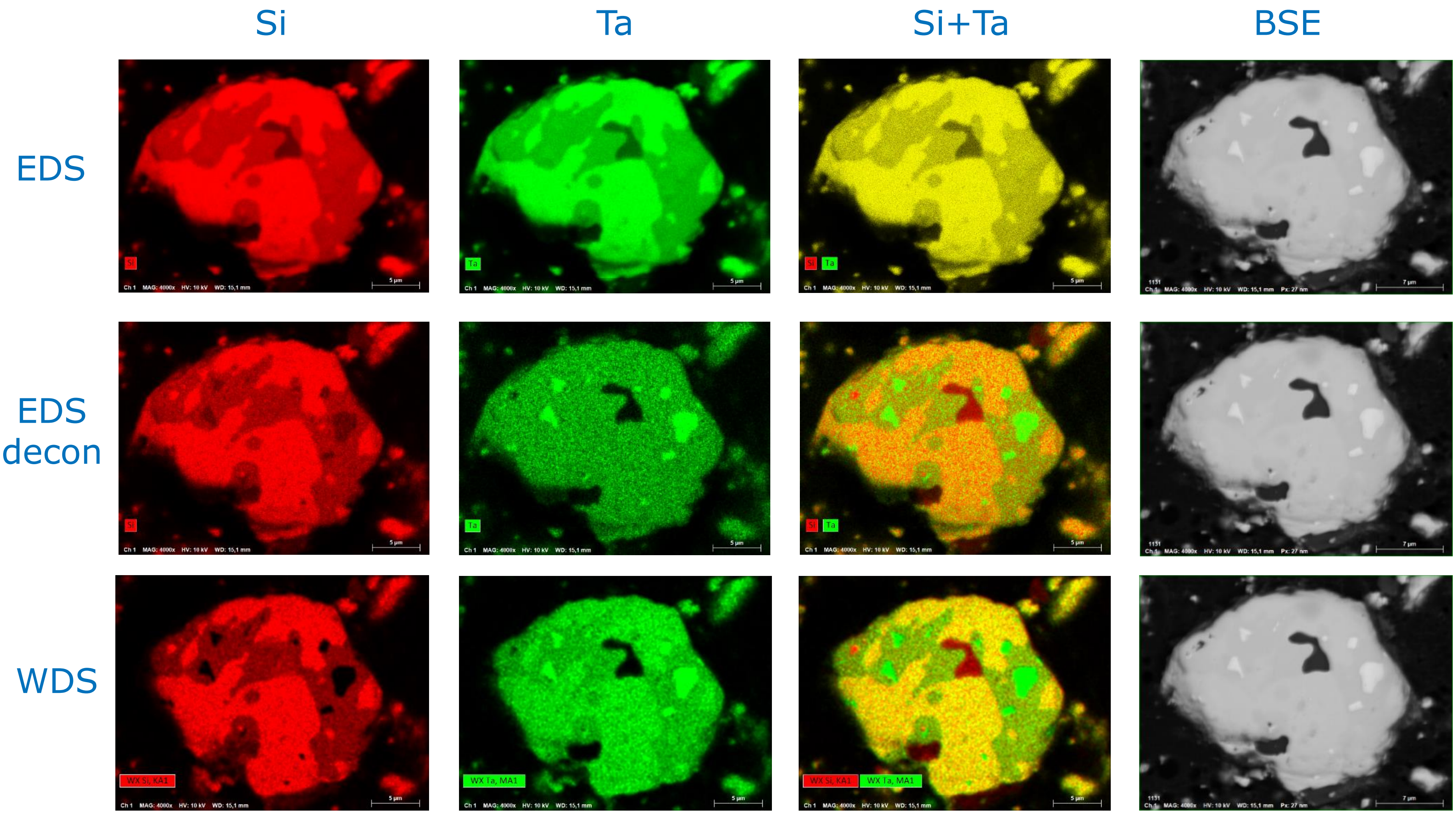
BSE



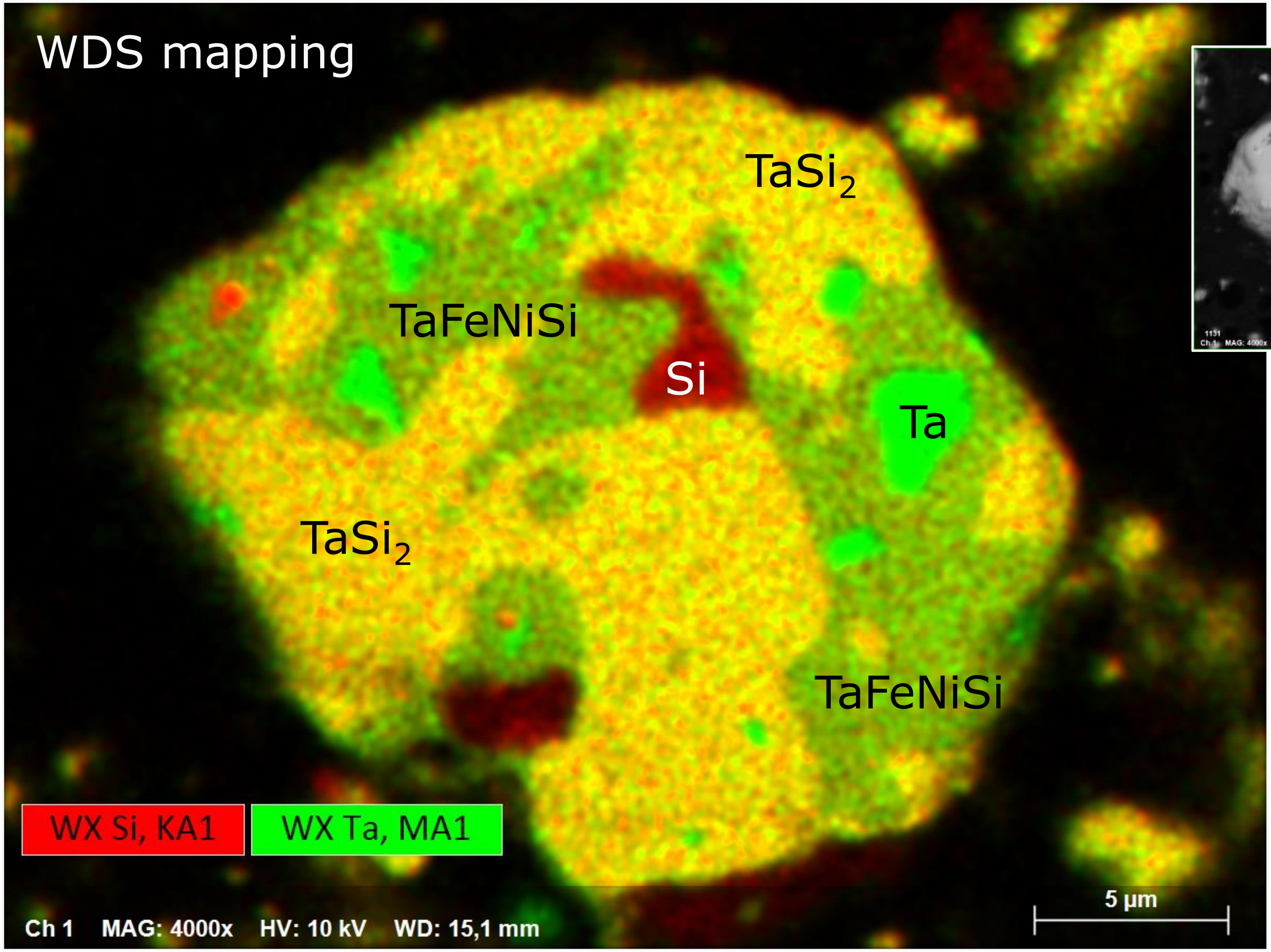
Application 3
Tantalum silicide ($TaSi_2$) @10kV

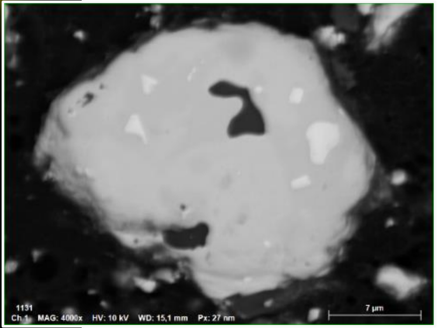


Application 3
Tantalum silicide ($TaSi_2$) @10kV



Application 3
Tantalum silicide ($TaSi_2$) @10kV





Application 4

Silver-doped lead telluride - (Ag)PbTe

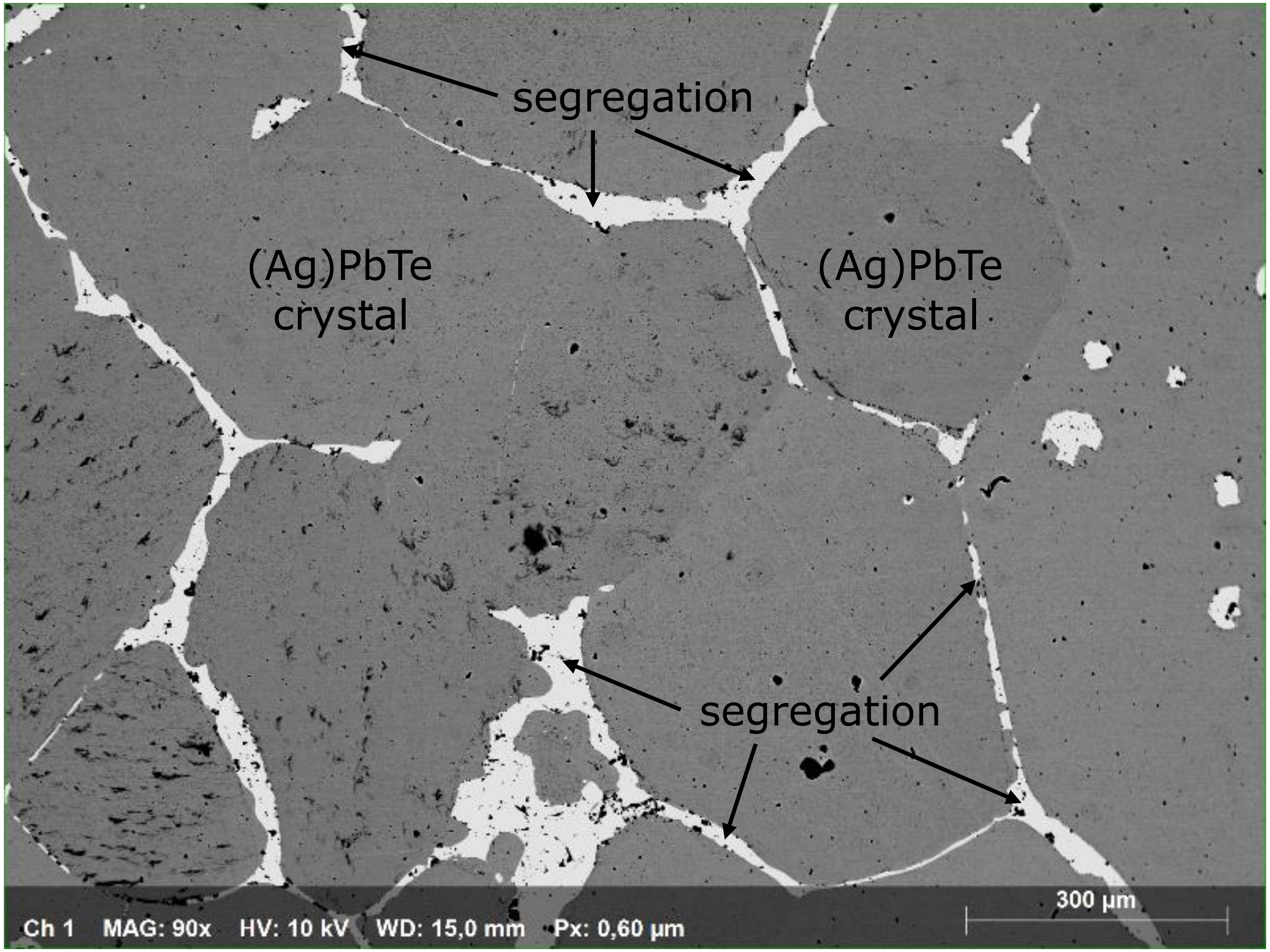
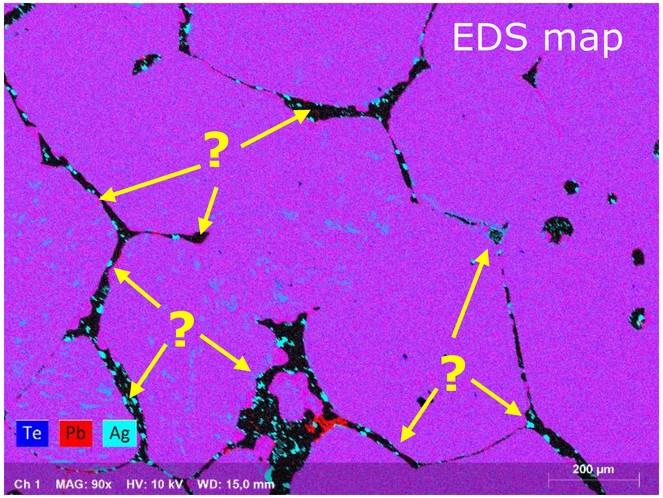


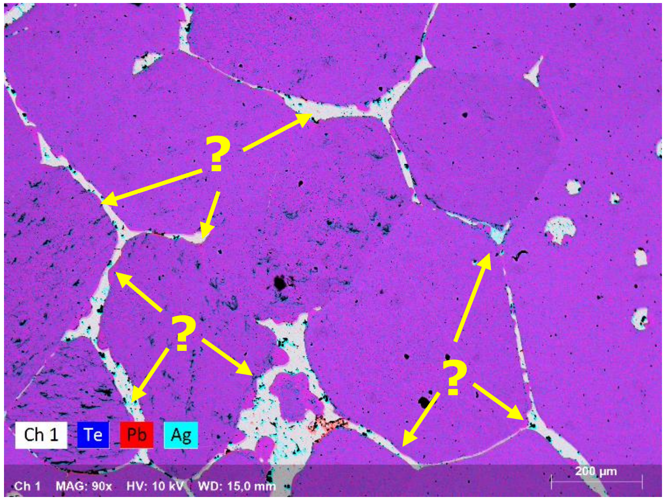
Image dimensions:

1.4 x 1.1 mm

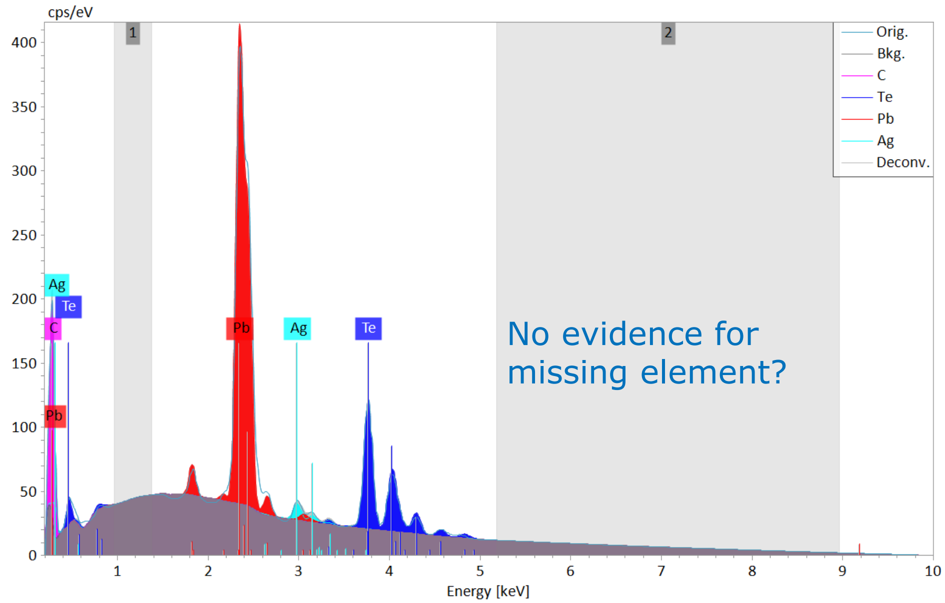
Application 4

(Ag)PbTe mapped by EDS





Map sum spectrum



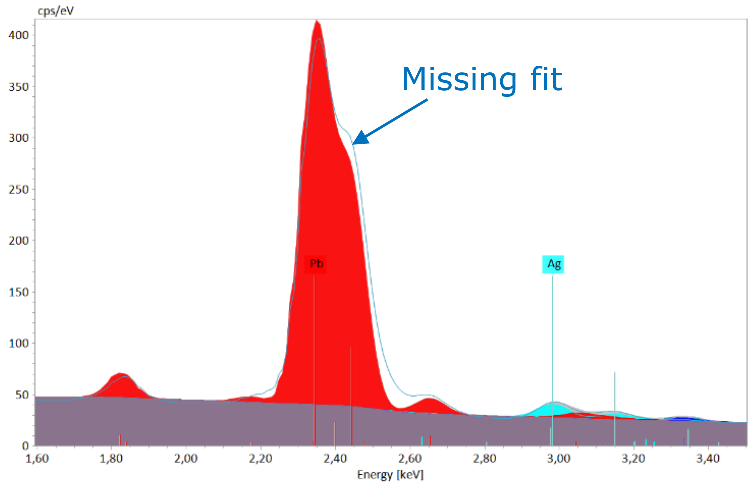
No evidence for missing element?

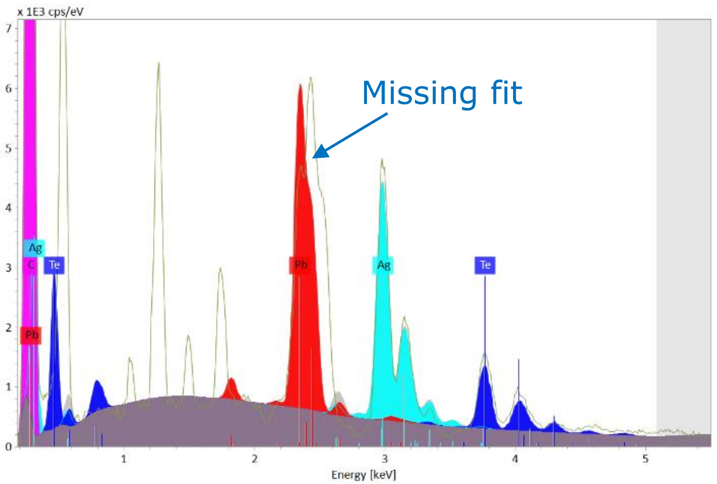
6% area remain undetermined

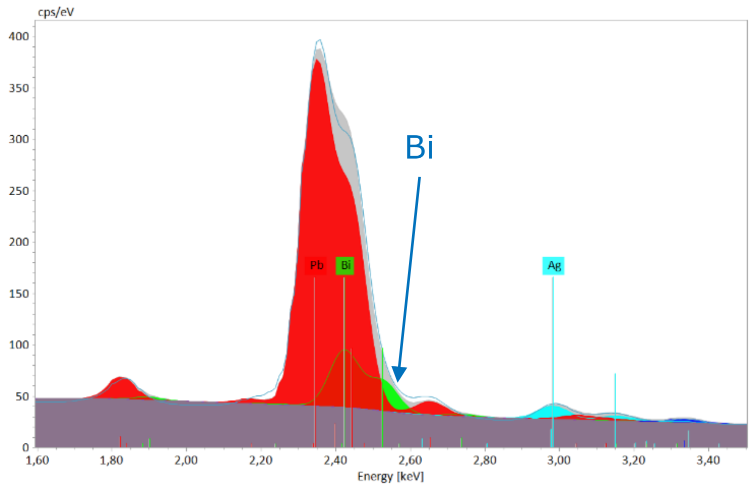
Application 4
EDS interactive deconvolution

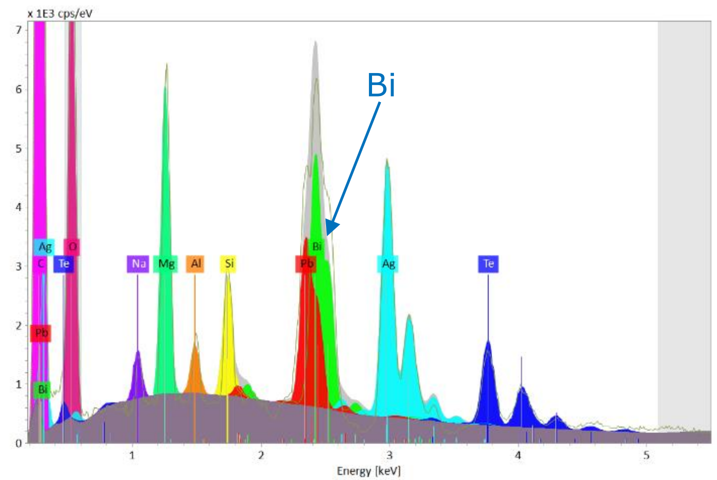
EDS sum spectrum

Maximum pixel spectrum

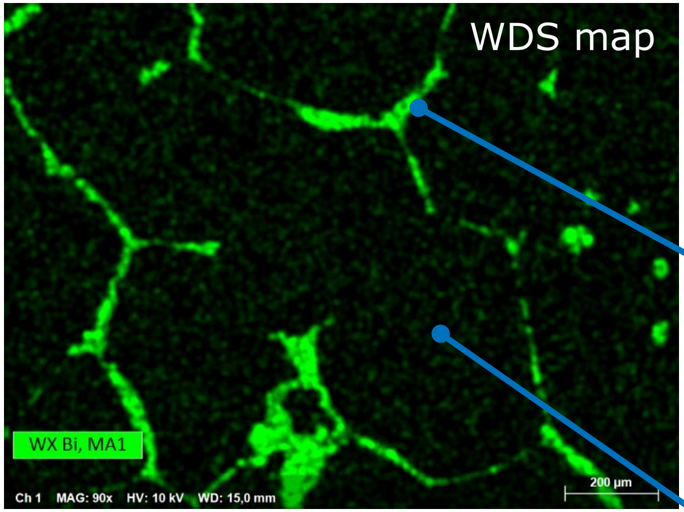


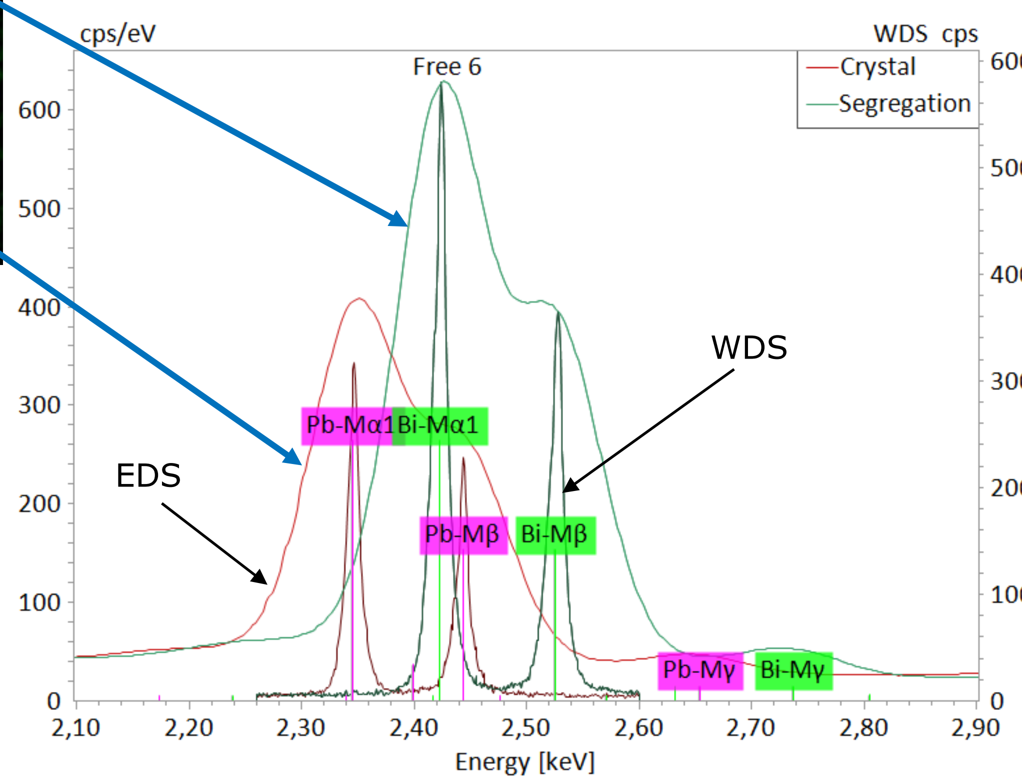






Application 4
(Ag)PbTe – Bi resolved by WDS



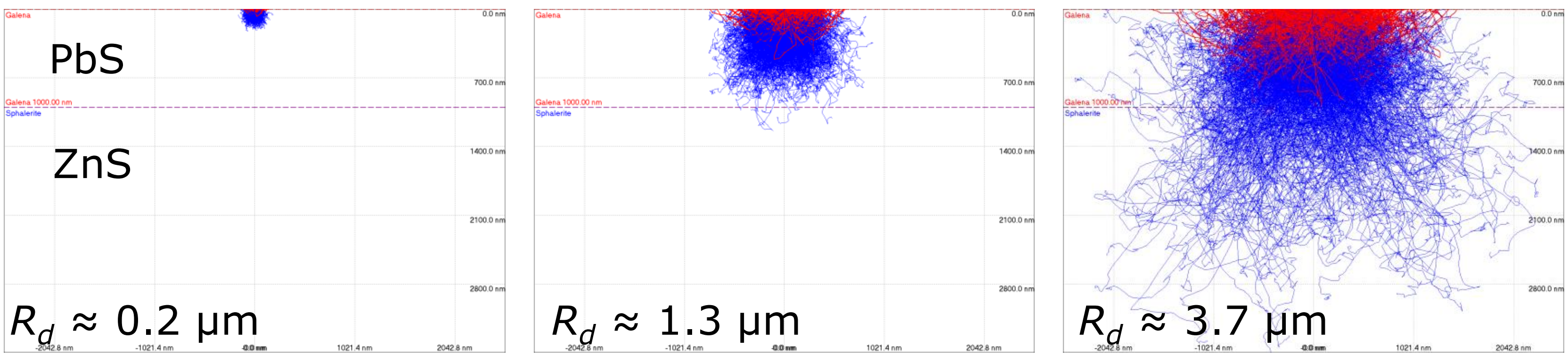


WDS: no post-processing required

Acceleration voltage
Effect on spatial/depth resolution

- Monte Carlo electron-trajectory simulations of interaction volume in layered sulphides as function of primary beam energy

EHT = 5 kV **EHT = 15 kV** **EHT = 25 kV**



Casino v.2.5.1

→ With higher primary electron energy penetration depth is increasing and spatial resolution of the analysis is decreasing

Application 5
Layered structure in microelectronics

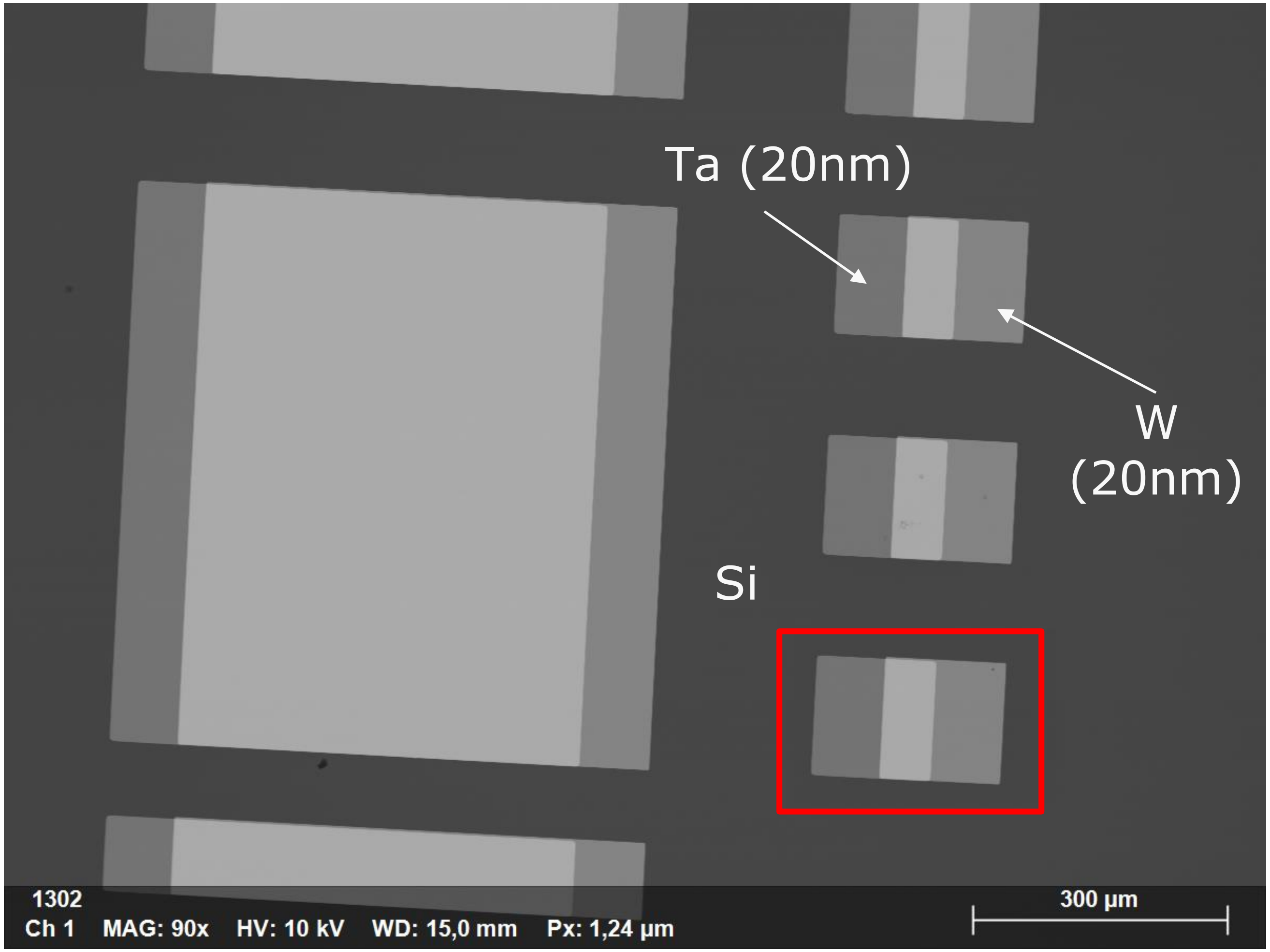
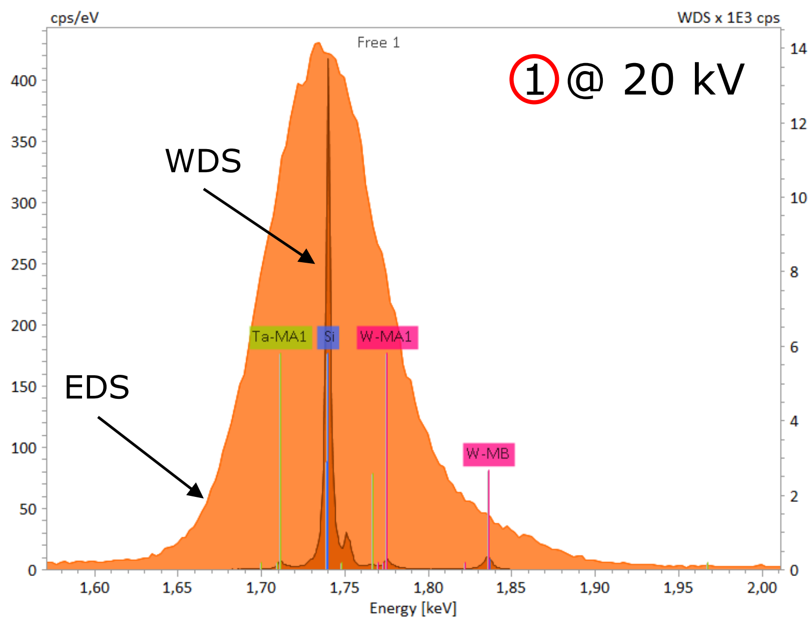
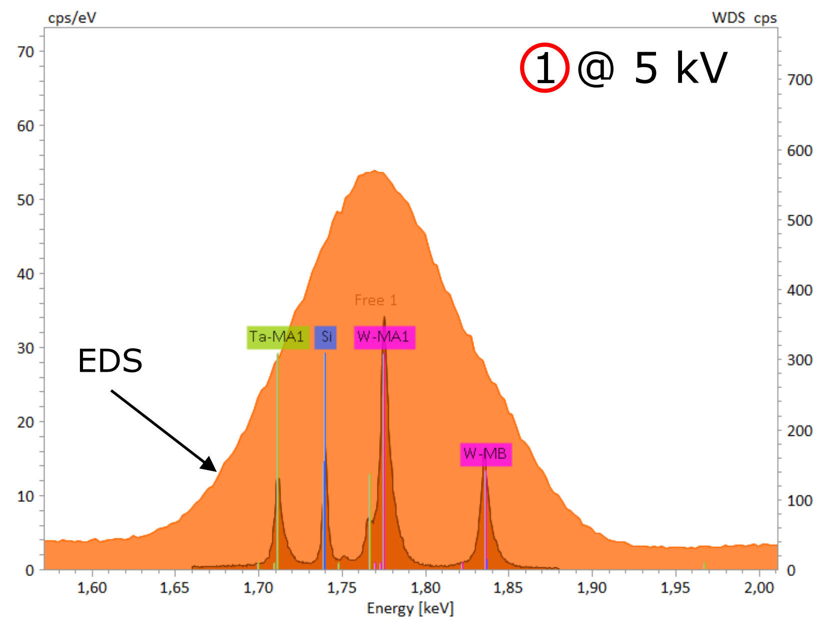


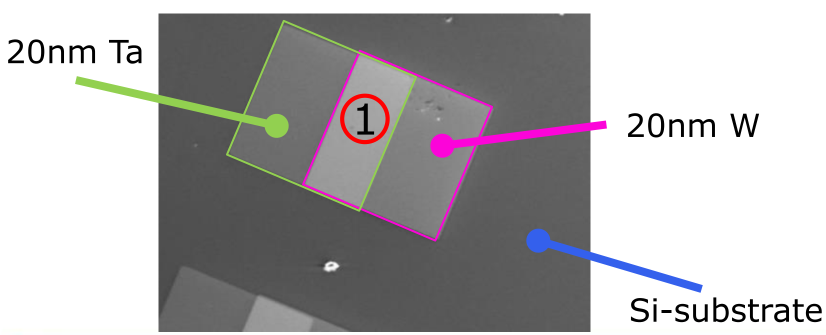
Image dimensions:

1.5 x 1.1 mm

Application 5
Layered structure in microelectronics

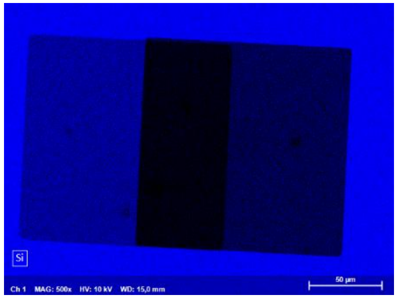
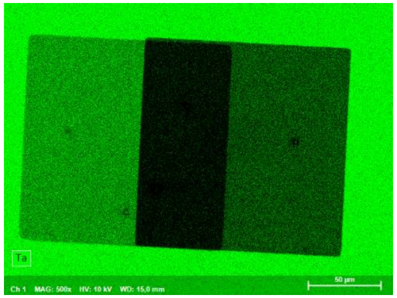
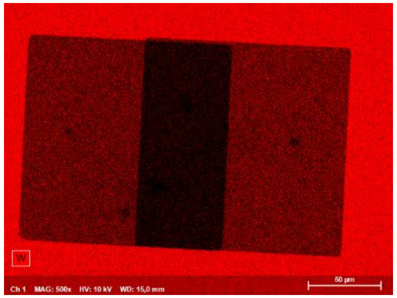
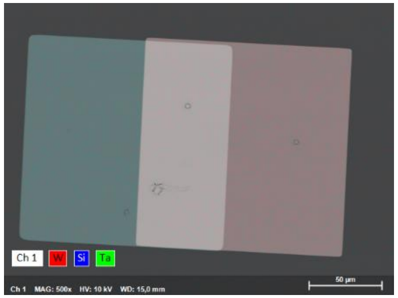






Decreasing voltage → decreasing interaction depth, increasing info on top layers

Application 5
Layered microelectronics @10kV

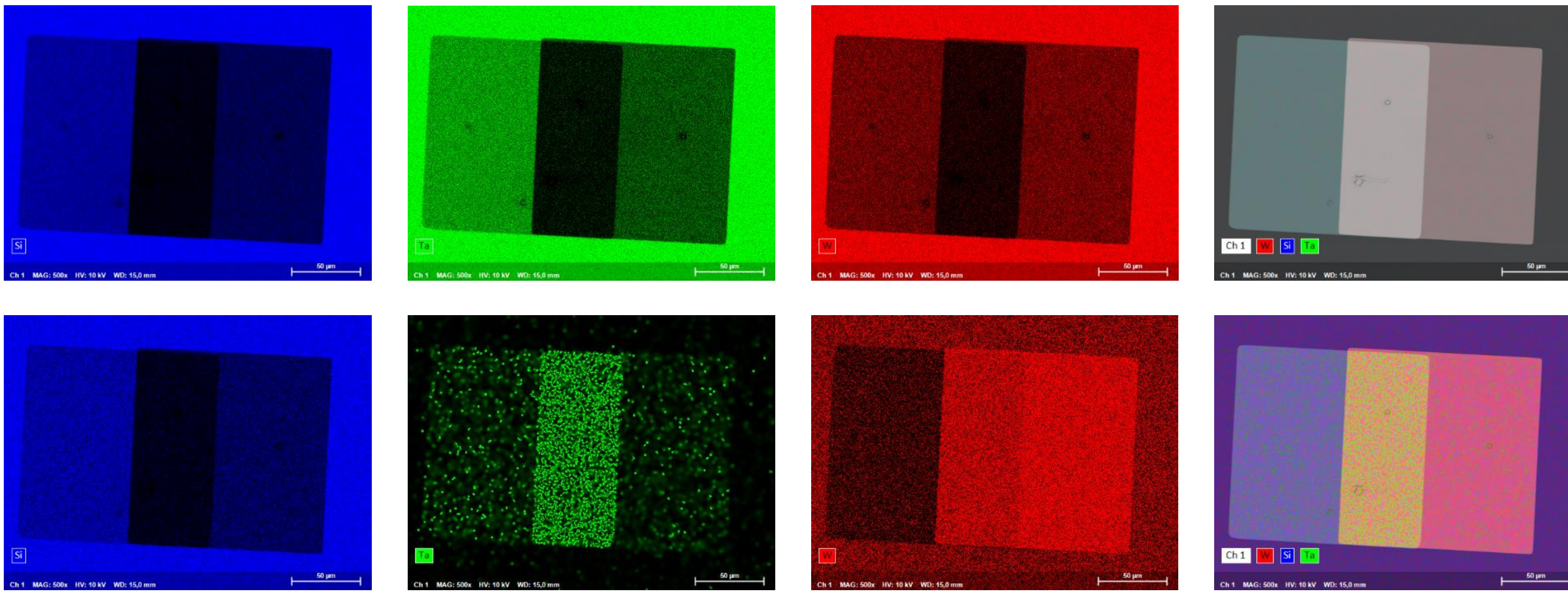
	Si	Ta	W	BSE+ Si+Ta+W
EDS				

Application 5
Layered microelectronics @10kV

Si | Ta | W | BSE+ Si+Ta+W

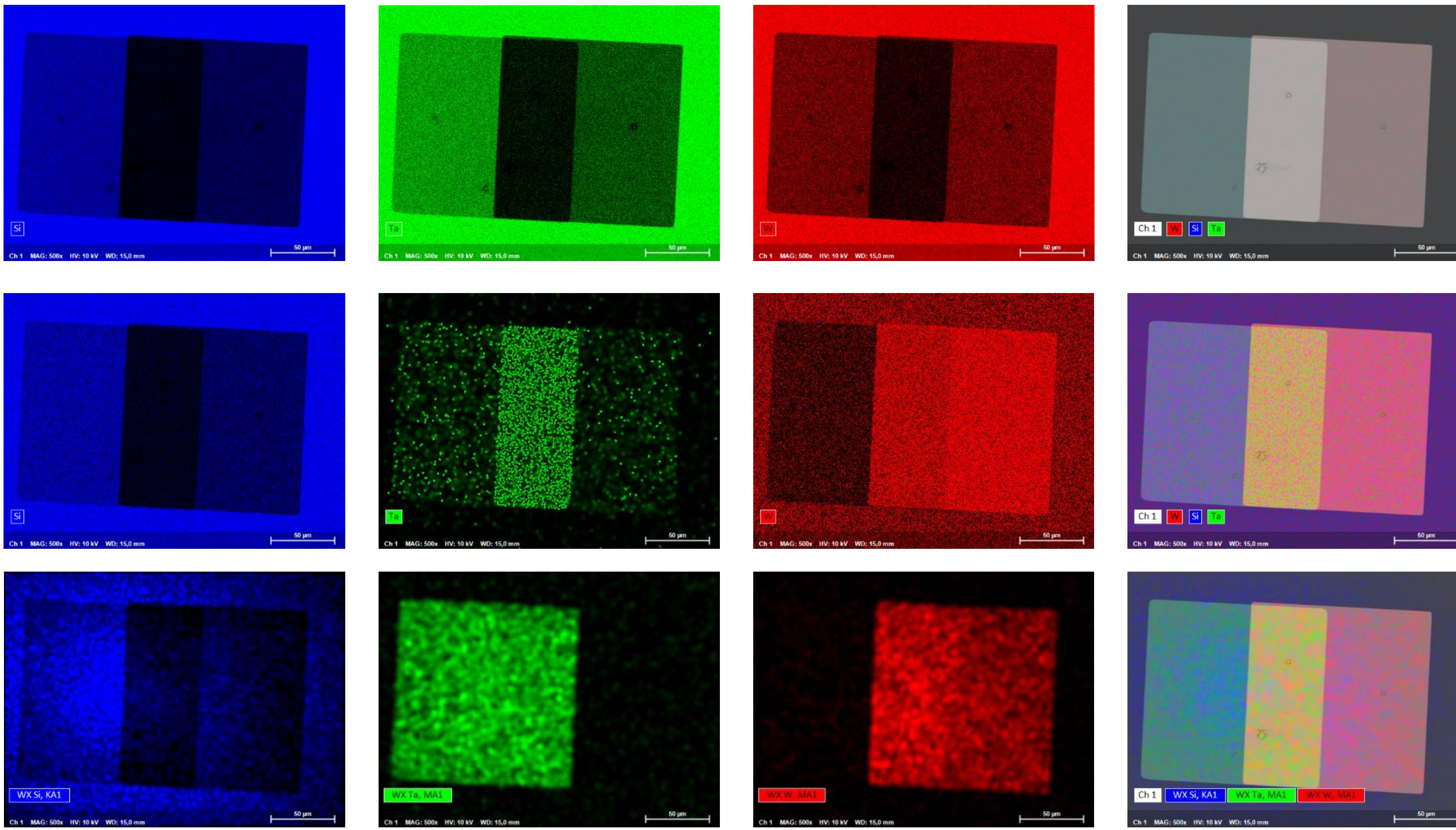
EDS

EDS decon



Application 5
Layered microelectronics @10kV

	Si	Ta	W	BSE+ Si+Ta+W
EDS				
EDS decon				
WDS				



Application 6
Semiconductor microchip

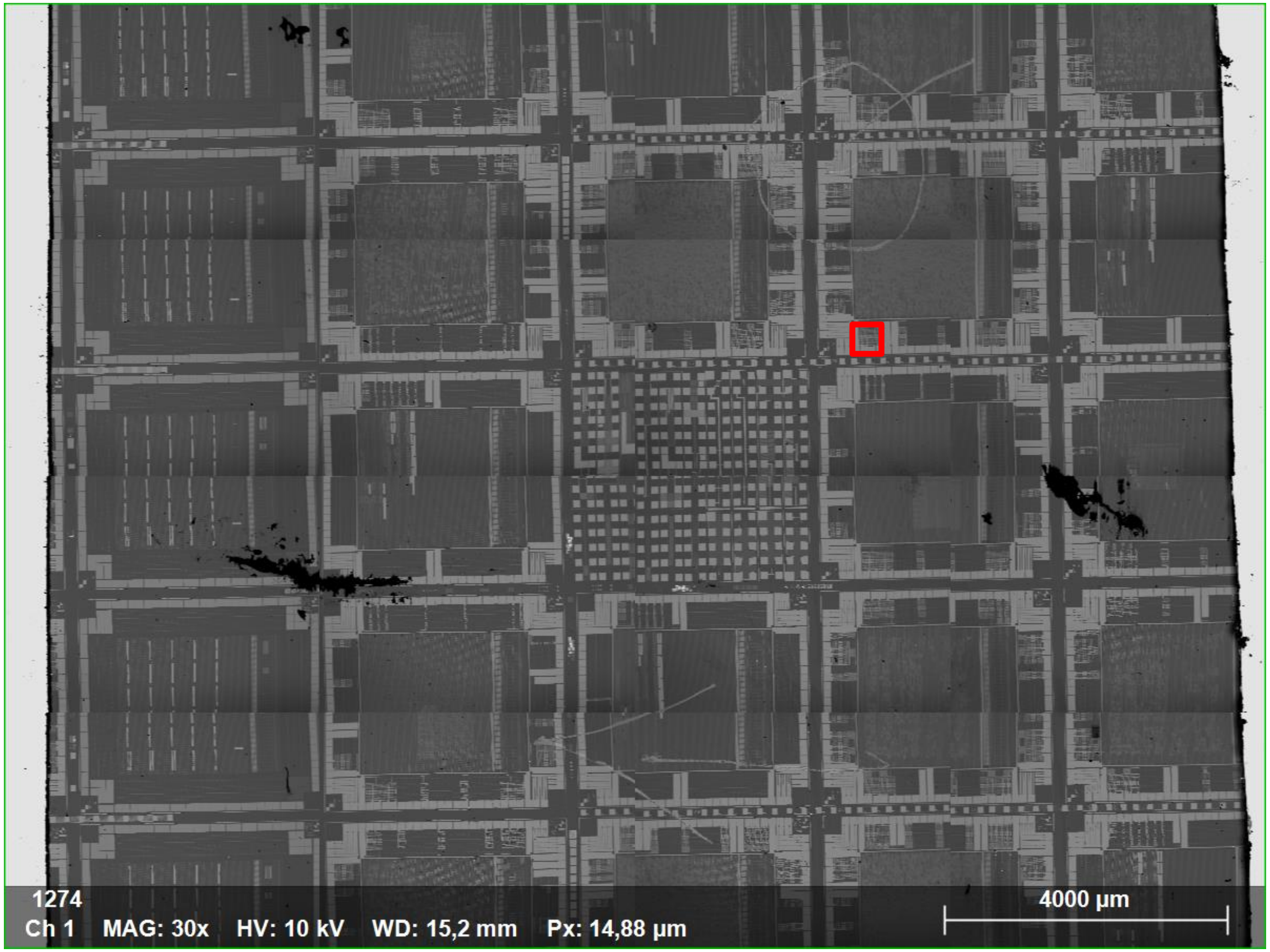
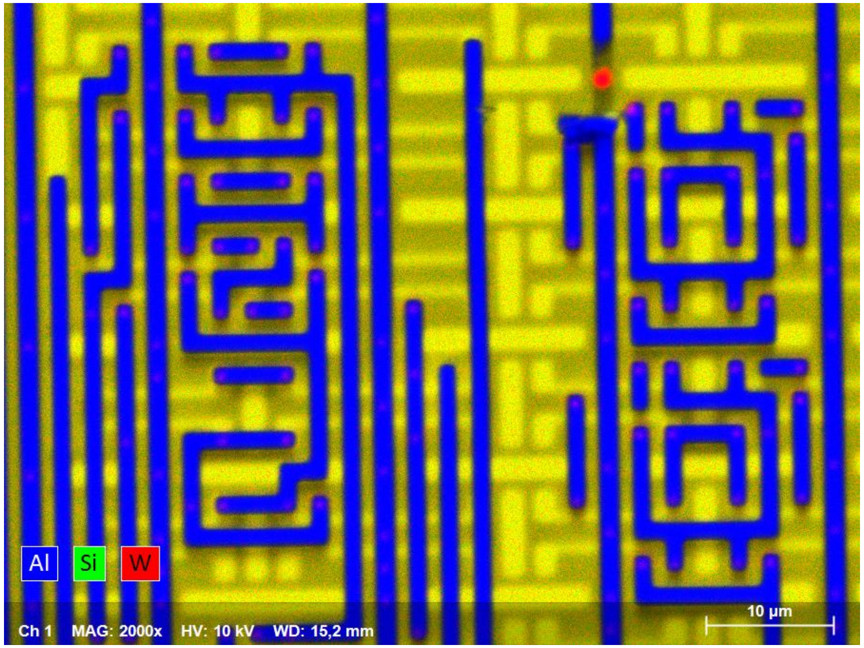


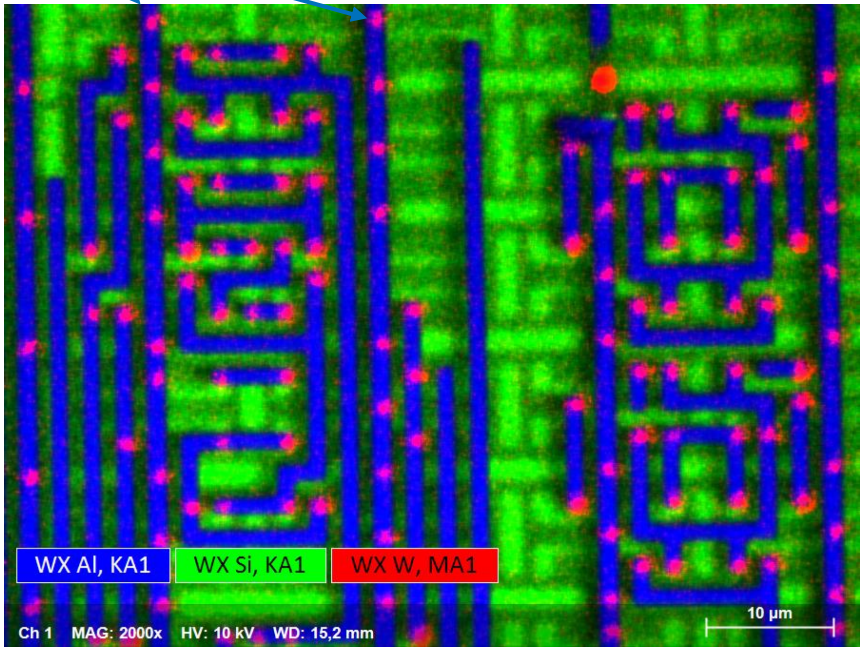
Image dimensions:

4.3 x 3.2 mm

Application 6
Semiconductor microchip (MOSFET)

buried gates (W)



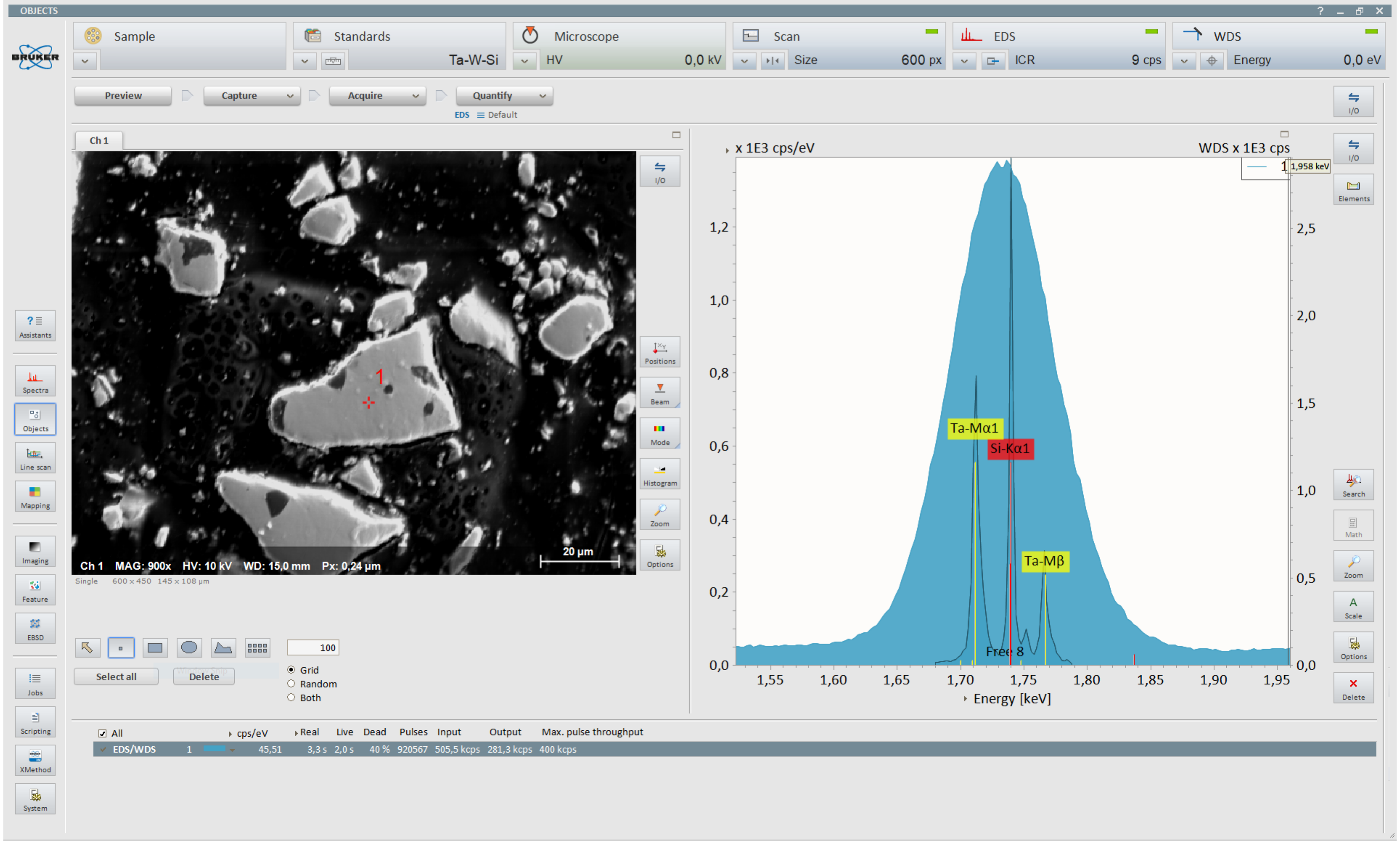


EDS w/ deconvolution

WDS

WDS reveals more details

Video
Workflow for WDS analyses



Summary and Conclusions
QUANTAX WDS Benefits

High spectral resolution

- Significant increase in spectral resolution
- Pathological EDS peak overlaps can be resolved
- Improved analytical information

High lateral and depth resolution

- Enables X-ray analysis at low kV
- Eneases X-ray analysis on the nano-scale
- Allows analysis of sub-µm structures
- Allows analysis of sub-µm layers

Q&A

Are There Any Questions?

Please type in the questions you might have

in the Q&A box and press *Send*.

Innovation with Integrity