



Crystallographic and topological textures of biological materials and anisotropy of the mechanical properties

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INVITED LECTURE

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Golm, Germany



Overview

Motivation



Textures

- Topological and hierarchical organization
- Crystallographic textures

Mechanical properties

- Macroscopic
- Microscopic

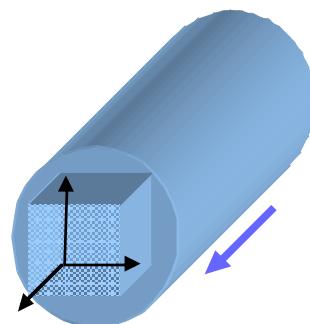
Conclusions



Motivation for texture studies on biological matter

Motivation

- Strong topological directionality
- Structure topology concedes with crystallographic orientation
- Hierarchical organisation of (topological and crystallographic) orientation as building principle
- Mechanical and functional properties orientation dependent





Overview

Motivation

Textures

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Mechanical properties

- Macroscopic
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Conclusions



3 species as examples

- *Homarus americanus*



- *Carabus auronitens*

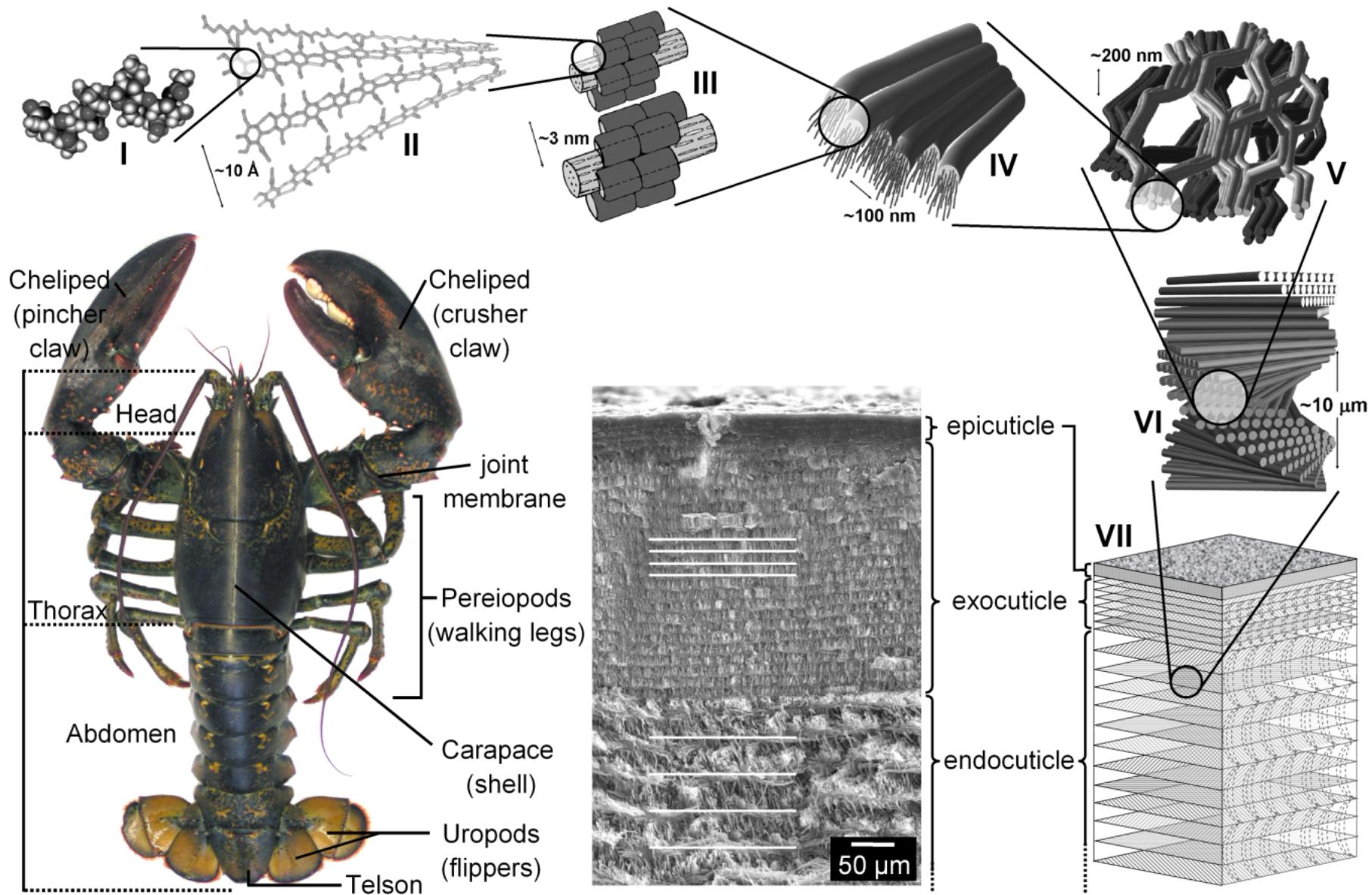


- *Chrysophanes virgaurea*

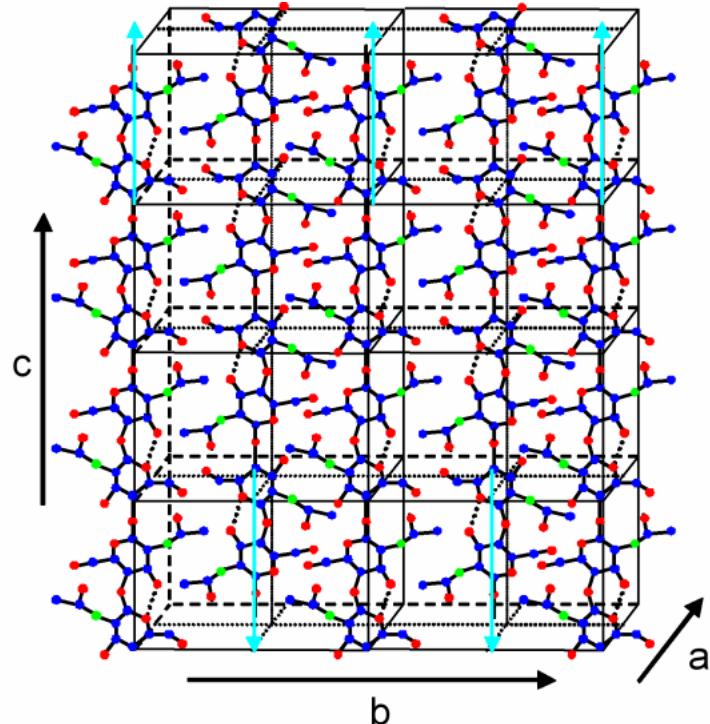




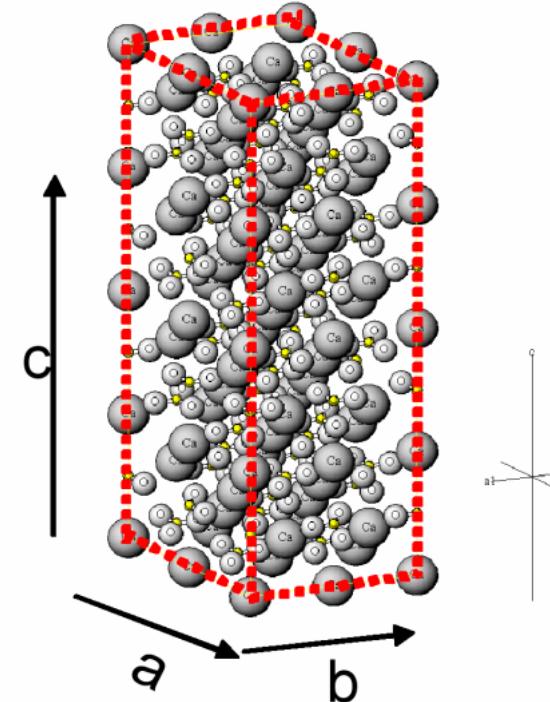
Hierarchical organization (*Homarus americanus*)



Phases and crystallography in crustaceans

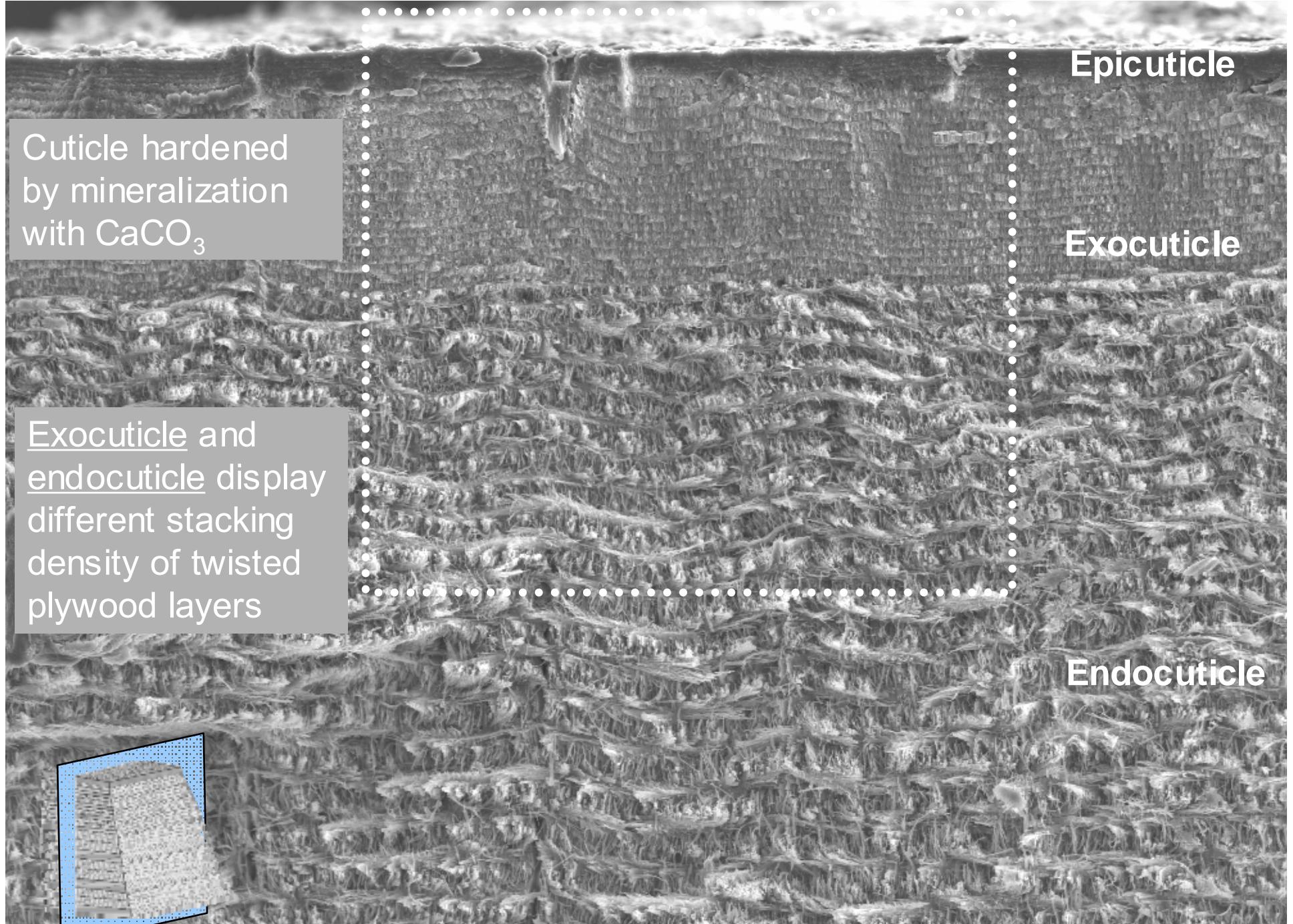


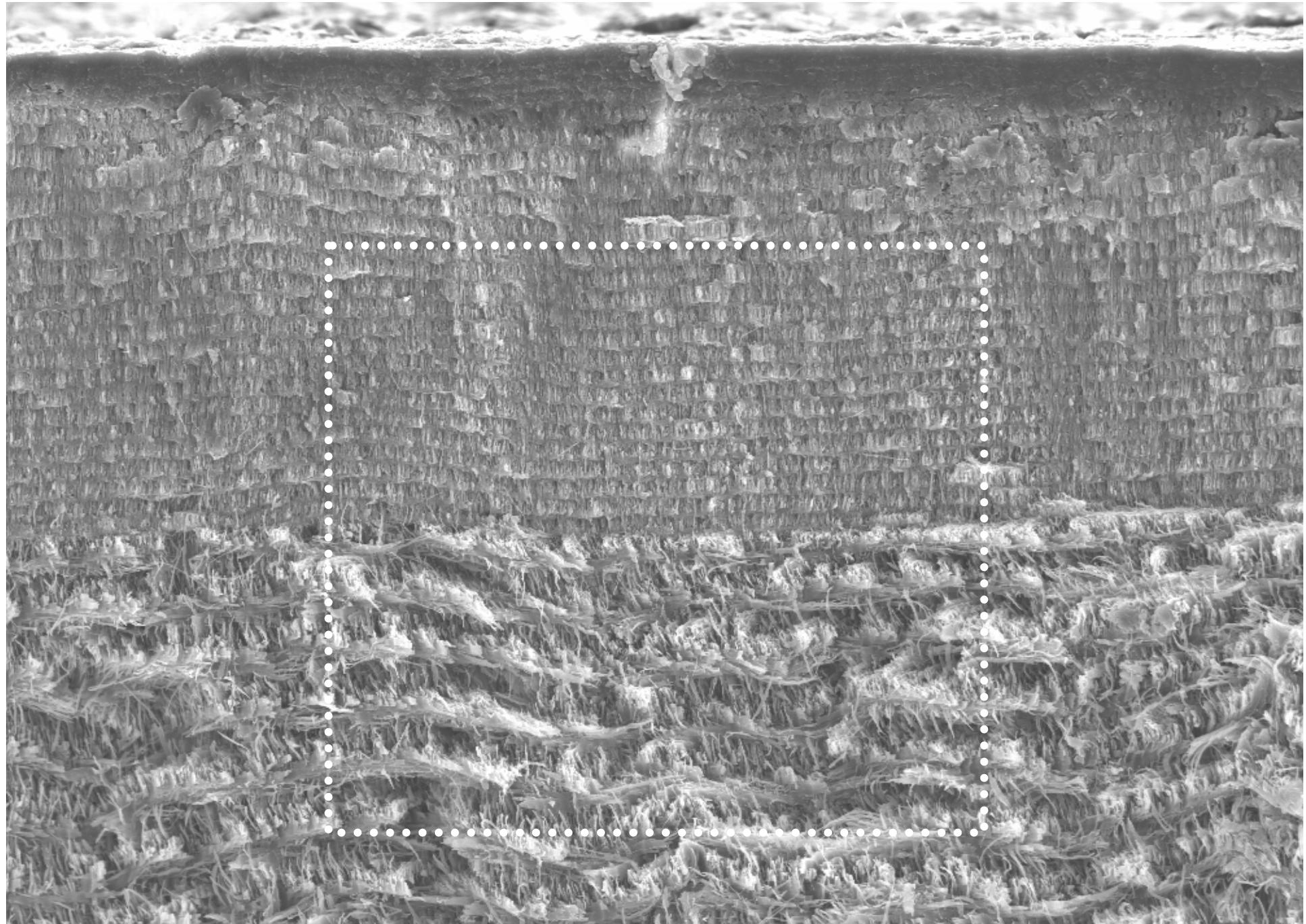
- Density: 1,41 gm/cm³
- Lin. absorbtion coef : 3700 μm^{-1} (@14 KeV($\sim 1 \text{\AA}$))
- Orthorhombic $a = 4.74 \text{\AA}$, $b = 18.86 \text{\AA}$, $c = 10.32 \text{\AA}$ (Takai et al, 1992)
- Space group: P222 (# 16 @ITC)
- Point group: 222



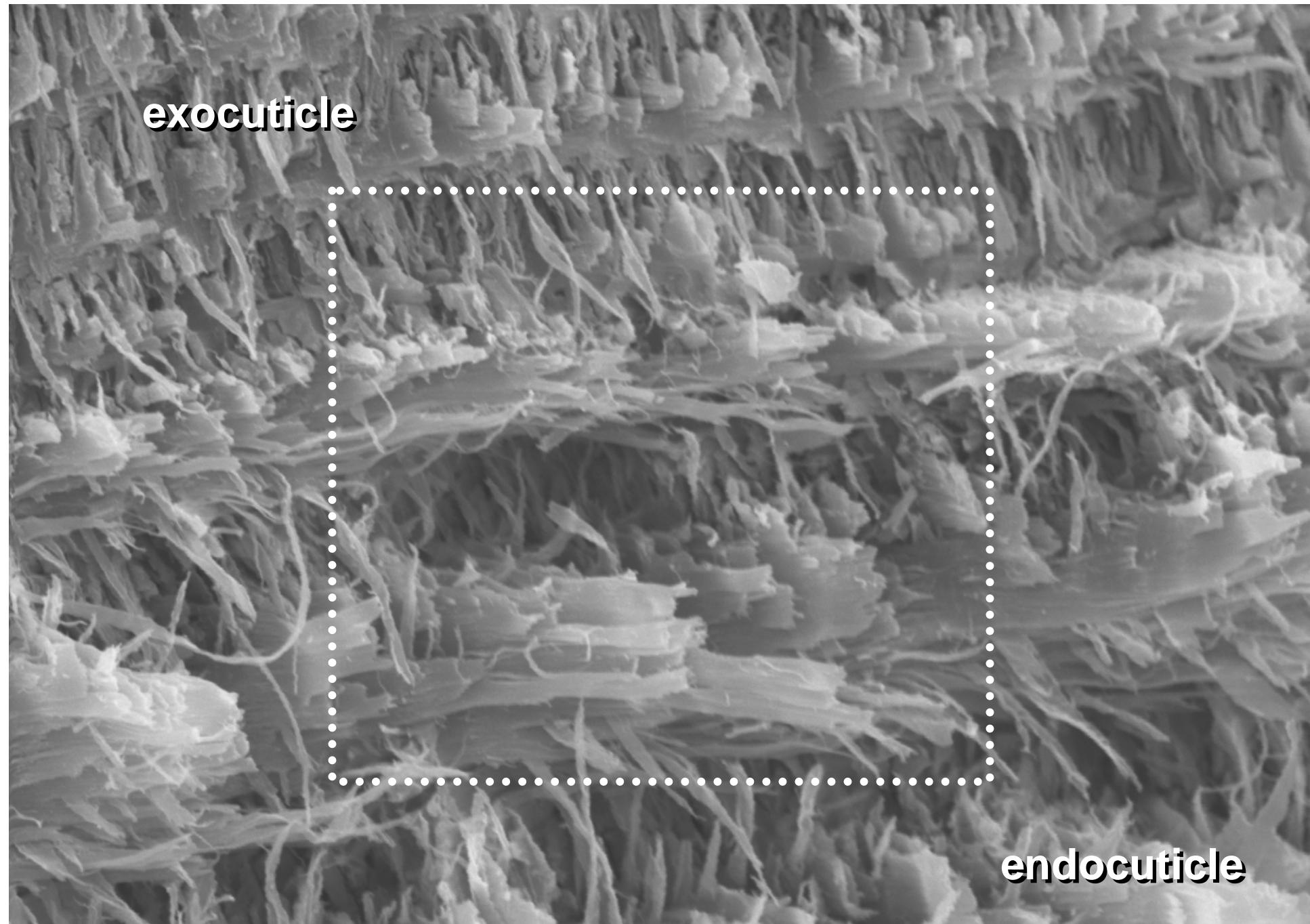
calcite
ACC

- Density: 2,71 gm/cm³
- Lin. Absorbtion Coef. : 200 μm^{-1} (@14 KeV($\sim 1 \text{\AA}$))
- Hexagonal , $a=b=4.989 \text{\AA}$, $c=17.062 \text{\AA}$ (Maslen et al. 1993)
- Space group: R -3 2/c (#167 @ITC)
- Point group: -3 2/m





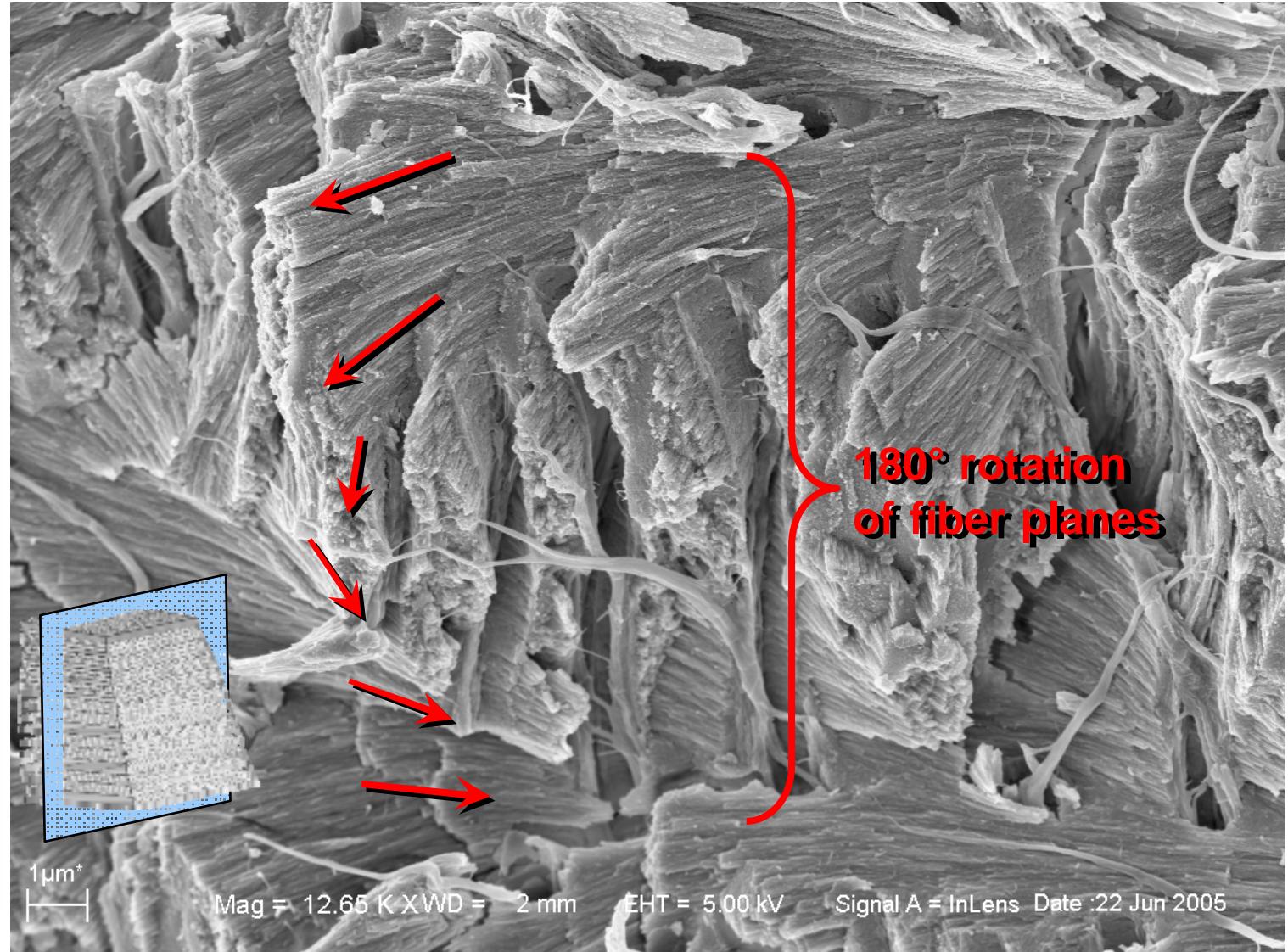
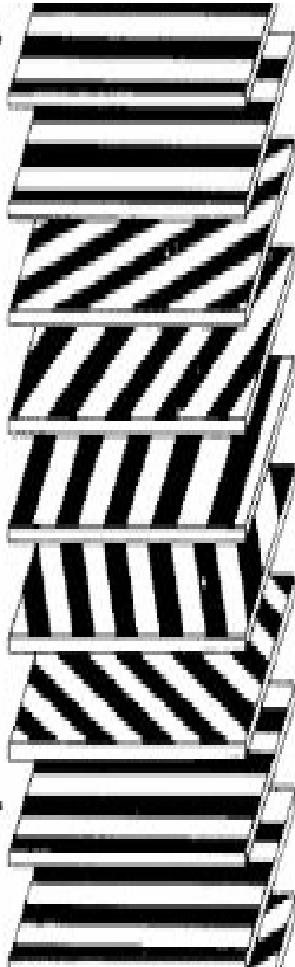
— 100 μm —

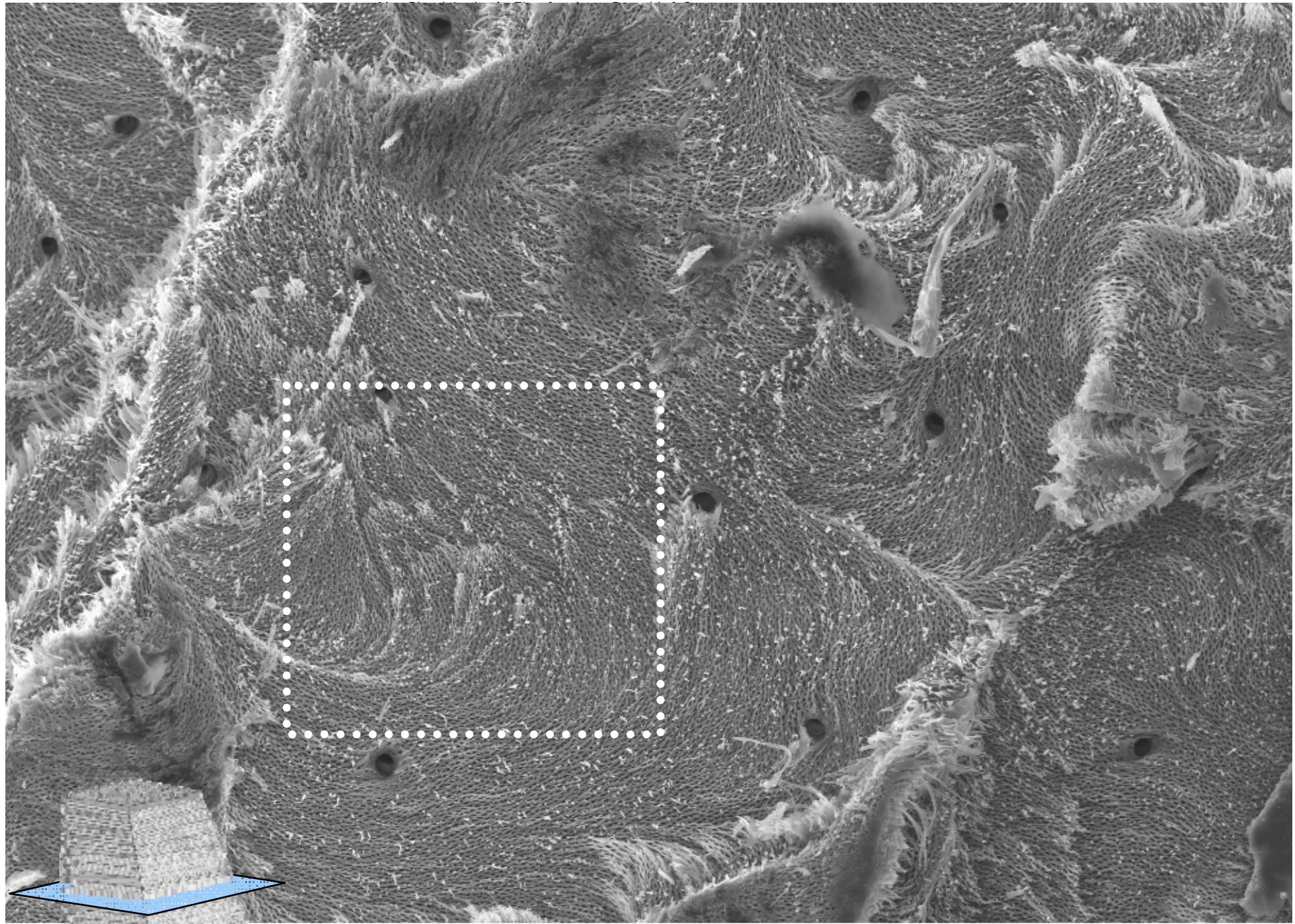


exocuticle

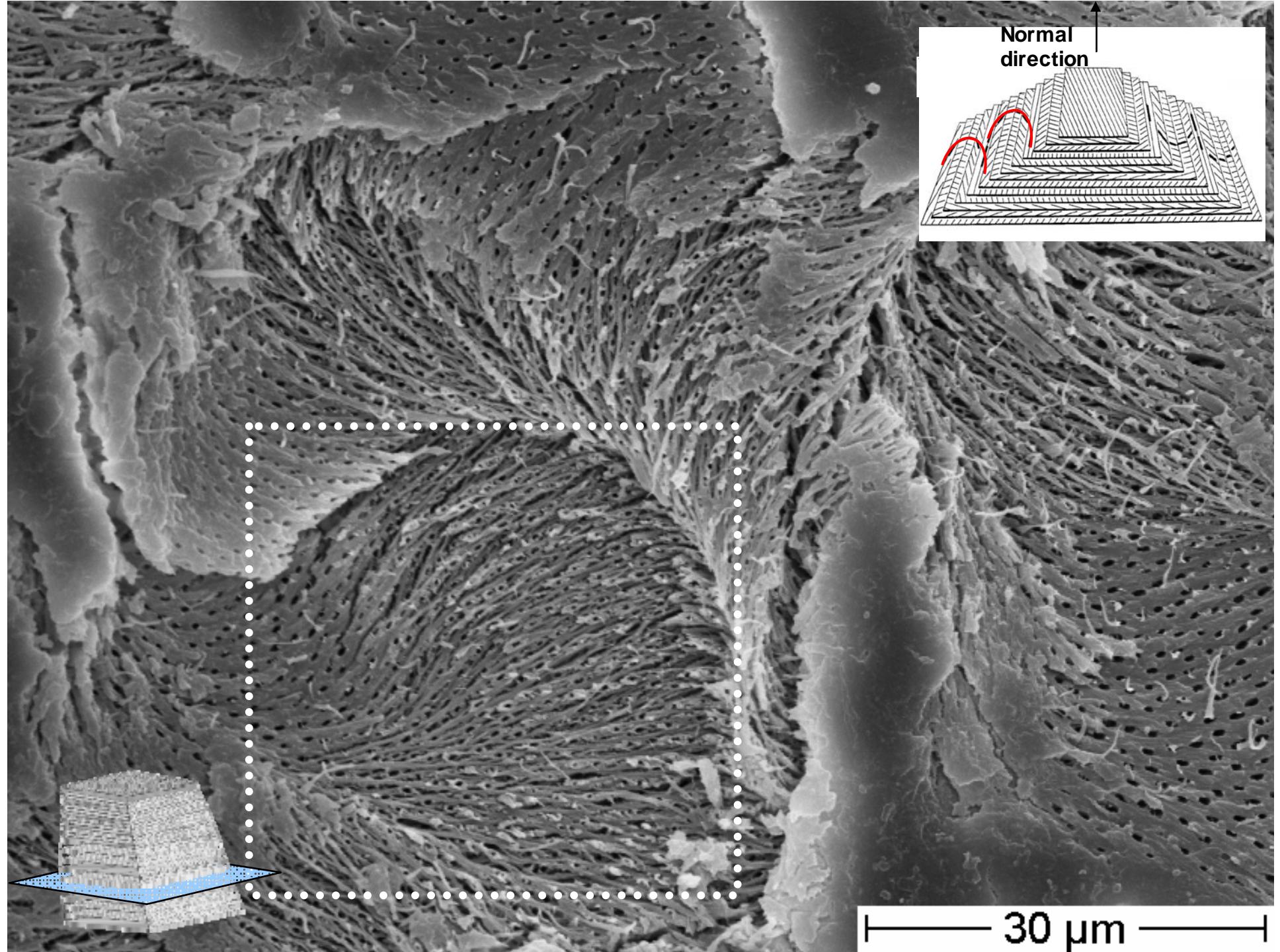
endocuticle

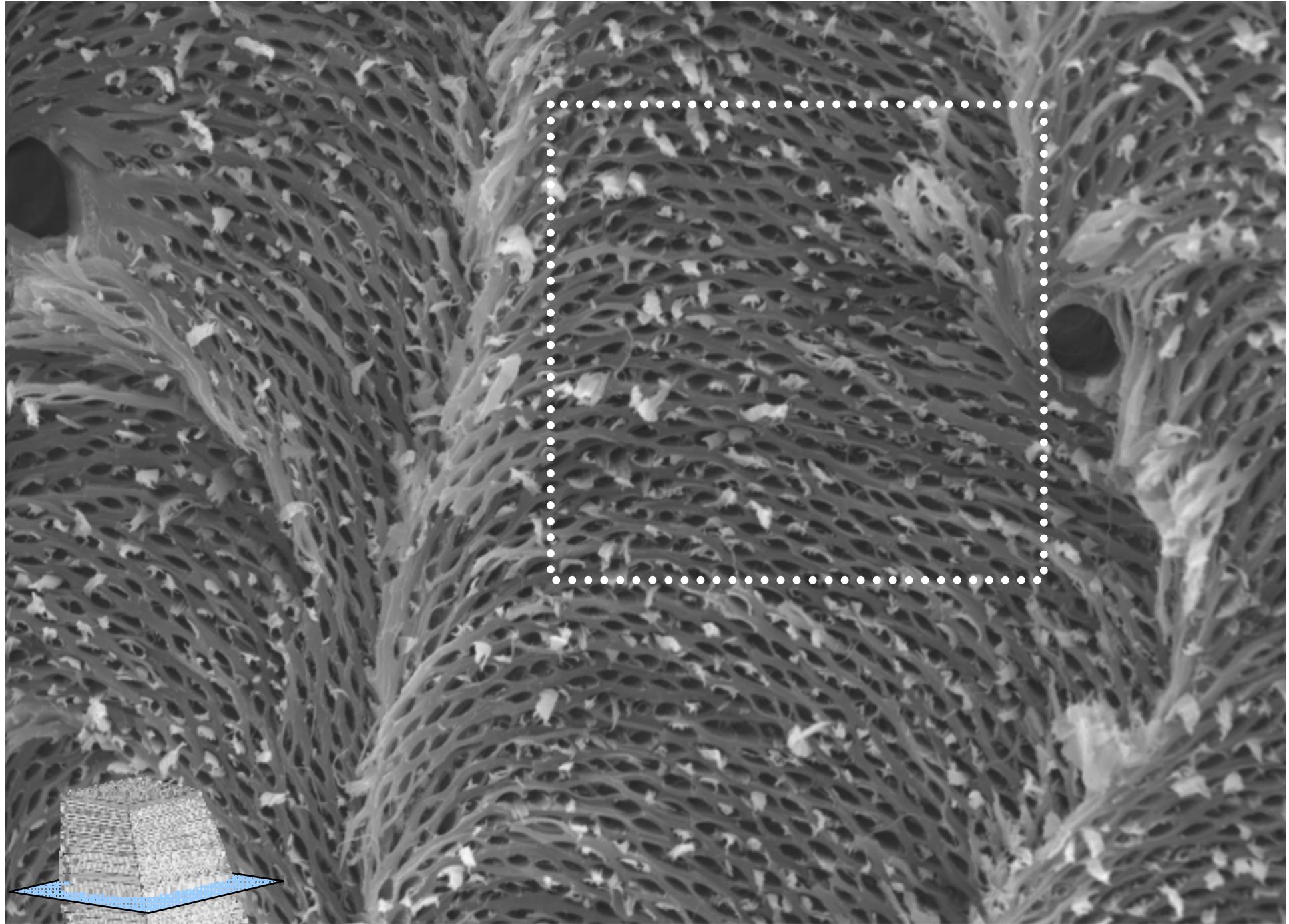
± 10 µm ±



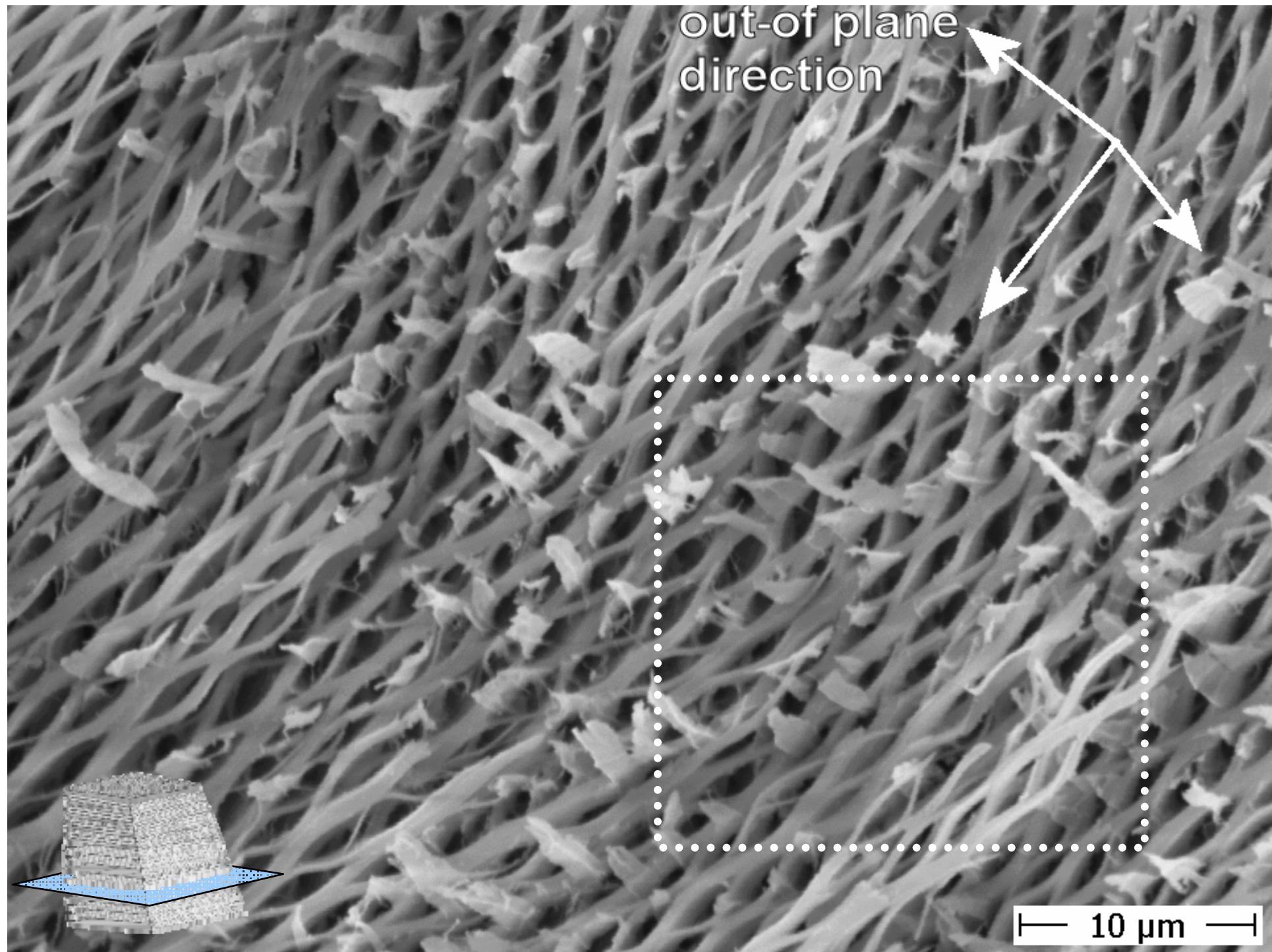


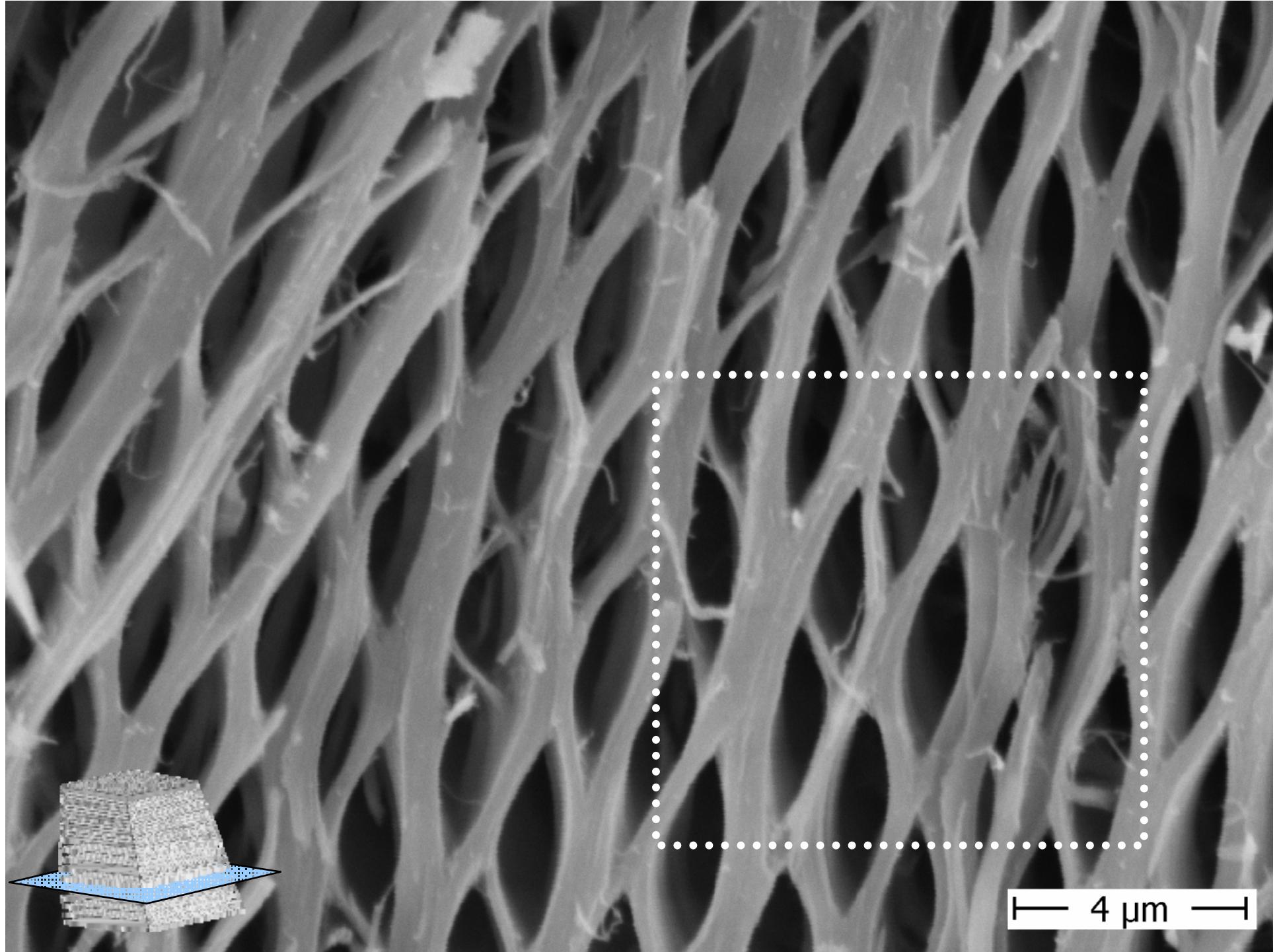
— 100 μm —

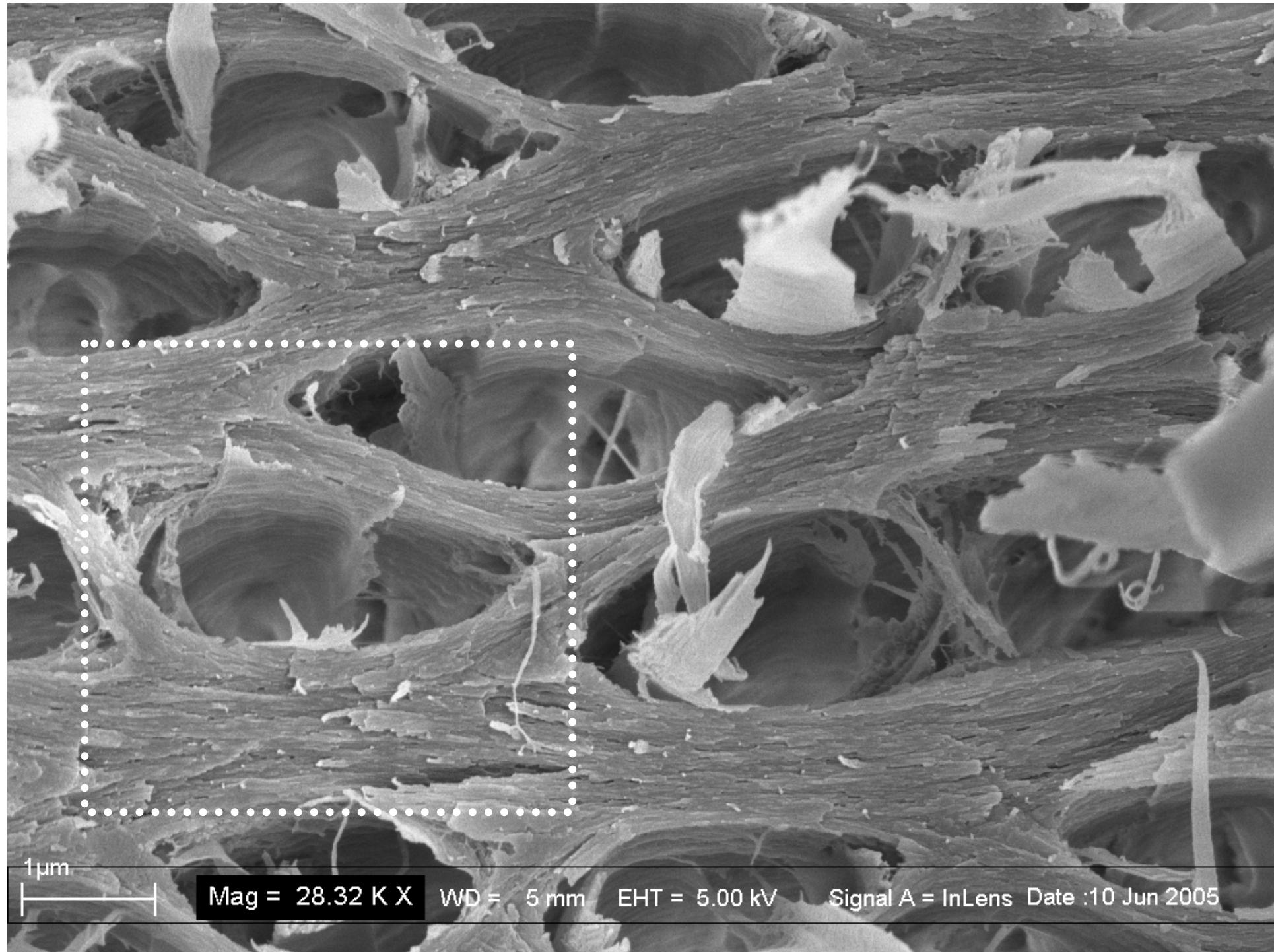




— 20 μm —



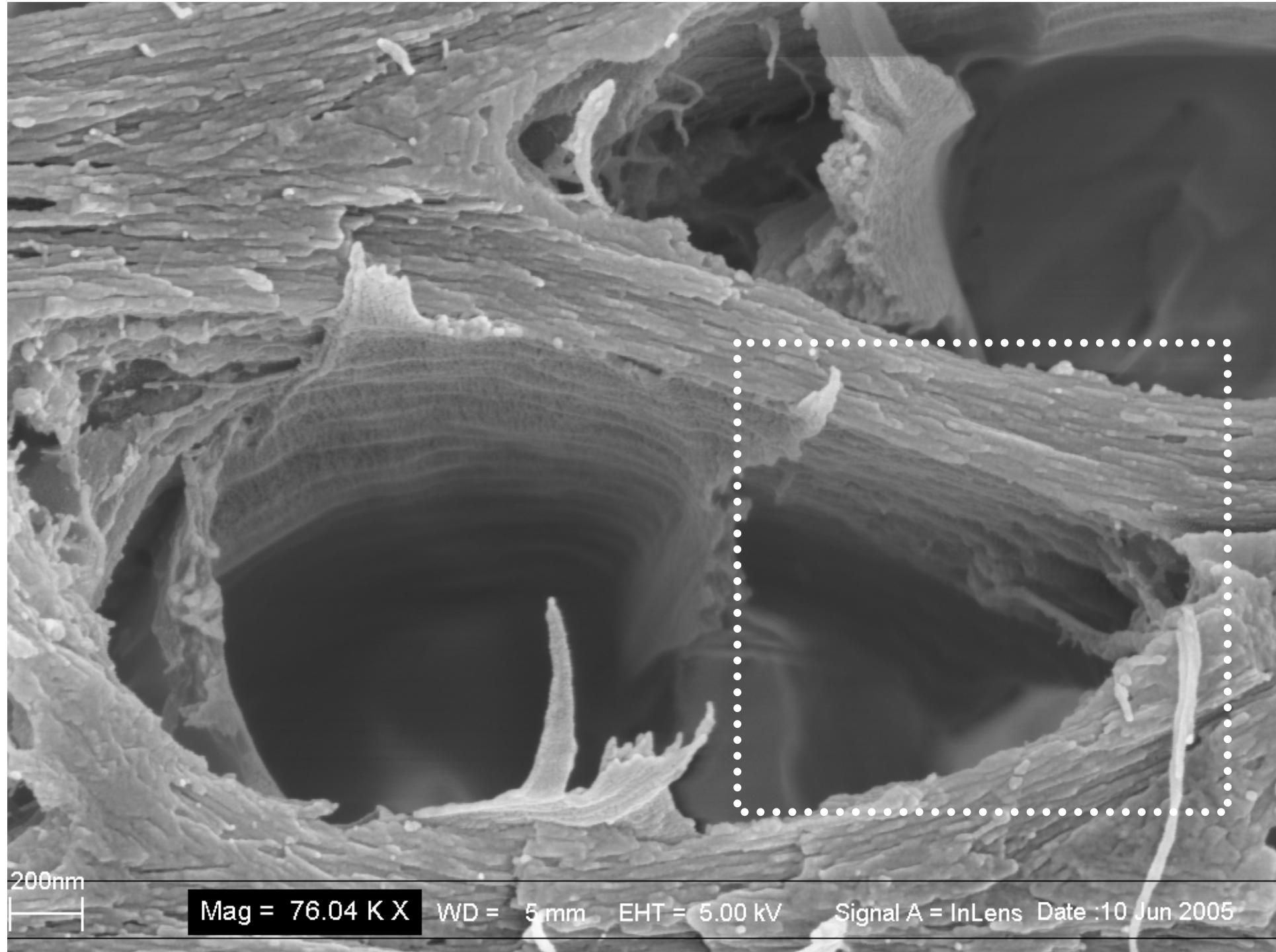




1 μ m



Mag = 28.32 K X WD = 5 mm EHT = 5.00 kV Signal A = InLens Date :10 Jun 2005

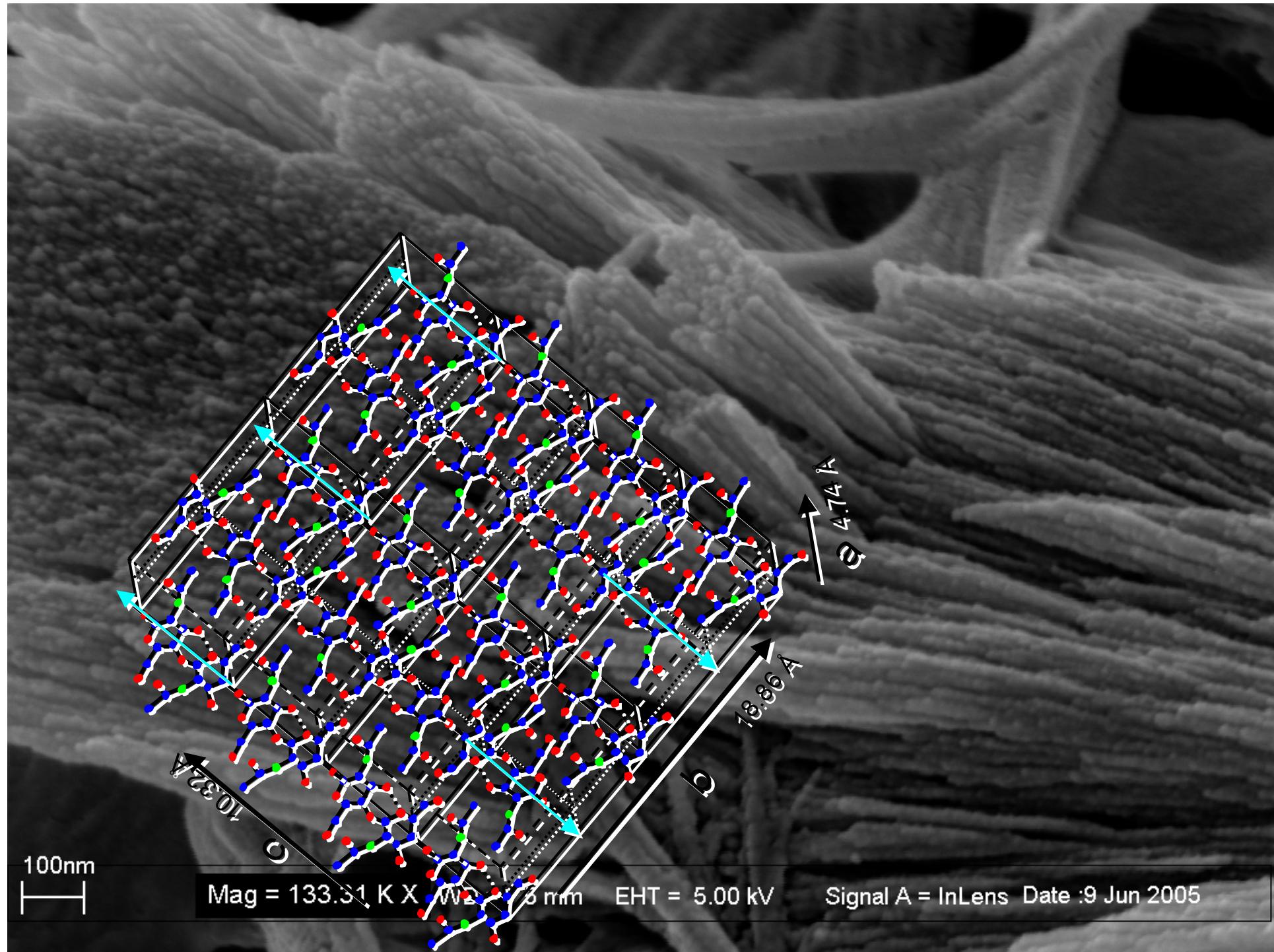


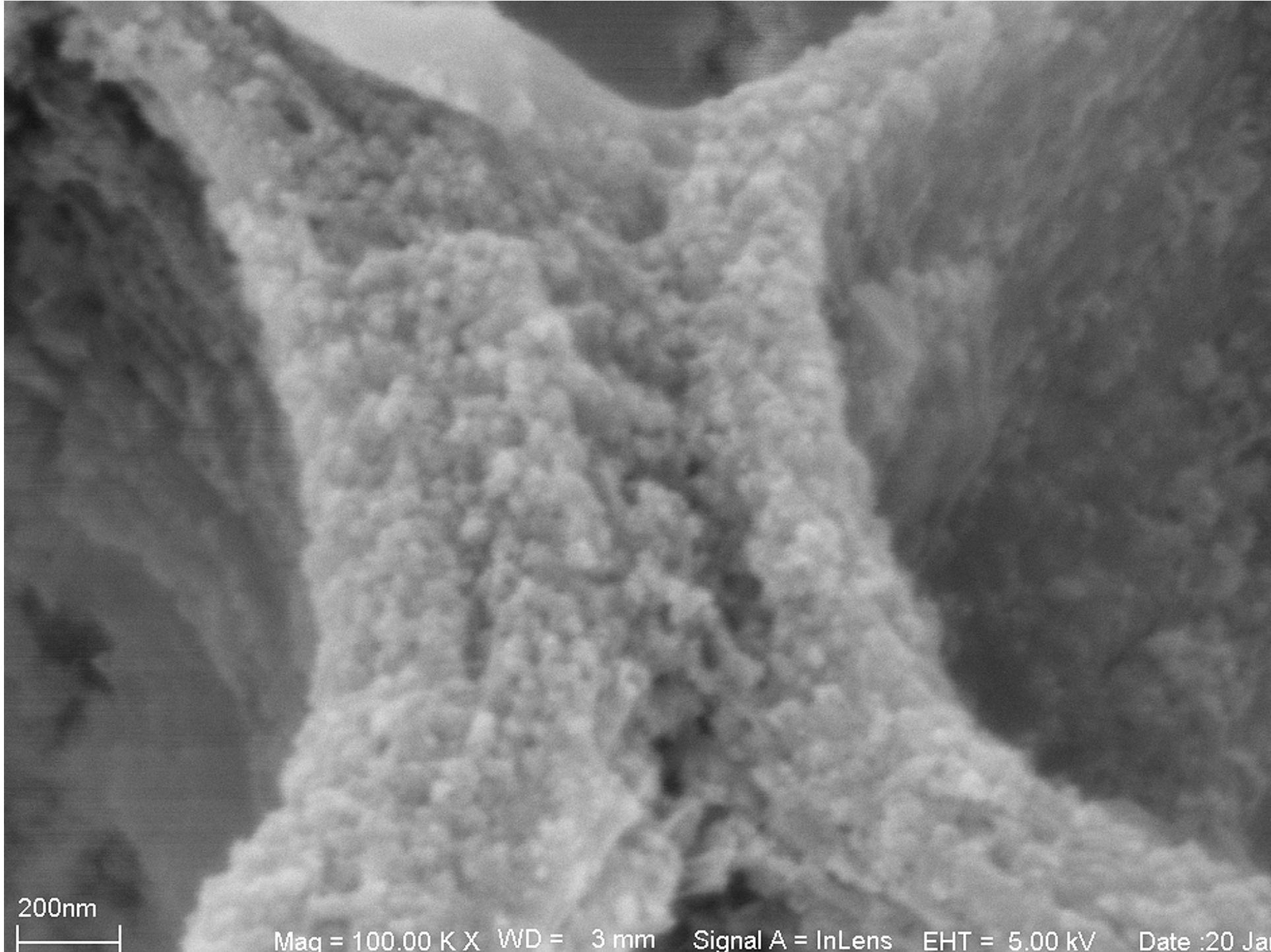
200nm
 A scale bar icon consisting of a horizontal line with a shorter vertical line at its left end.

Mag = 76.04 K X

WD = 5 mm EHT = 5.00 kV

Signal A = InLens Date :10 Jun 2005





200nm

Mag = 100.00 K X WD = 3 mm Signal A = InLens EHT = 5.00 kV Date :20 Ja



3 species as examples

- *Homarus americanus*



- *Carabus auronitens*



- *Chrysophanes virgaurea*



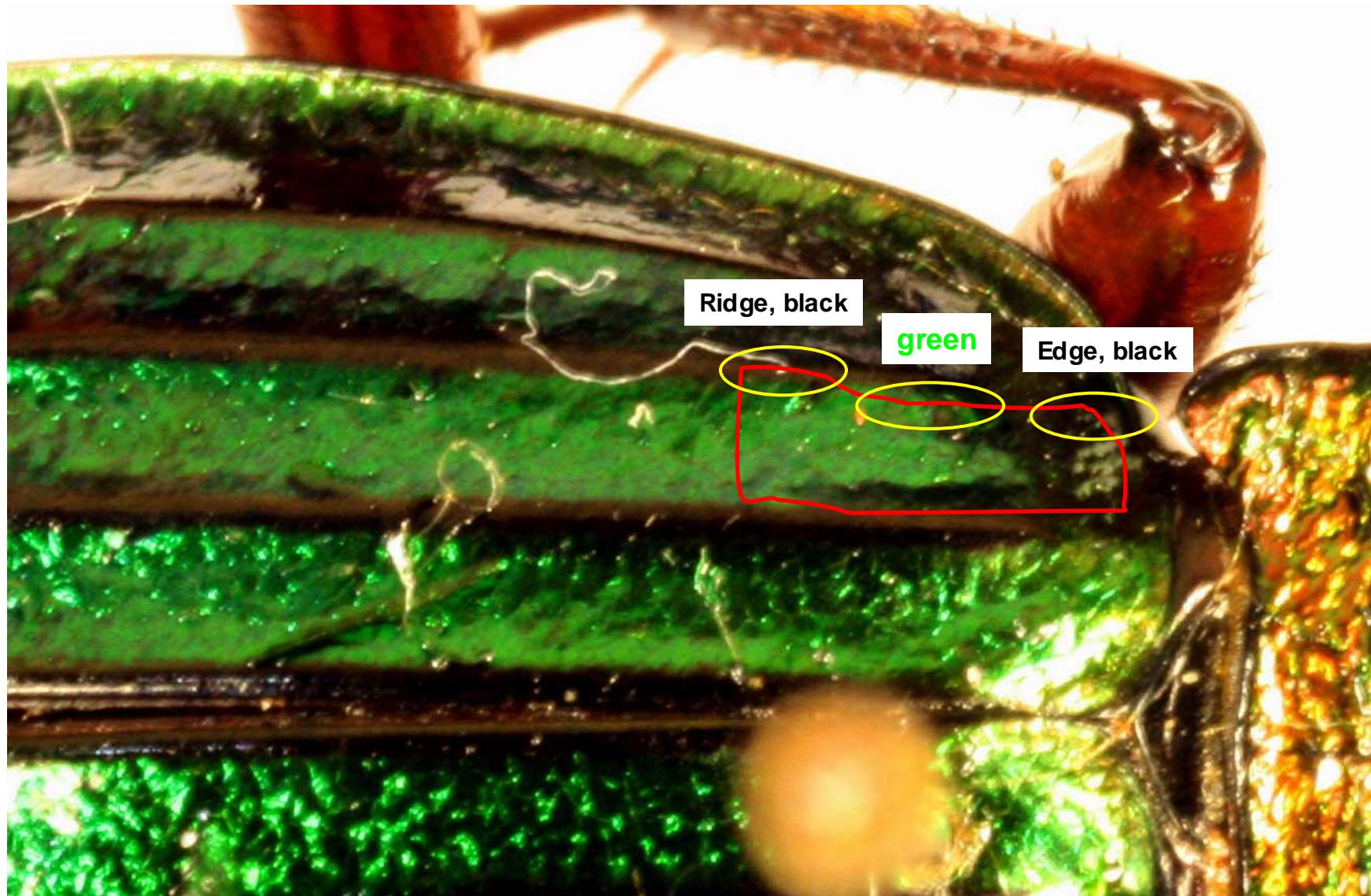


Carabus auronitens



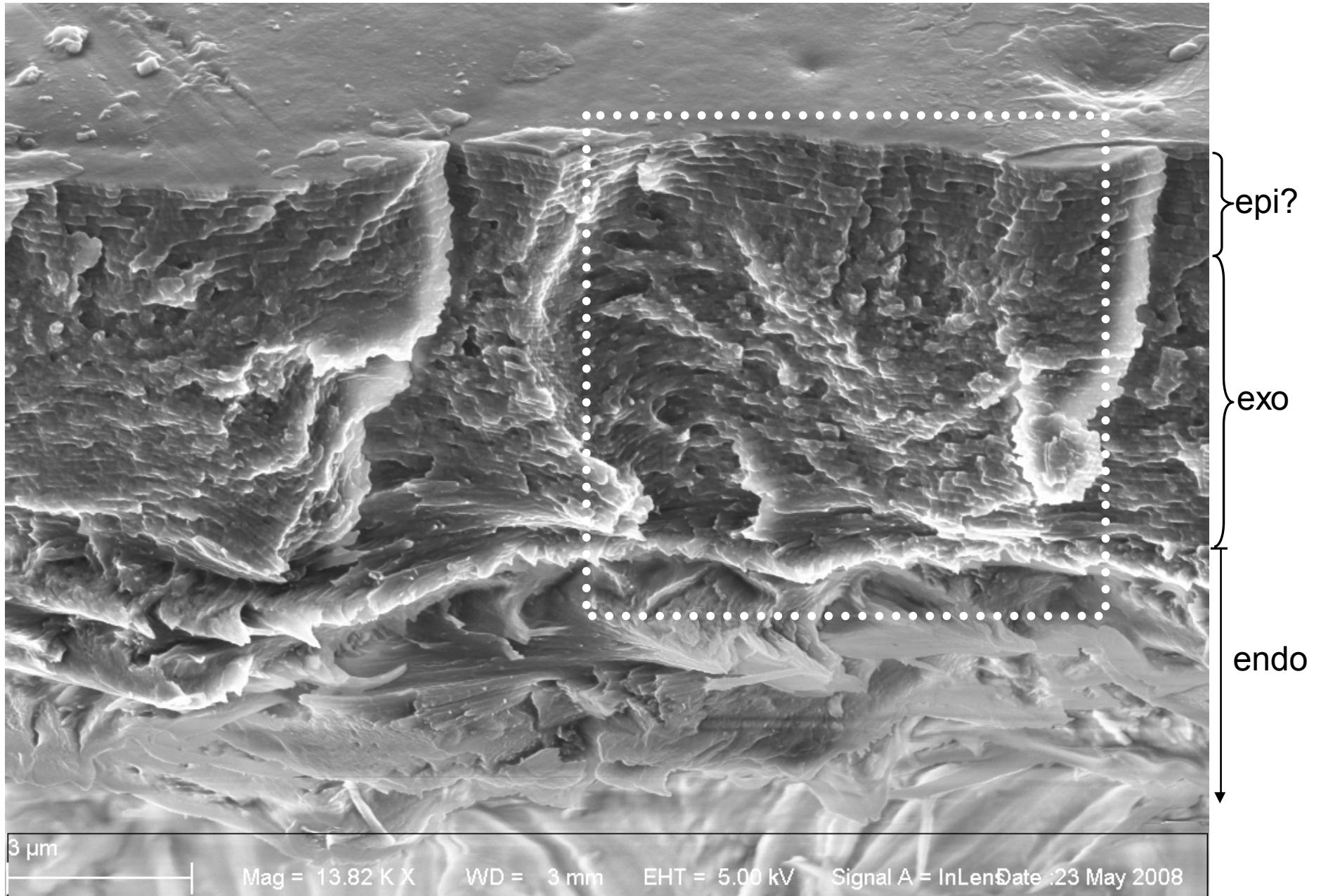


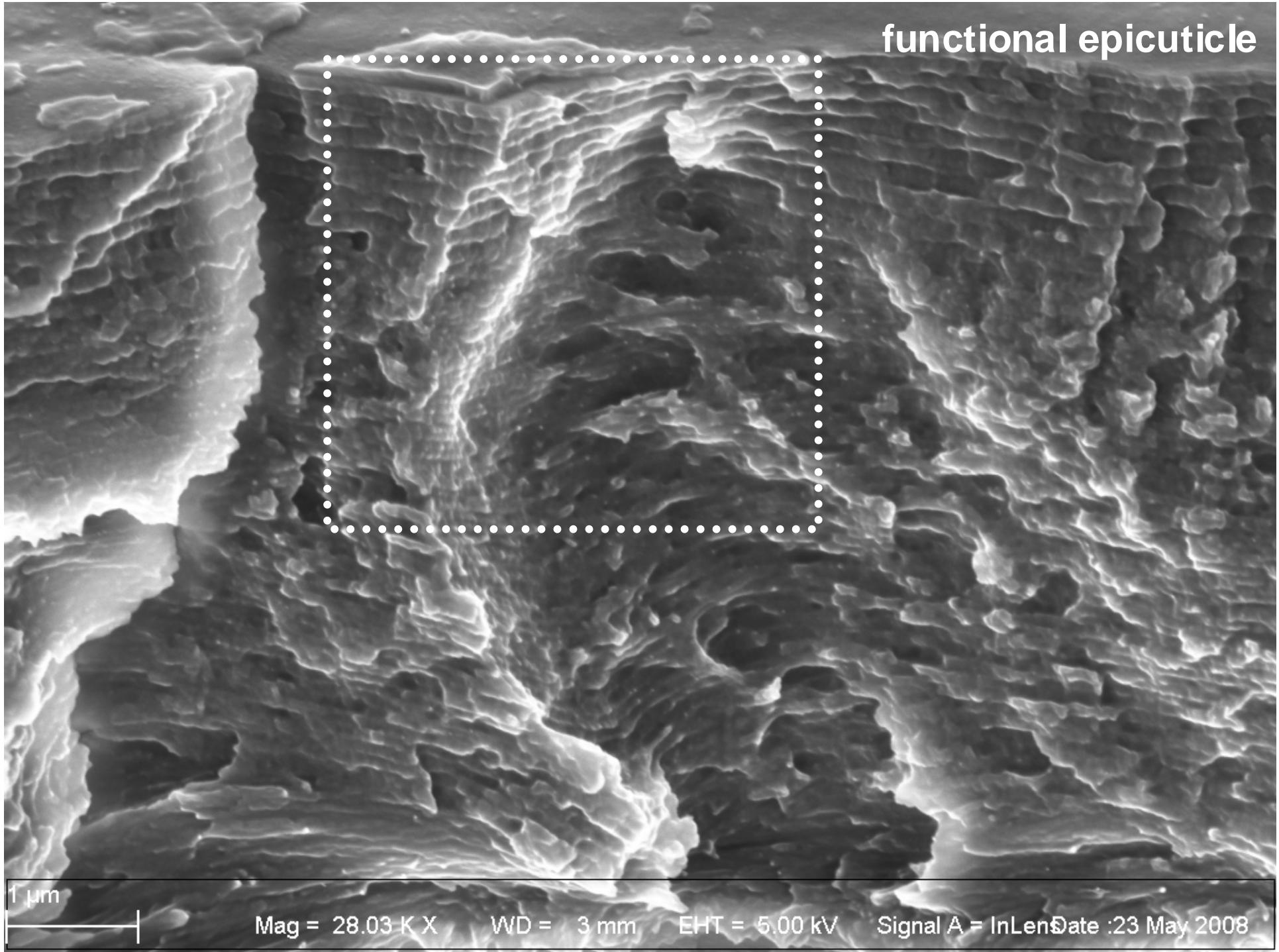
Carabus auronitens





Carabus auronitens

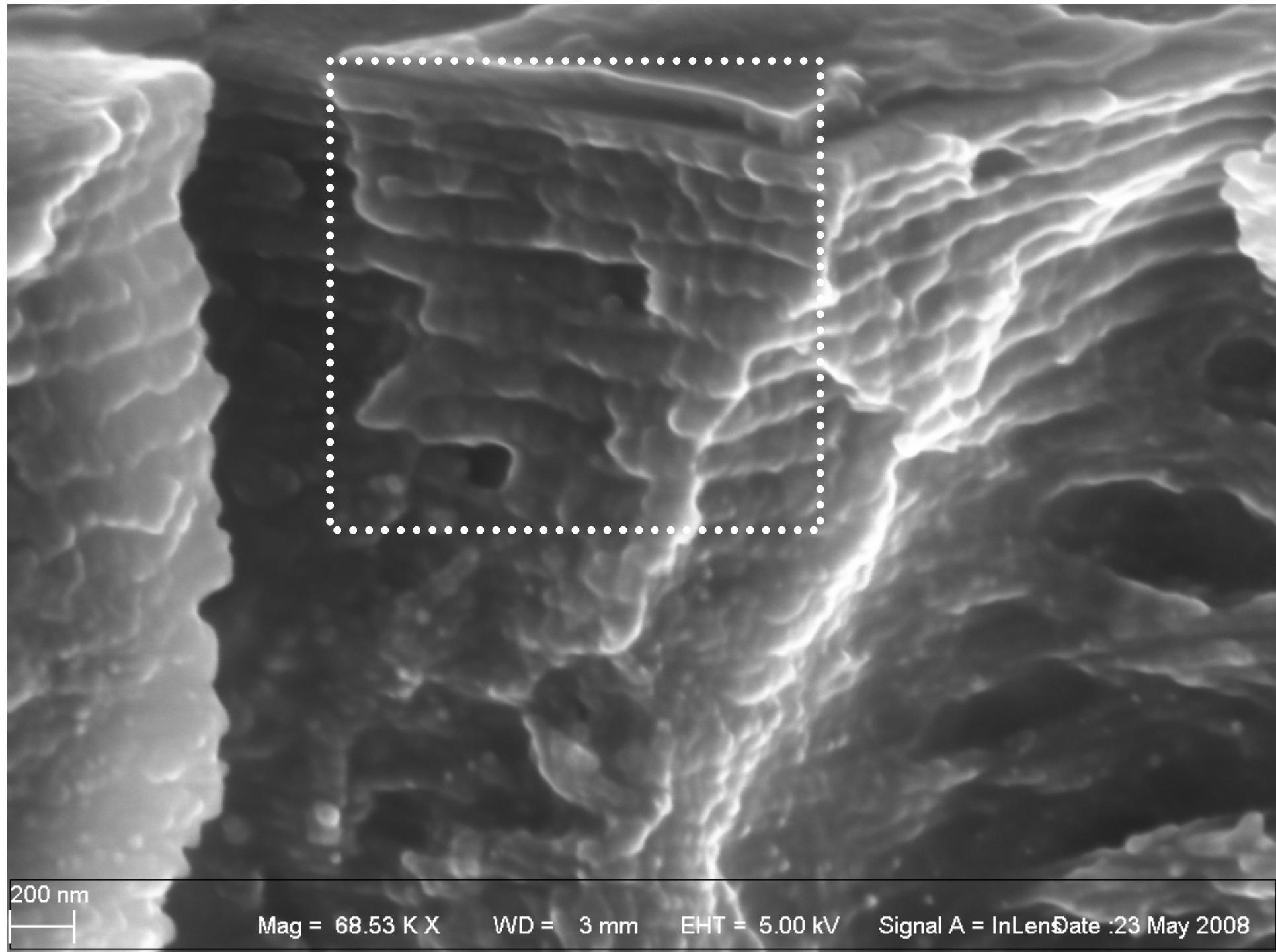




functional epicuticle

1 μm

Mag = 28.03 K X WD = 3 mm EHT = 5.00 kV Signal A = InLen Date :23 May 2008



200 nm

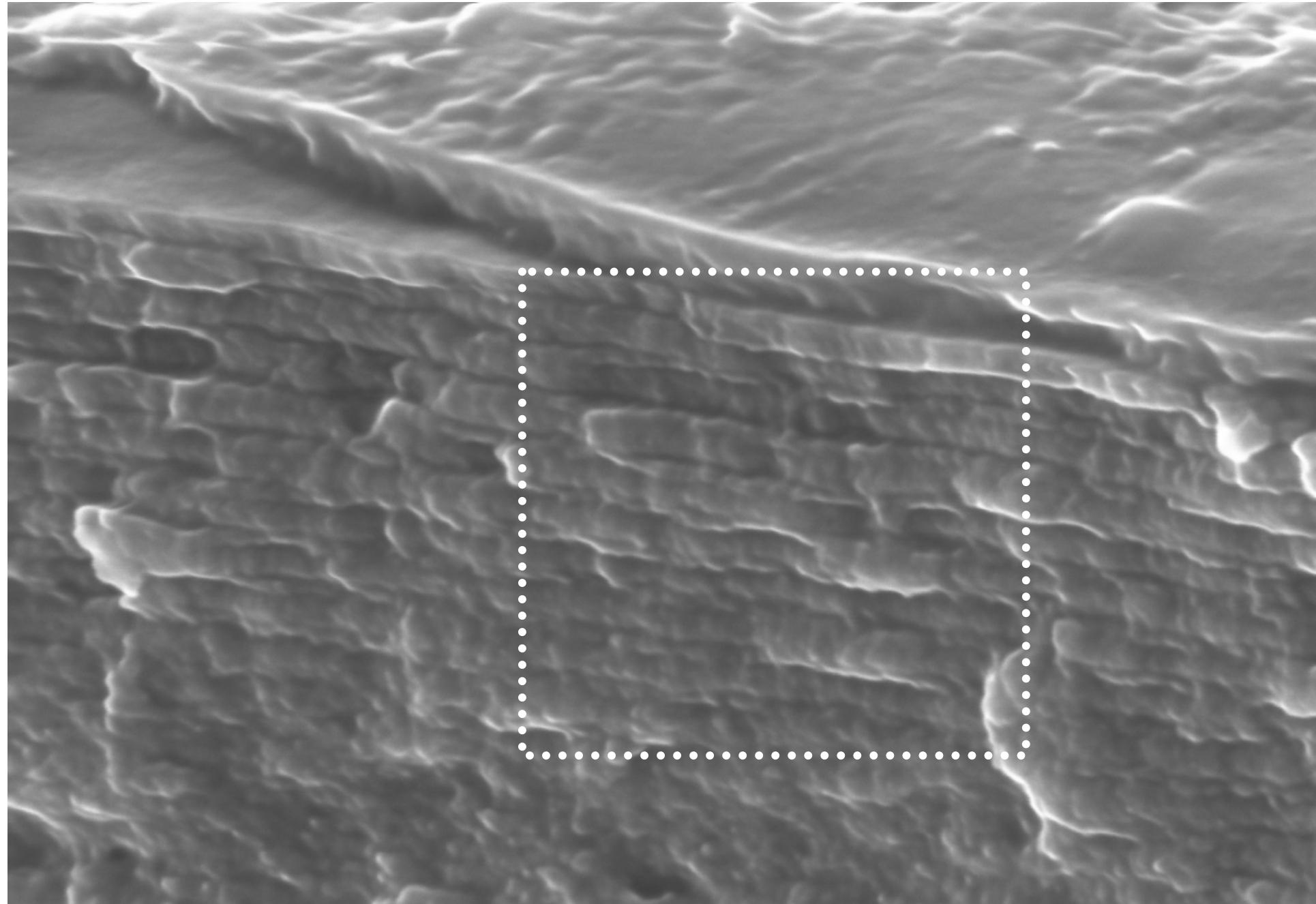


Mag = 68.53 K X

WD = 3 mm

EHT = 5.00 kV

Signal A = InLen Date :23 May 2008



200 nm

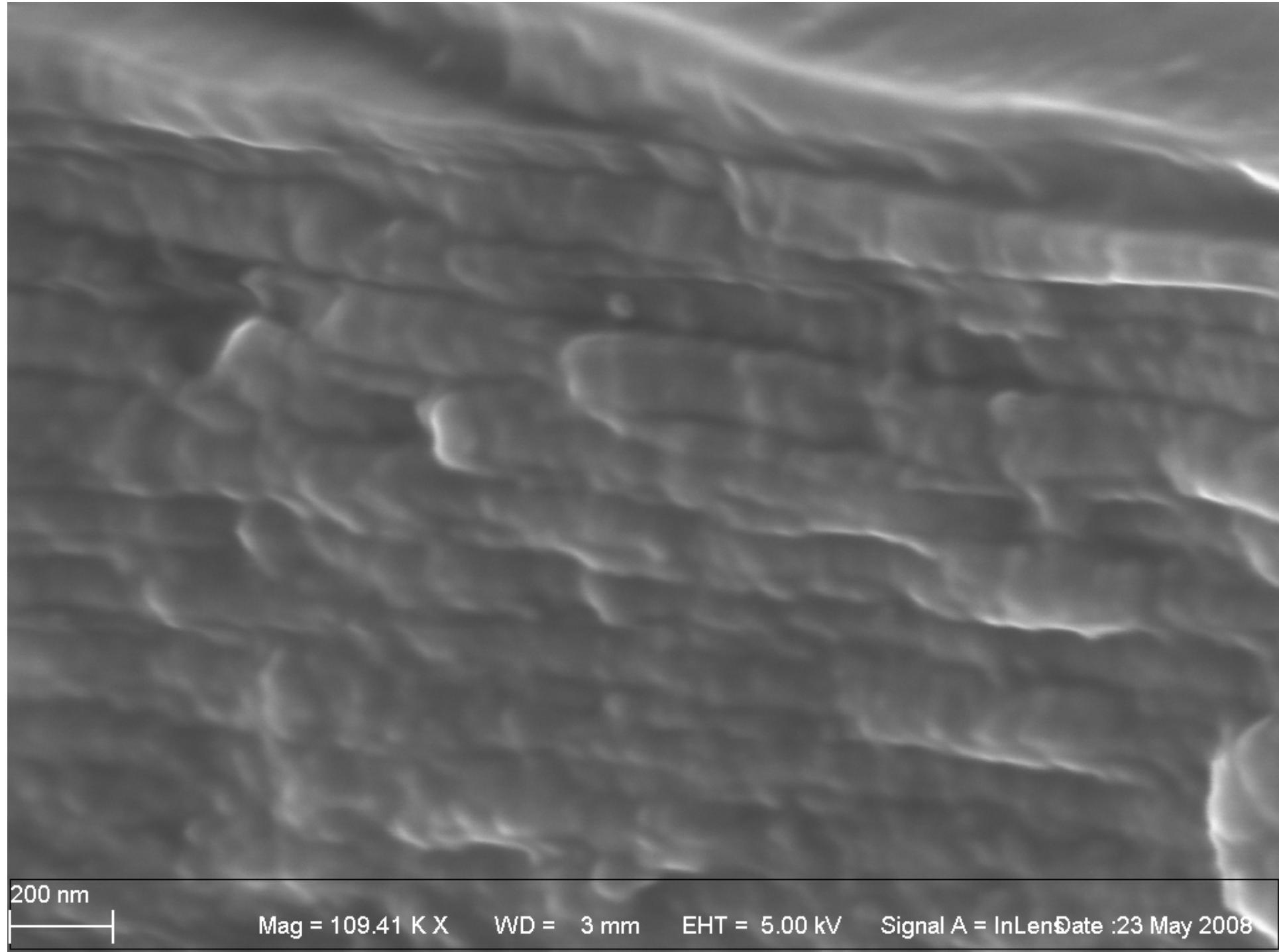


Mag = 65.06 K X

WD = 3 mm

EHT = 5.00 kV

Signal A = InLens Date :23 May 2008



200 nm



Mag = 109.41 K X WD = 3 mm EHT = 5.00 kV Signal A = InLen Date :23 May 2008



3 species as examples

- *Homarus americanus*



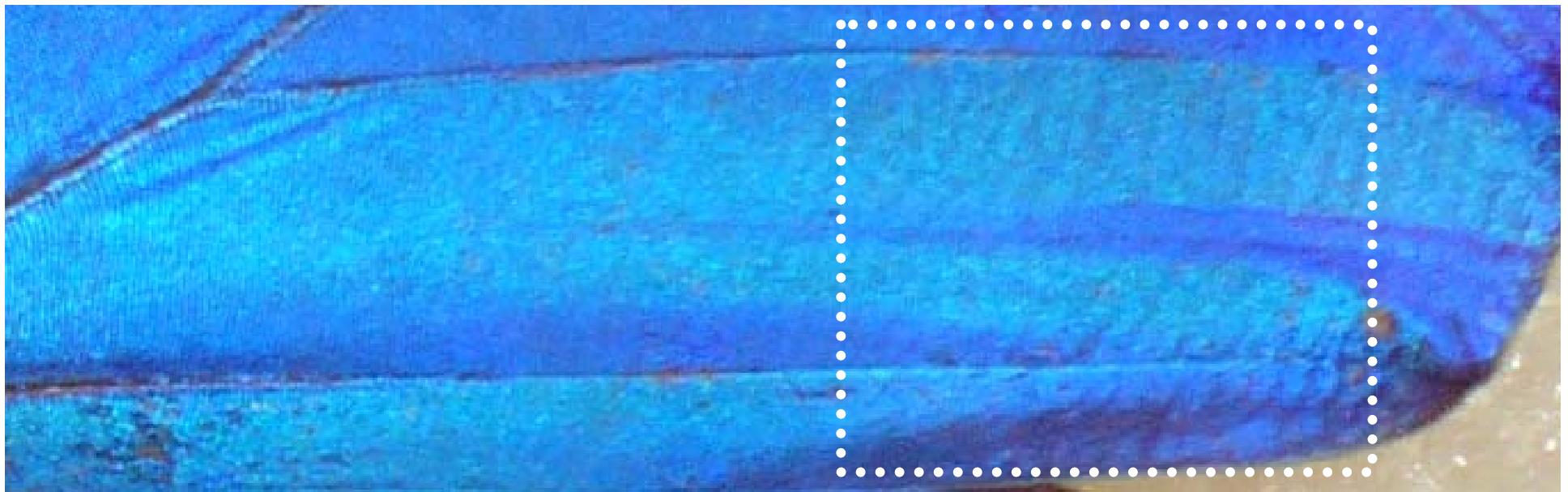
- *Carabus auronitens*

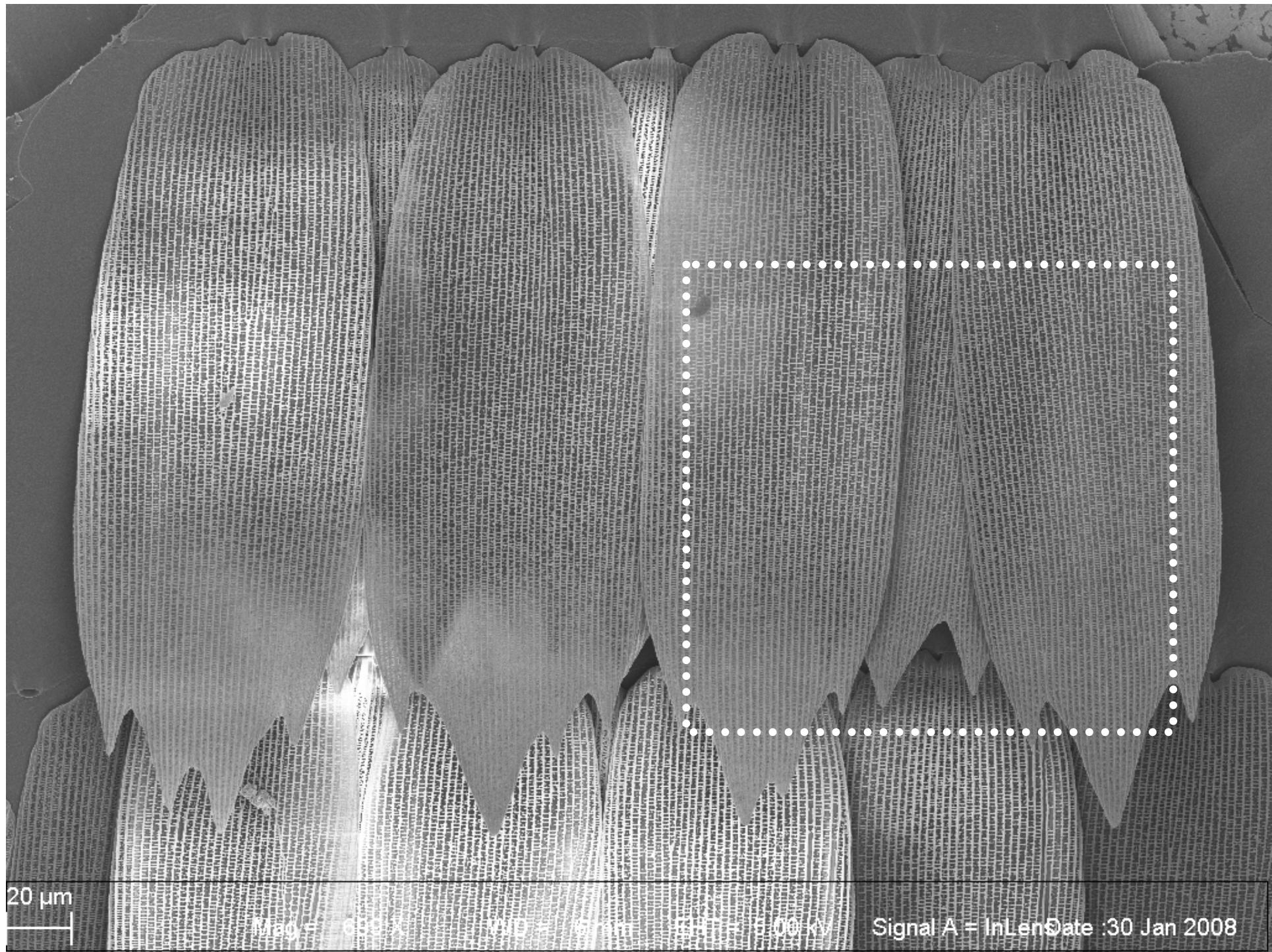


- *Chrysophanes virgaurea*







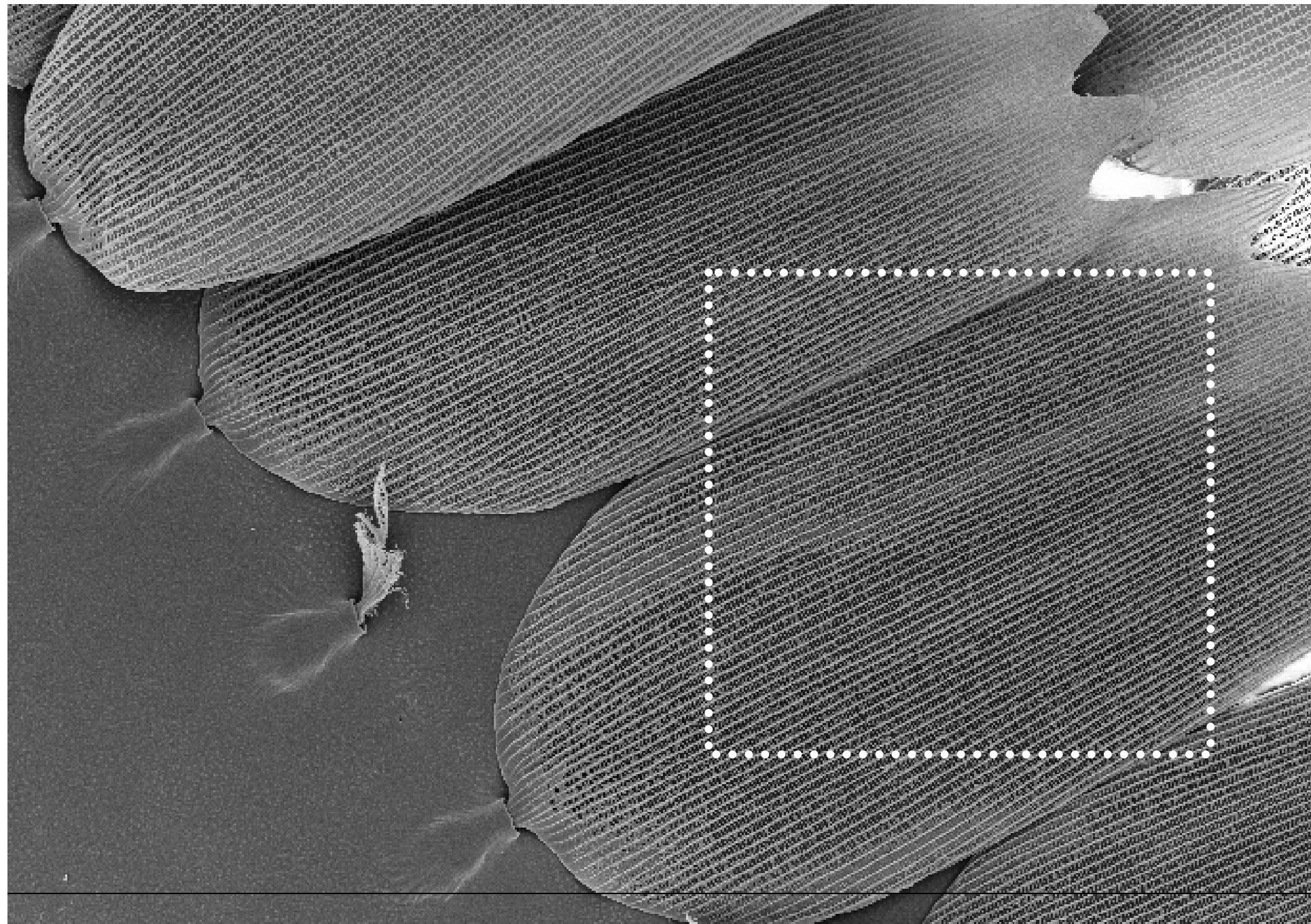


20 μ m

Mag:

100 kV

Signal A = InLenDate :30 Jan 2008

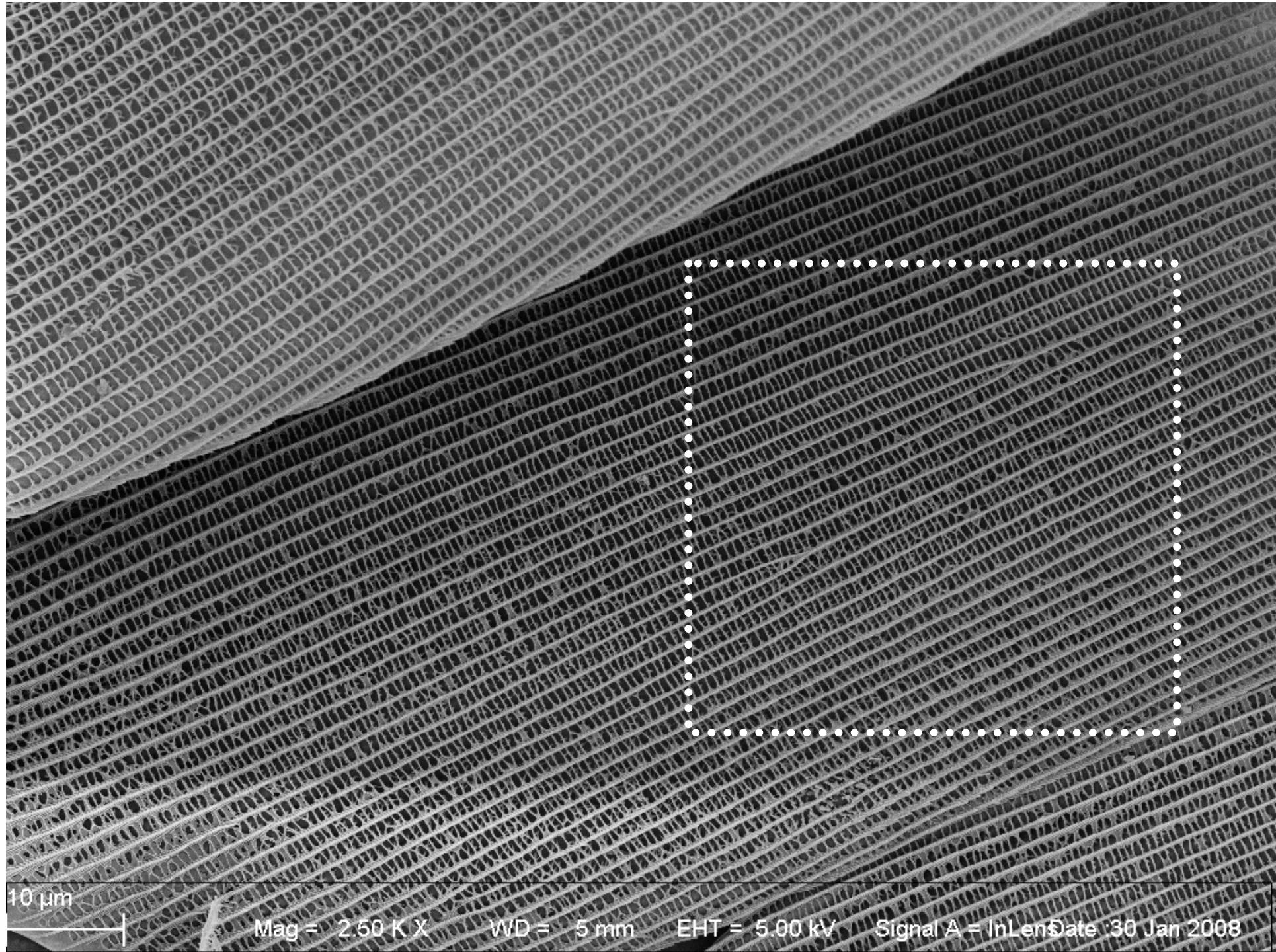


Mag = 800 X

WD = 5 mm

EHT = 5.00 kV

Signal A = InLensDate



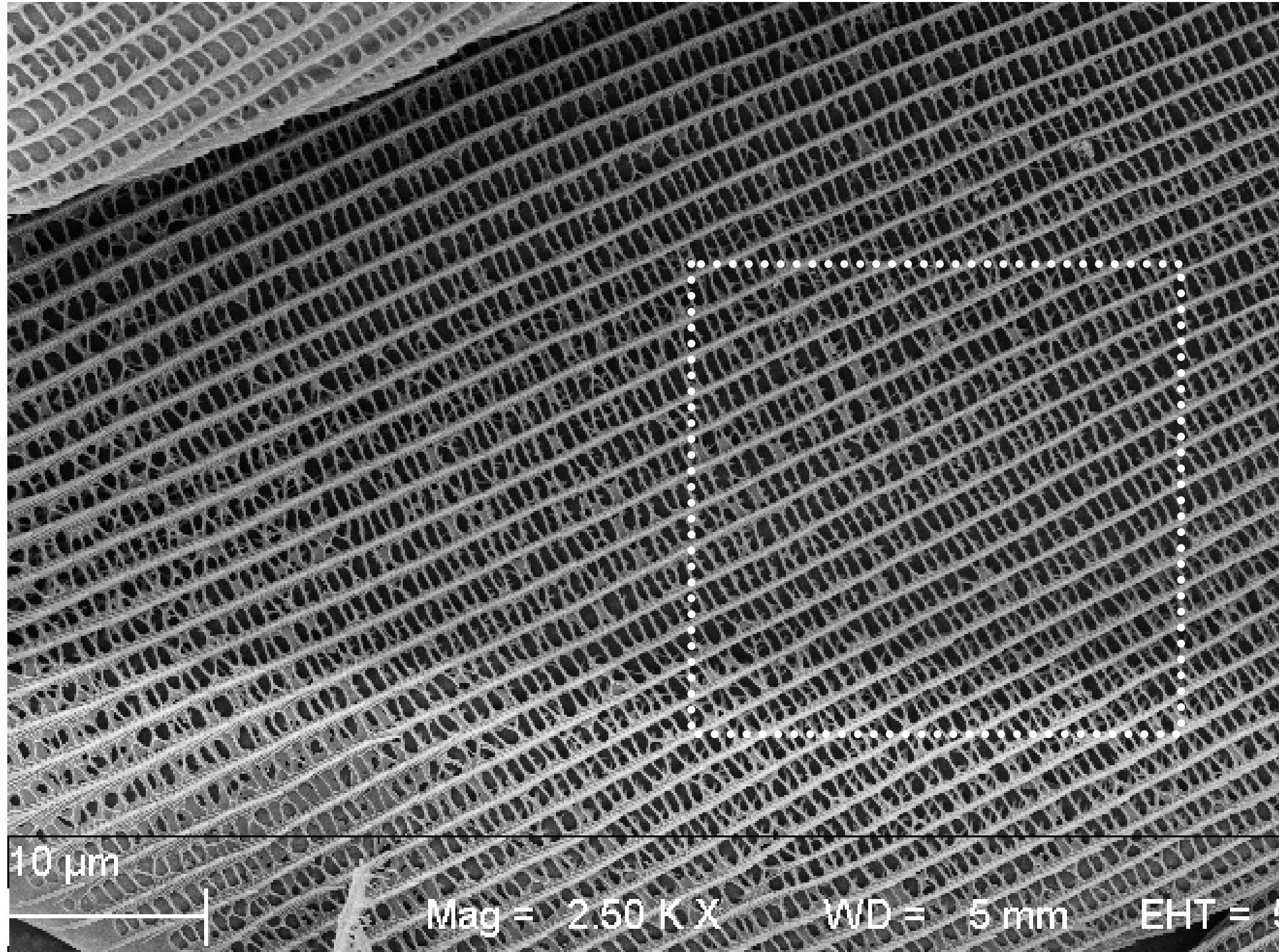
10 μm

Mag = 2.50 KX

WD = 5 mm

EHT = 5.00 kV

Signal A = InLensDate : 30 Jan 2008

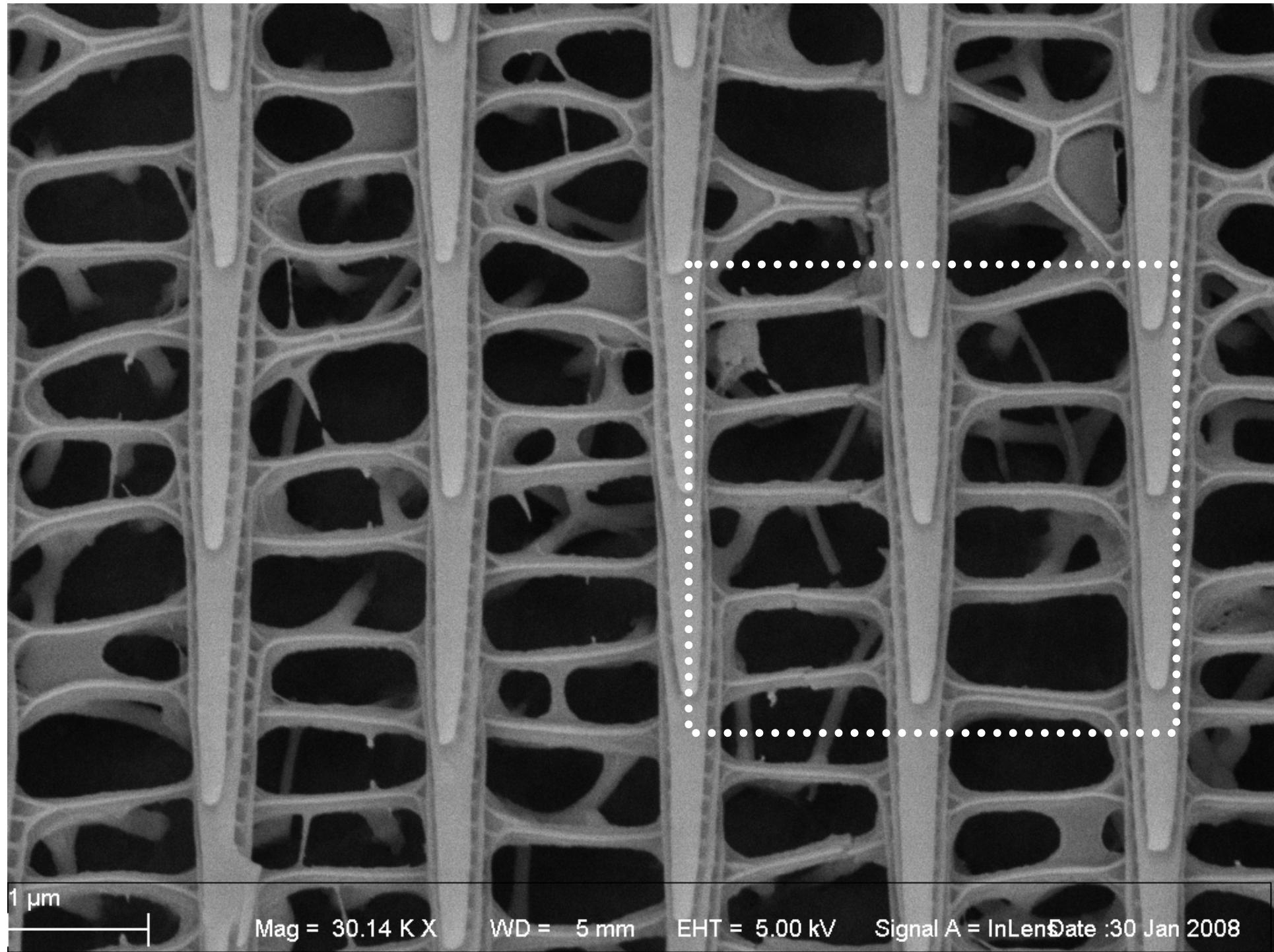


10 μm

Mag = 2.50 Kx

WD = 5 mm

EHT =



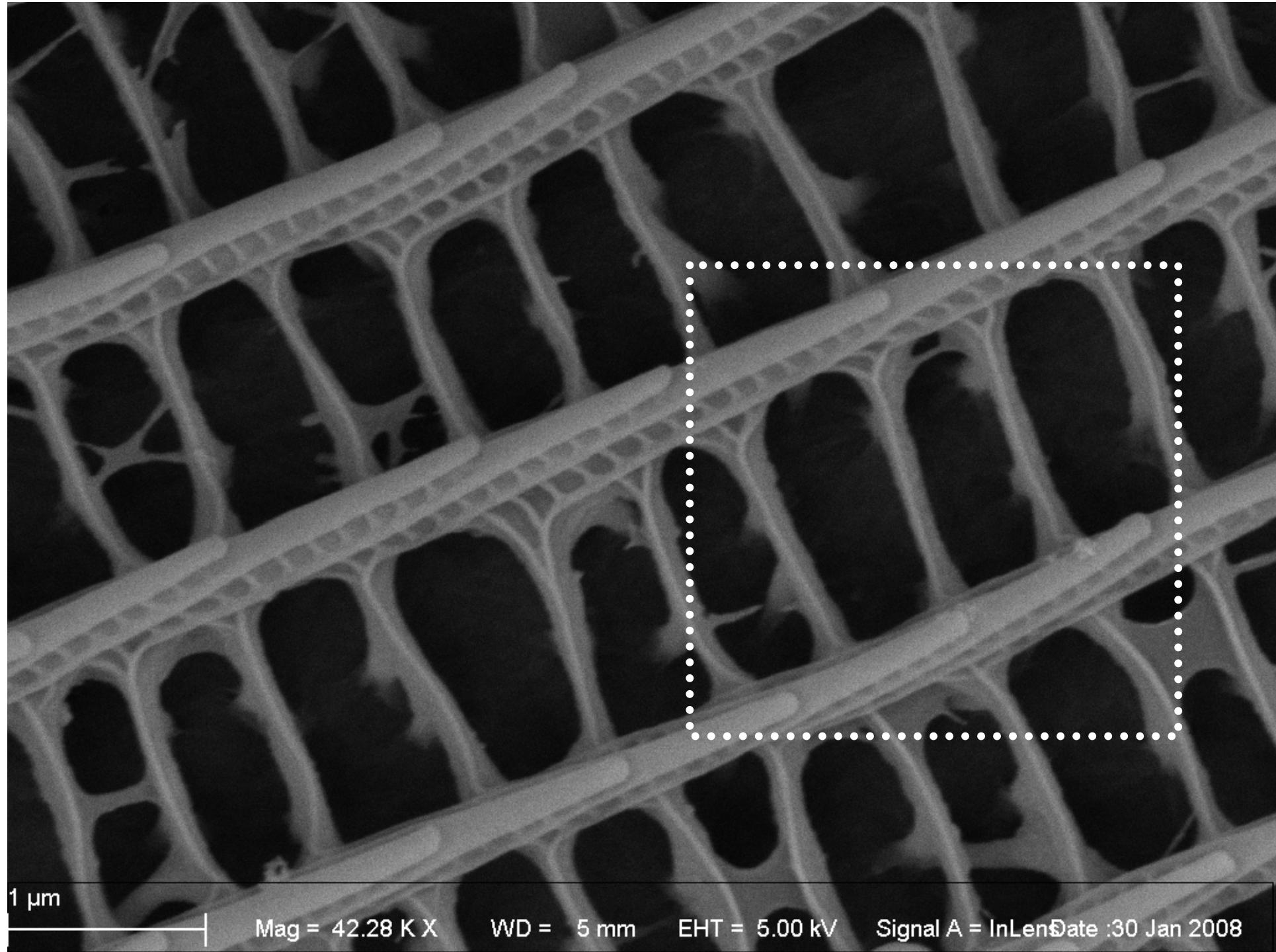
1 μ m

Mag = 30.14 K X

WD = 5 mm

EHT = 5.00 kV

Signal A = InLens Date :30 Jan 2008



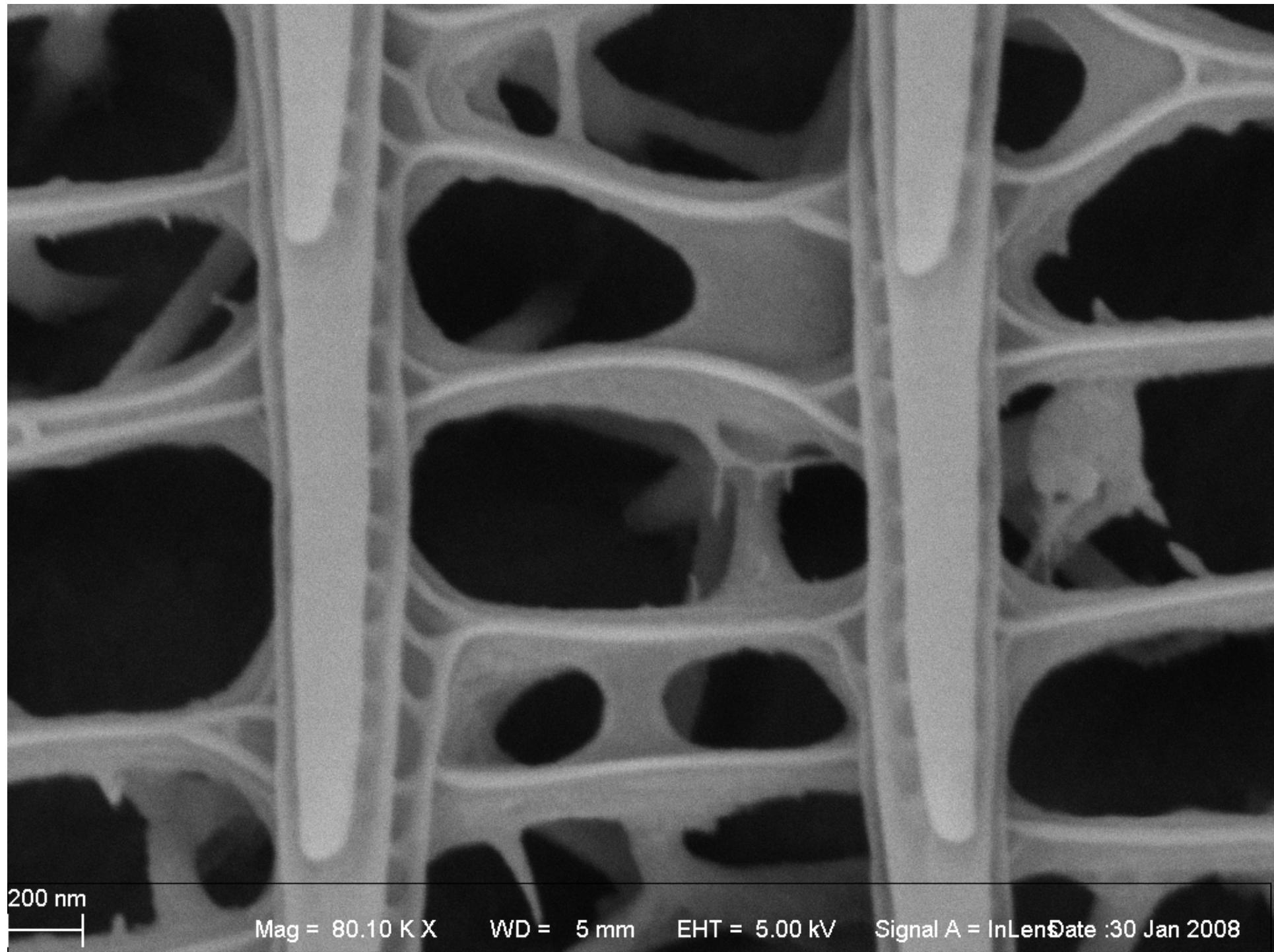
1 μm

Mag = 42.28 K X

WD = 5 mm

EHT = 5.00 kV

Signal A = InLenDate :30 Jan 2008



200 nm

Mag = 80.10 K X WD = 5 mm EHT = 5.00 kV Signal A = InLen Date :30 Jan 2008



Overview

Motivation

Textures

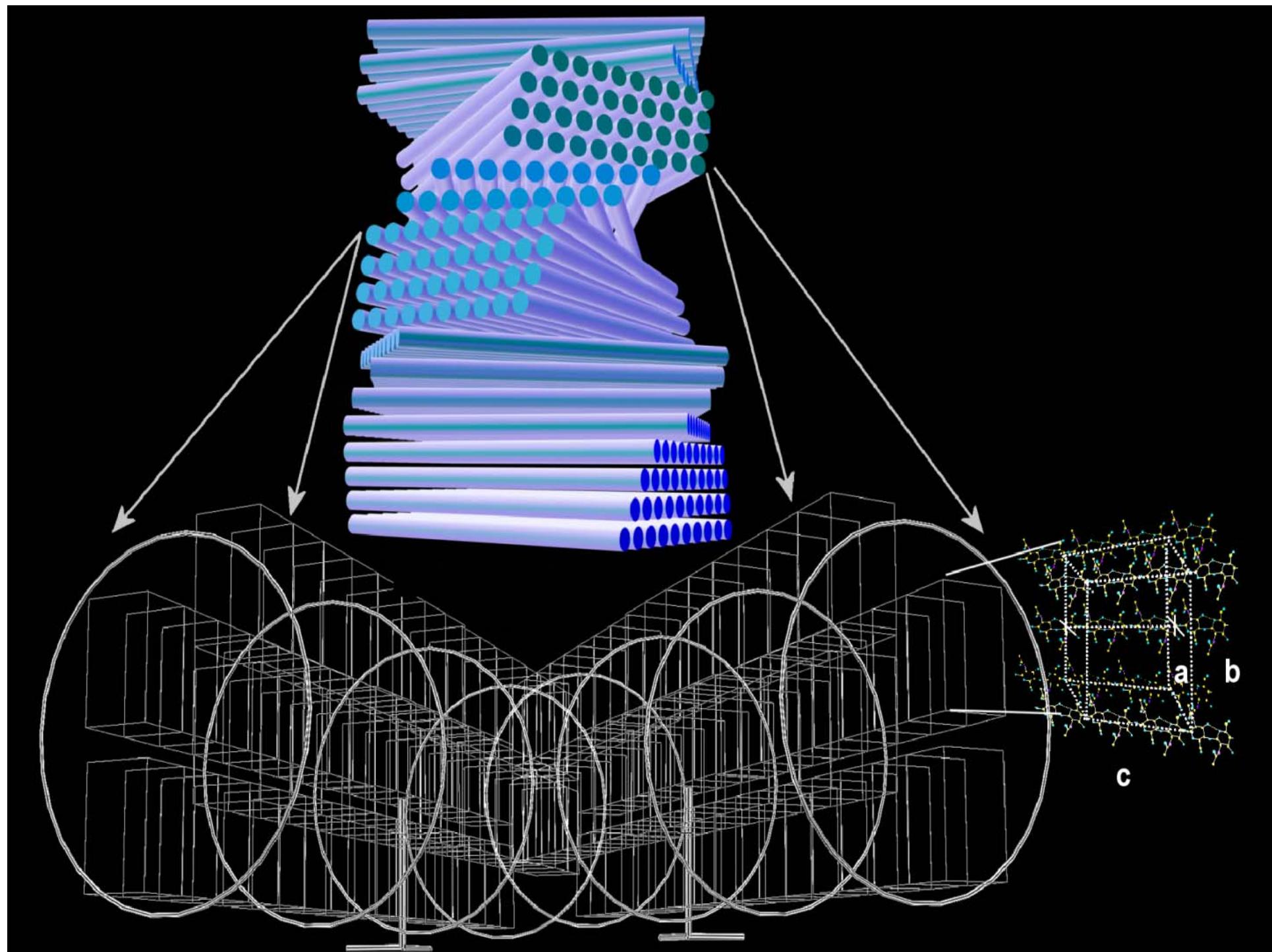
- Topological and hierarchical organization
- Crystallographic textures



Mechanical properties

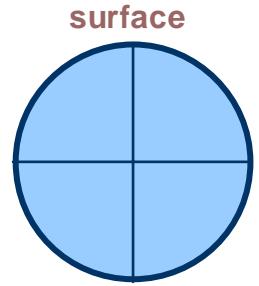
- Macroscopic
- Microscopic

Conclusions

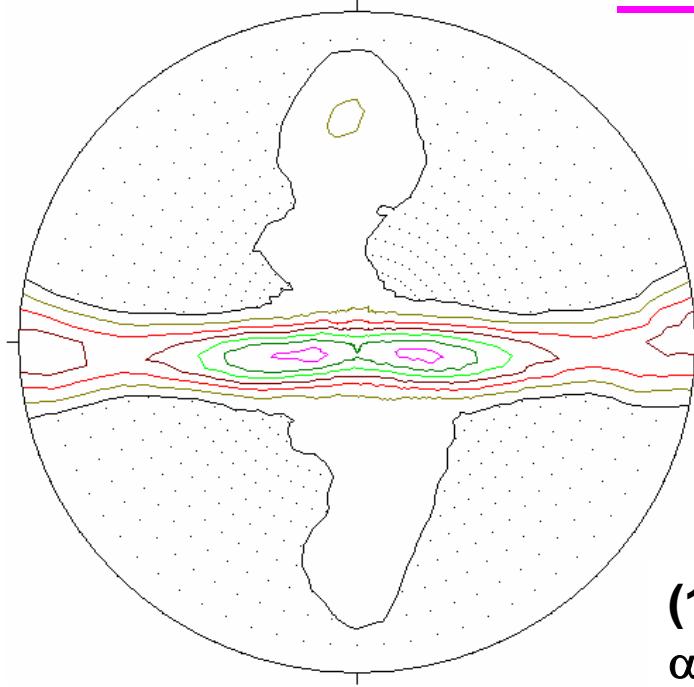




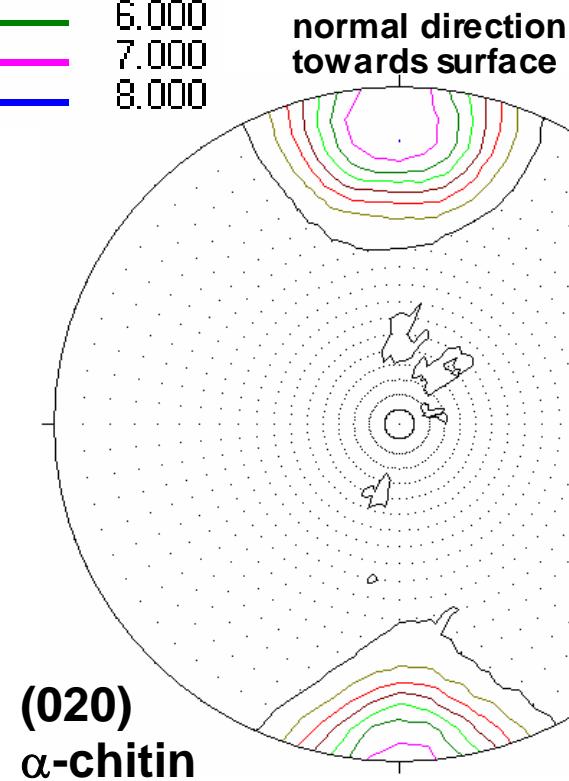
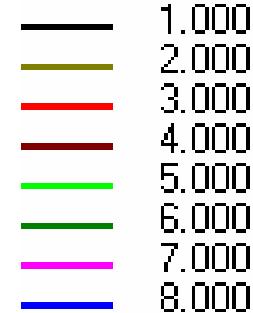
Synchrotron x-ray wide angle, lobster, chitin



normal direction
towards surface

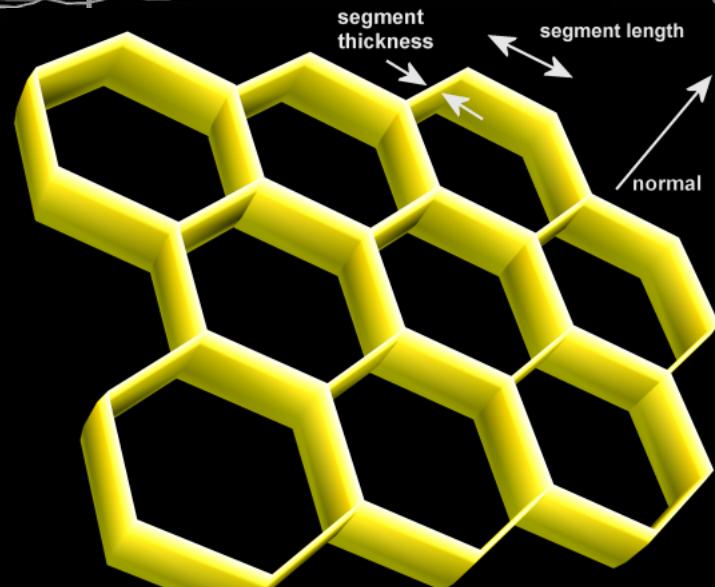
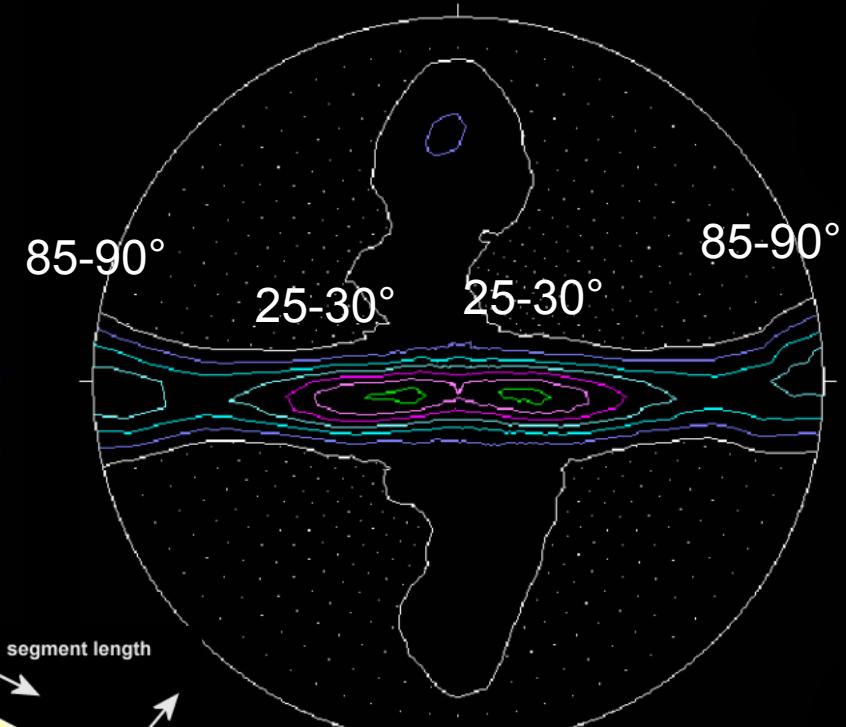
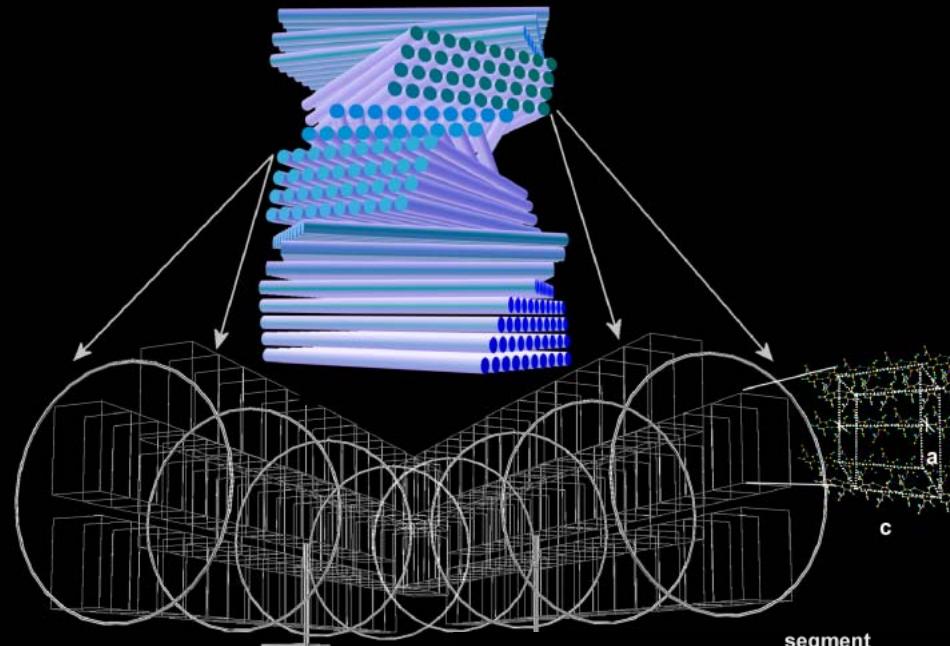


cross direction
within section



normal direction
towards surface

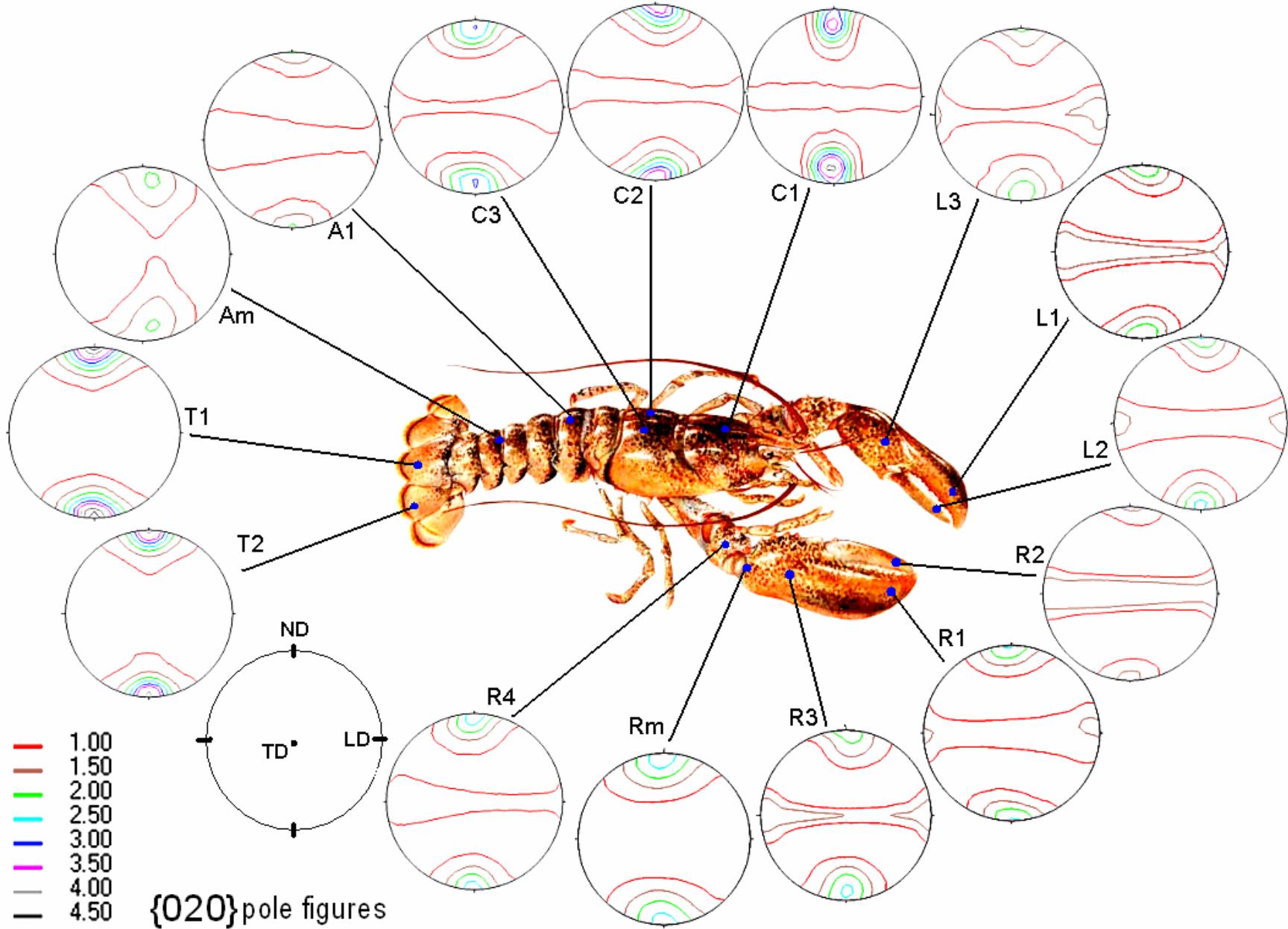
Structure and texture of chitin

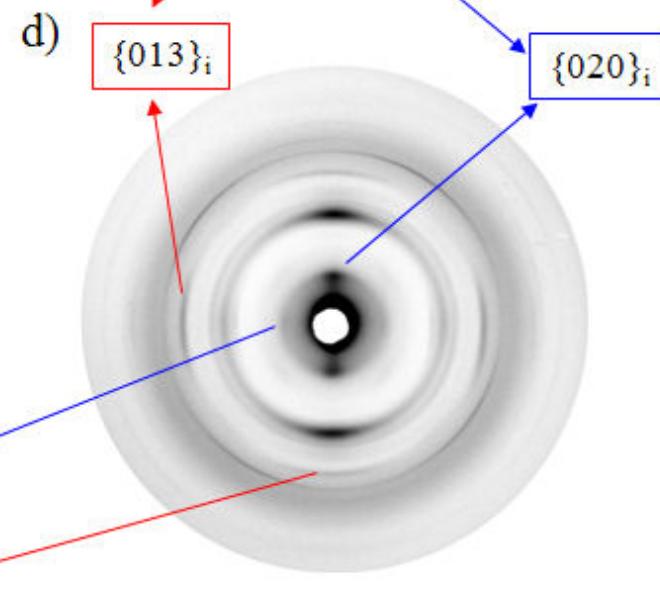
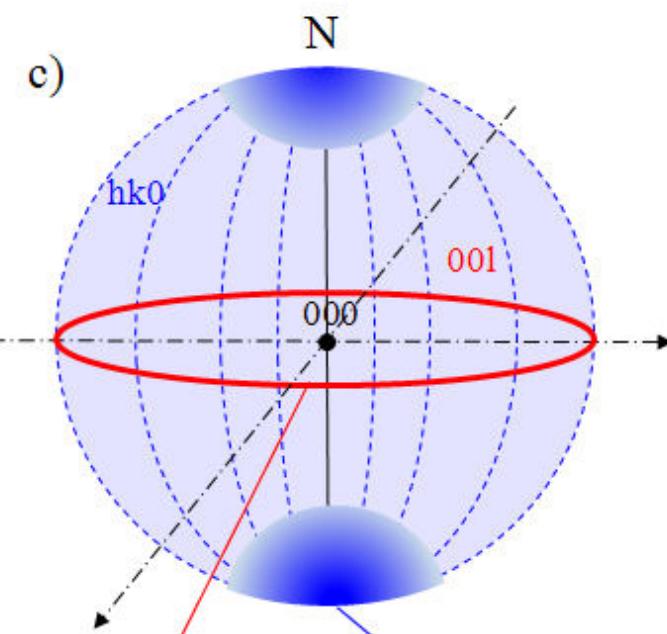
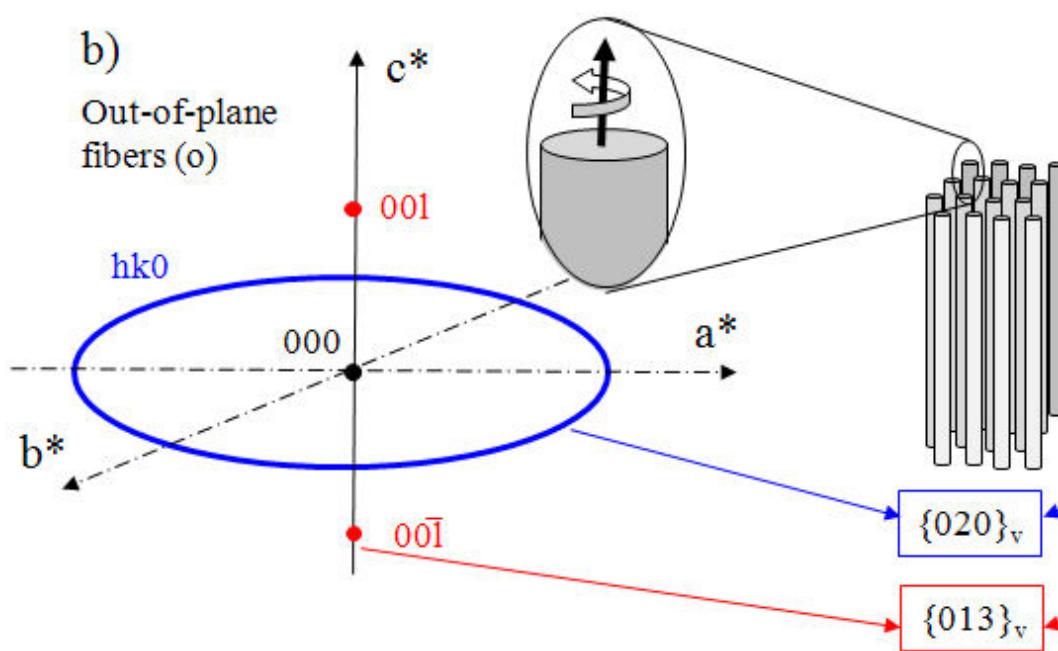
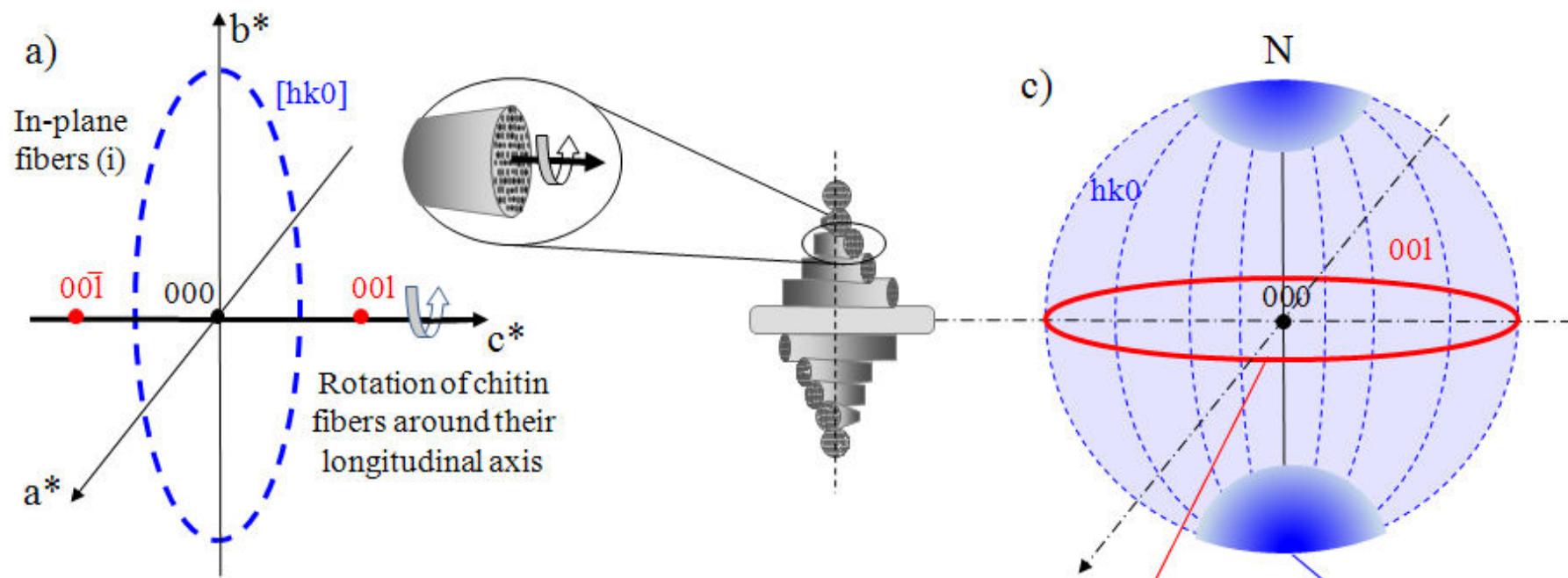


(100)
 α -chitin



Synchrotron x-ray wide angle, lobster, chitin







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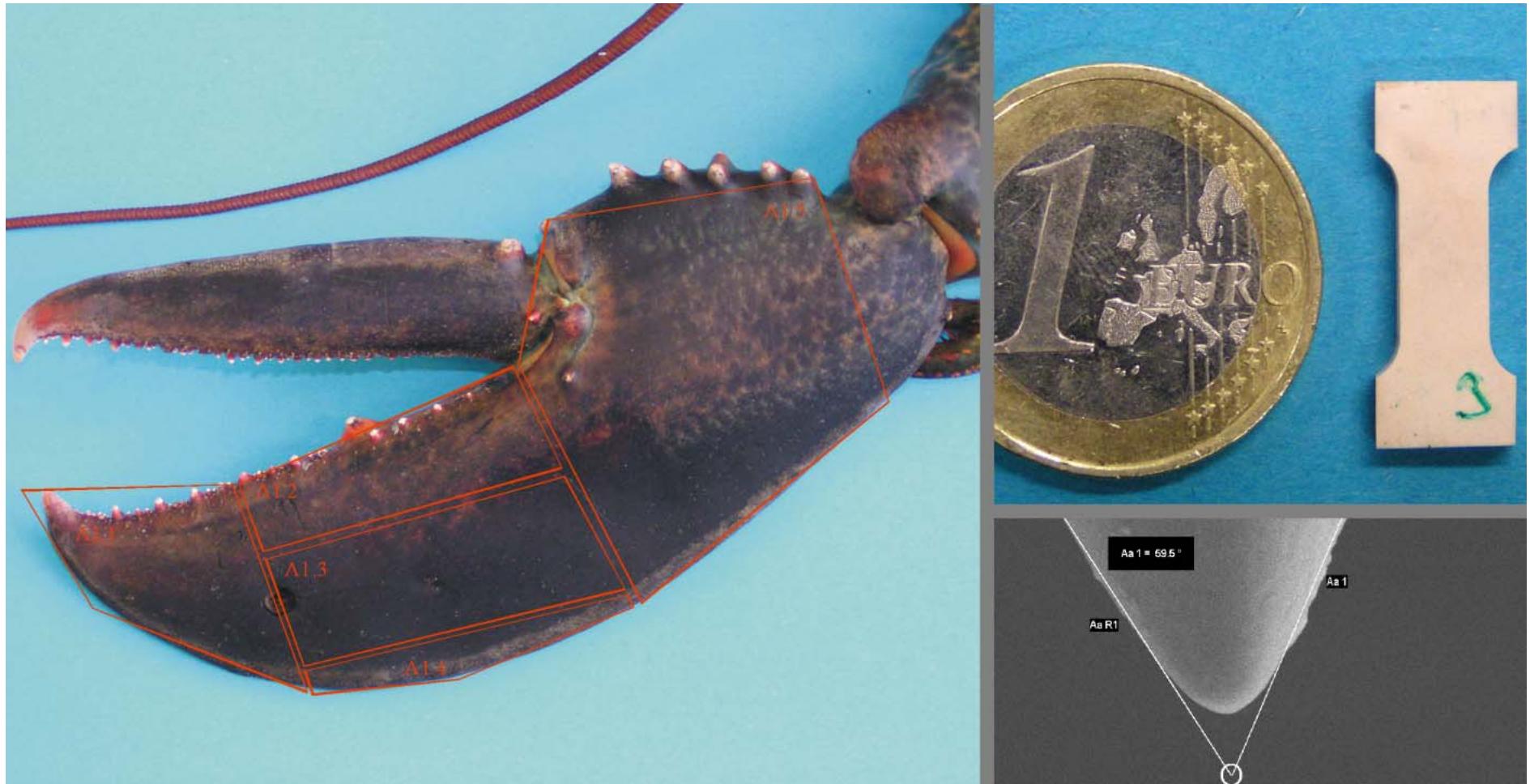


- Macroscopic
- Microscopic

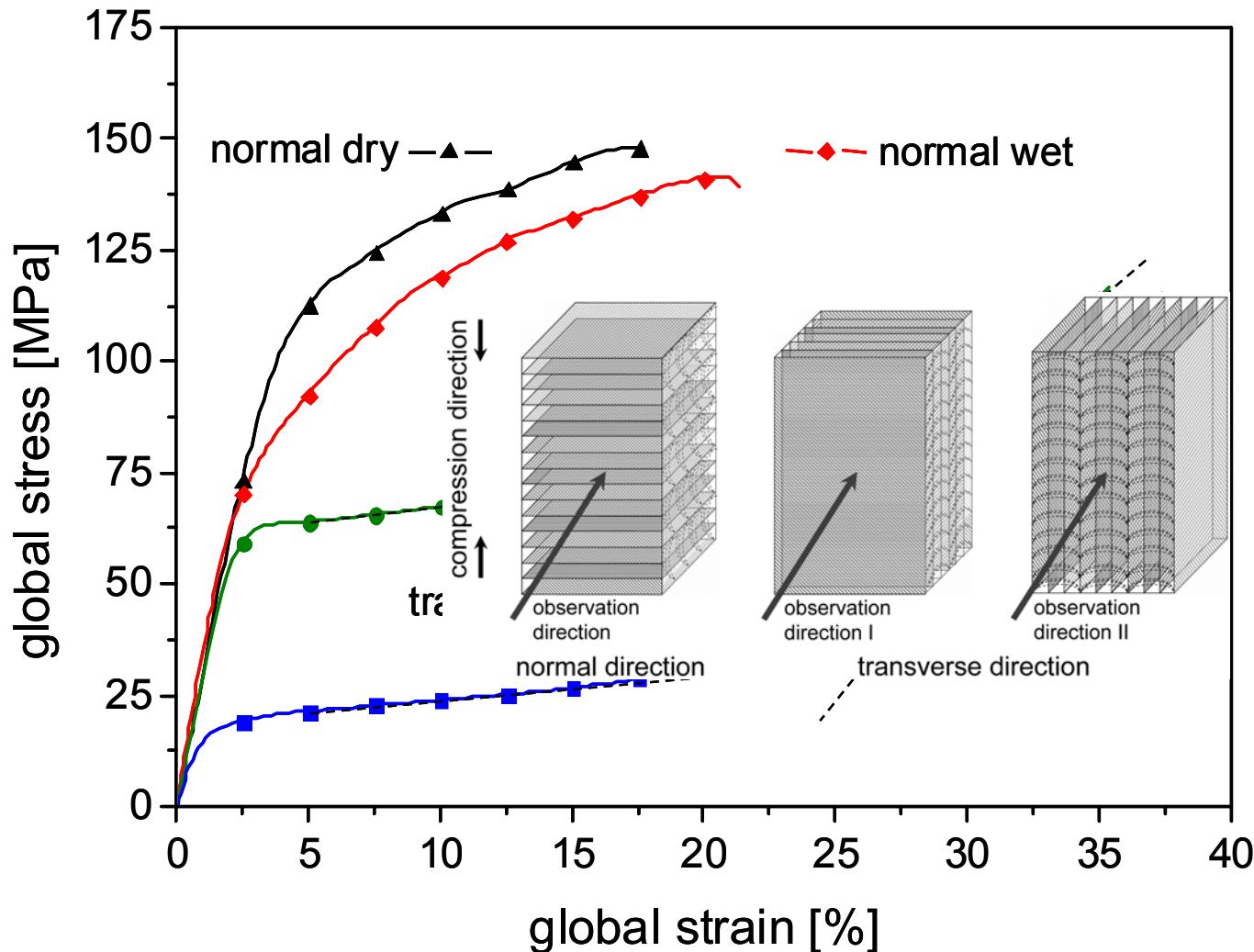
Conclusions



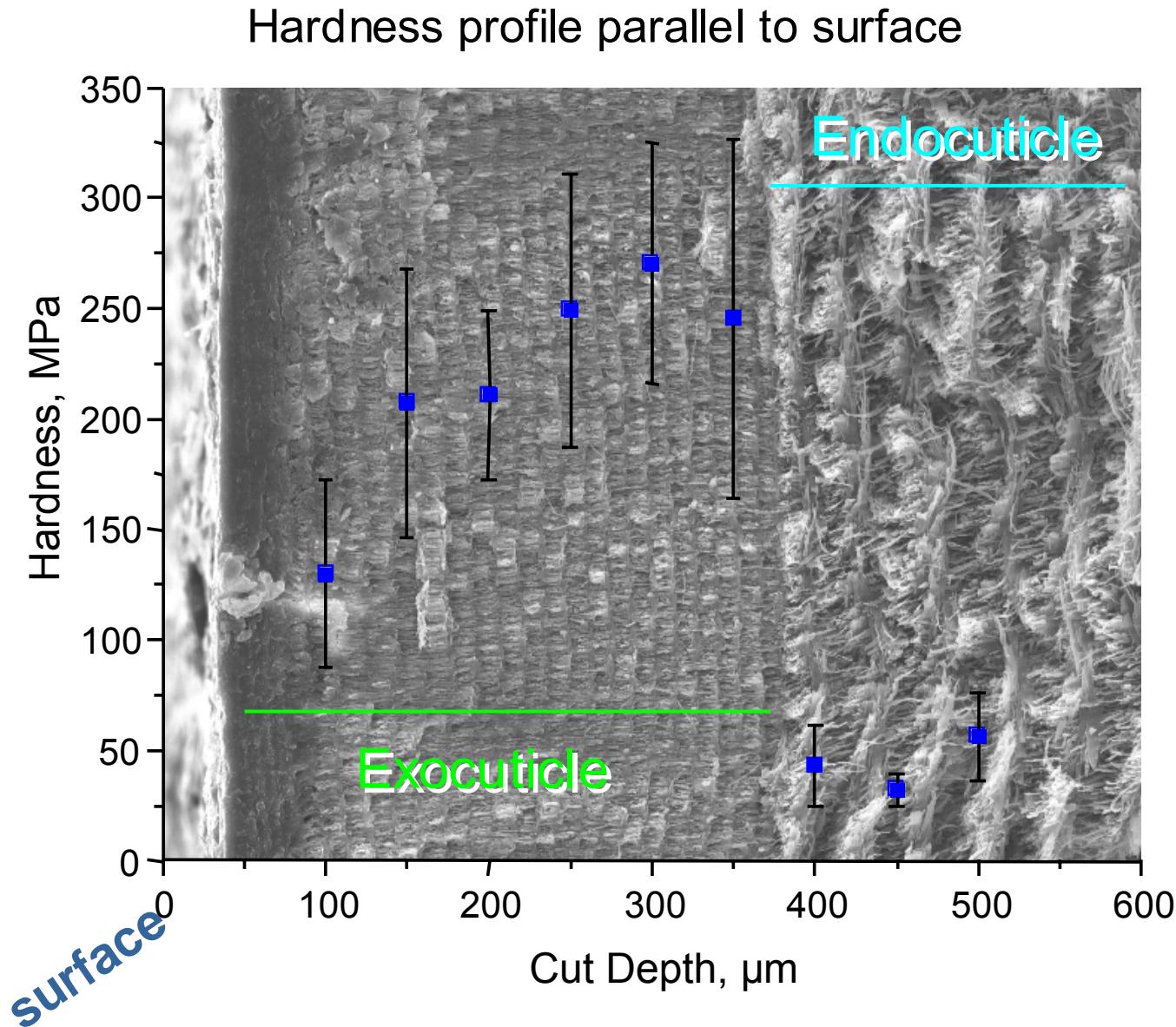
Mechanical testing



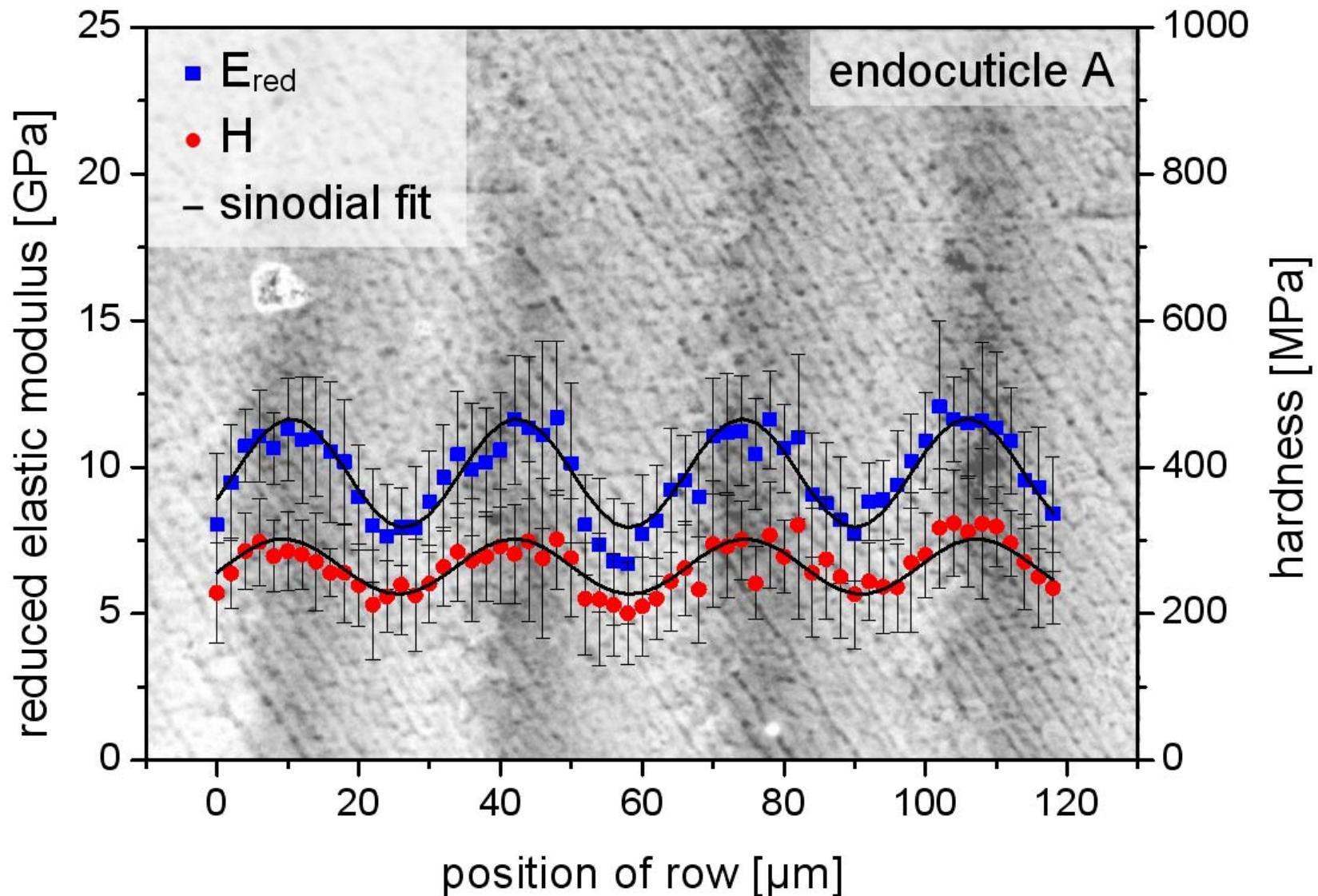
Compression tests (macroscopic), lobster



Hardness (mesoscopic)



Scanning nanoindentation (nanoscopic), lobster





Conclusions

- Hierarchical mechanical and functional principles of nanocomposites
- Strong topological directionality
- Structure topology concedes with crystallographic orientation
- Hierarchical organisation of (topological and crystallographic) orientation as building principle
- Mechanical properties orientation dependent (micro, macro)
- Directional structure and properties of photonic crystals
- Joint construction principles can provide explanations for the relationships between structure and mechanical properties
- In biological materials the mechanical properties vary on different length scales due to the hierarchical organization



Further Reading

- D. Raabe, P. Romano, A. Al-Sawalmih, C. Sachs, G. Servos, H.G. Hartwig: "Mesostructure of the Exoskeleton of the Lobster *Homarus Americanus*", Mater. Res. Soc. Sympos. Proc. Vol. 874 (2005) L.5.2; pages: 155-160.
- D. Raabe, C. Sachs: "Mechanical Properties of the Lobster Cuticle", Mater. Res. Soc. Sympos. Proc. Vol. 874 (2005) L.5.3; pages: 161-166.
- D. Raabe, P. Romano, C. Sachs, H. Fabritius, A. Al-Sawalmih, S.-B. Yi, G. Servos, H.G. Hartwig, Materials Science and Engineering A 421 (2006) 143–153, "Microstructure and crystallographic texture of the chitin-protein network in the biological composite material of the exoskeleton of the lobster *Homarus americanus*"
- D. Raabe, C. Sachs, P. Romano, Acta Materialia 53 (2005) 4281-4292, "The crustacean exoskeleton as an example of a structurally and mechanically graded biological nanocomposite material"
- D. Raabe, P. Romano, C. Sachs, A. Al-Sawalmih, H.-G. Brokmeier, S.-B. Yi, G. Servos, H.G. Hartwig, Journal of Crystal Growth 283 (2005) 1–7, "Discovery of a honeycombstructure in the twisted plywood patterns of fibrous biological nanocomposite tissue"
- C. Sachs, H. Fabritius, D. Raabe, Journal of Structural Biology 155 (2006) 409–425, "Experimental investigation of the elastic-plastic deformation of mineralized lobster cuticle by digital image correlation"
- C. Sachs, H. Fabritius, D. Raabe, Journal of Material Research, Vol. 21, No. 8, August 2006, pages 1987-1995 , "Hardness and elastic properties of dehydrated cuticle from the lobster *Homarus americanus* obtained by nanoindentation"
- P. Romano, H. Fabritius, D. Raabe, Acta Biomaterialia. Vol.3 (2007) pages 301-309 , "The exoskeleton of the lobster *Homarus americanus* as an example of a smart anisotropic biological material"
- D. Raabe, A. Al-Sawalmih, S. B. Yi, H. Fabritius, Acta Biomaterialia 3 (2007) 882-895, Preferred crystallographic texture of α -chitin as a microscopic and macroscopic design principle of the exoskeleton of the lobster *Homarus americanus*"
- F. Boßelmann, P. Romano, H. Fabritius, D. Raabe, M. Epple, Thermochimica Acta 463 (2007) 65-68, "The composition of the exoskeleton of two crustacea: The American lobster *Homarus americanus* and the edible crab *Cancer pagurus*"
- C. Sachs, H. Fabritius, D. Raabe, Journal of Structural Biology 161 (2008) 120-132, "Influence of microstructure on deformation anisotropy of mineralized cuticle from the lobster *Homarus americanus*"