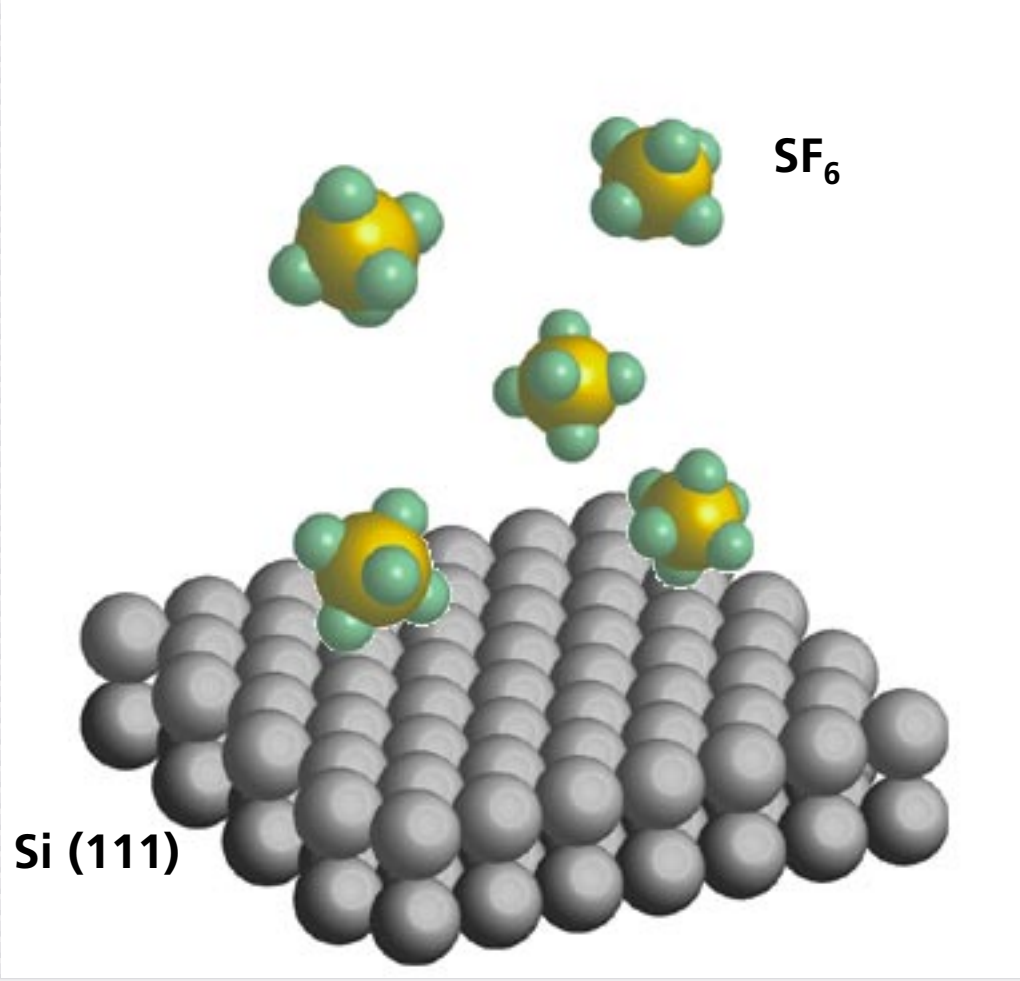
BLACK SILICON:
hot properties and many open questions

Eric Mazur
Jim Carey
Catherine Crouch
Rebecca Younkin

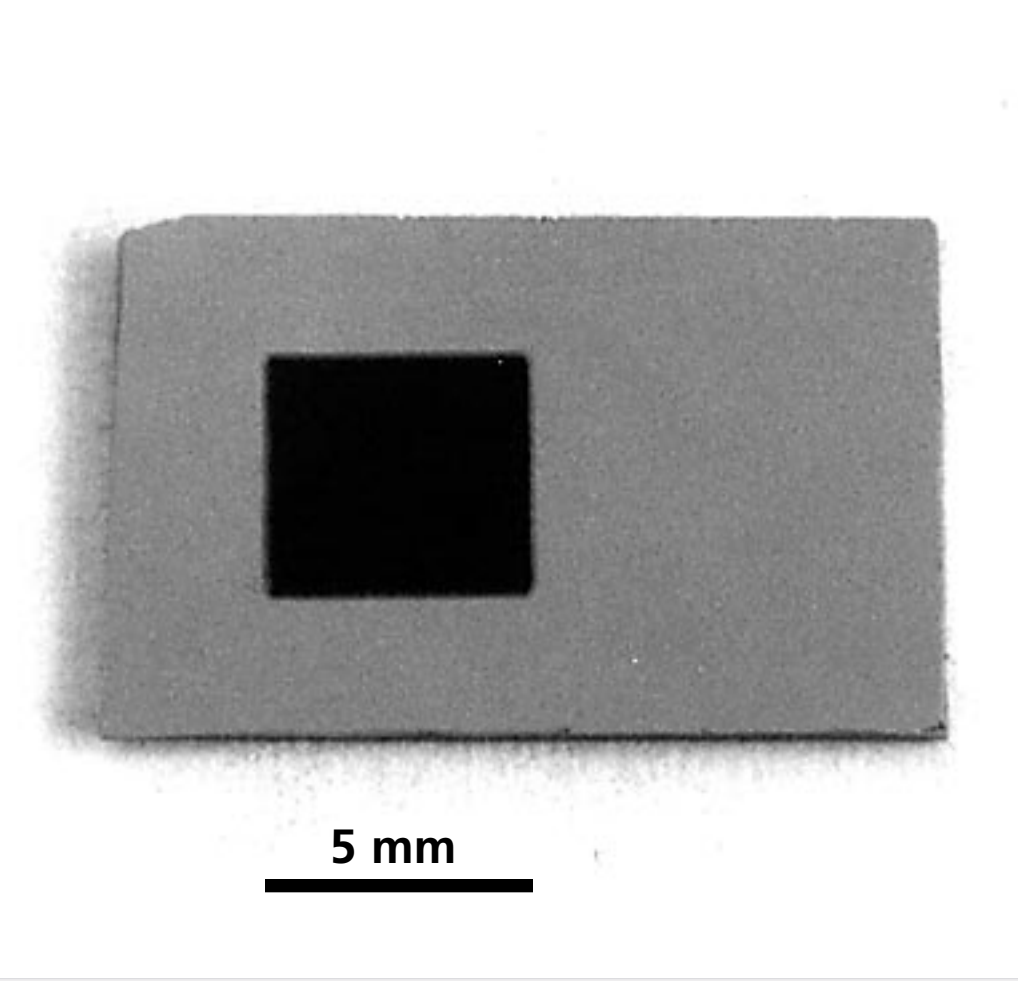
ITAMP Workshop
Cambridge, 14 June 2001

Introduction



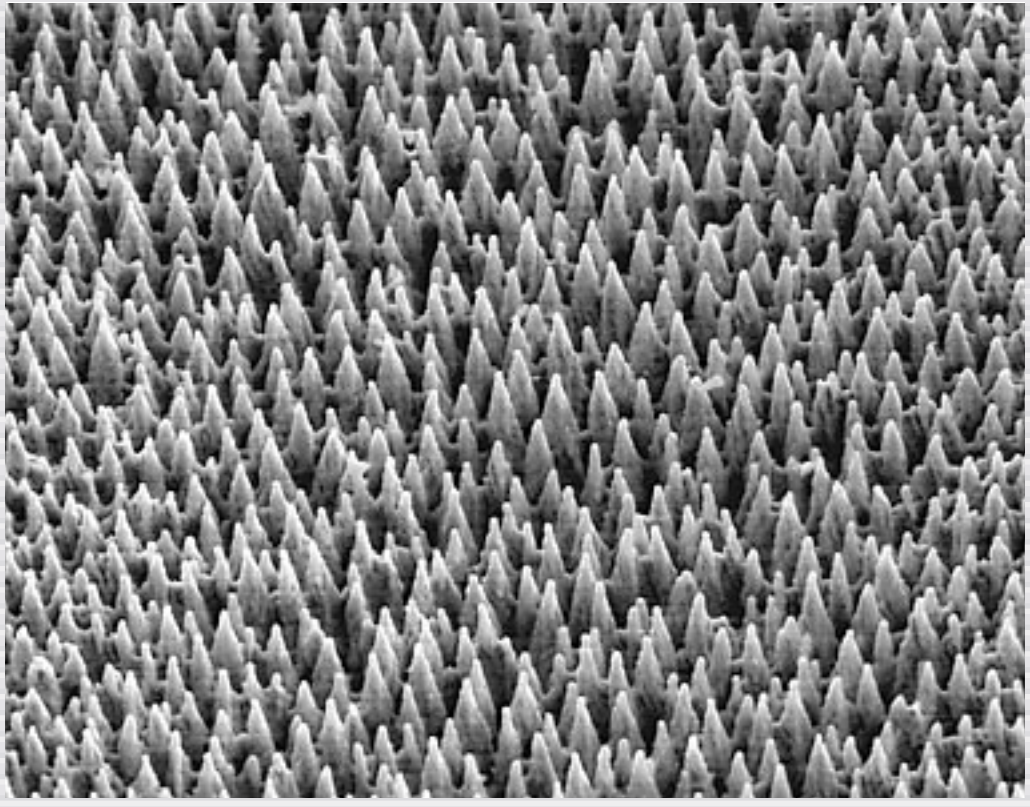
irradiate with 100-fs 10 kJ/m^2 pulses

Introduction



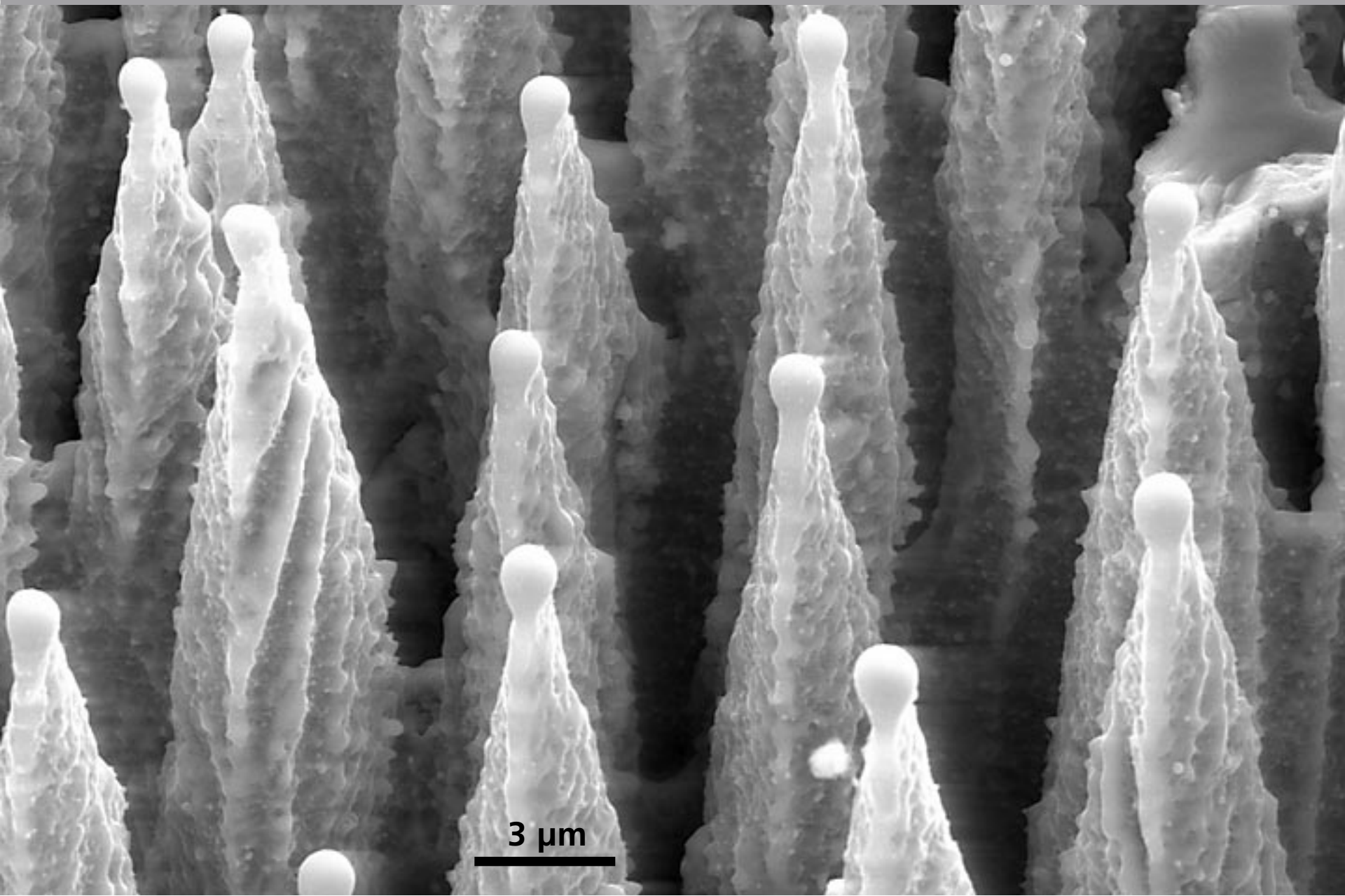
“black silicon”

Introduction

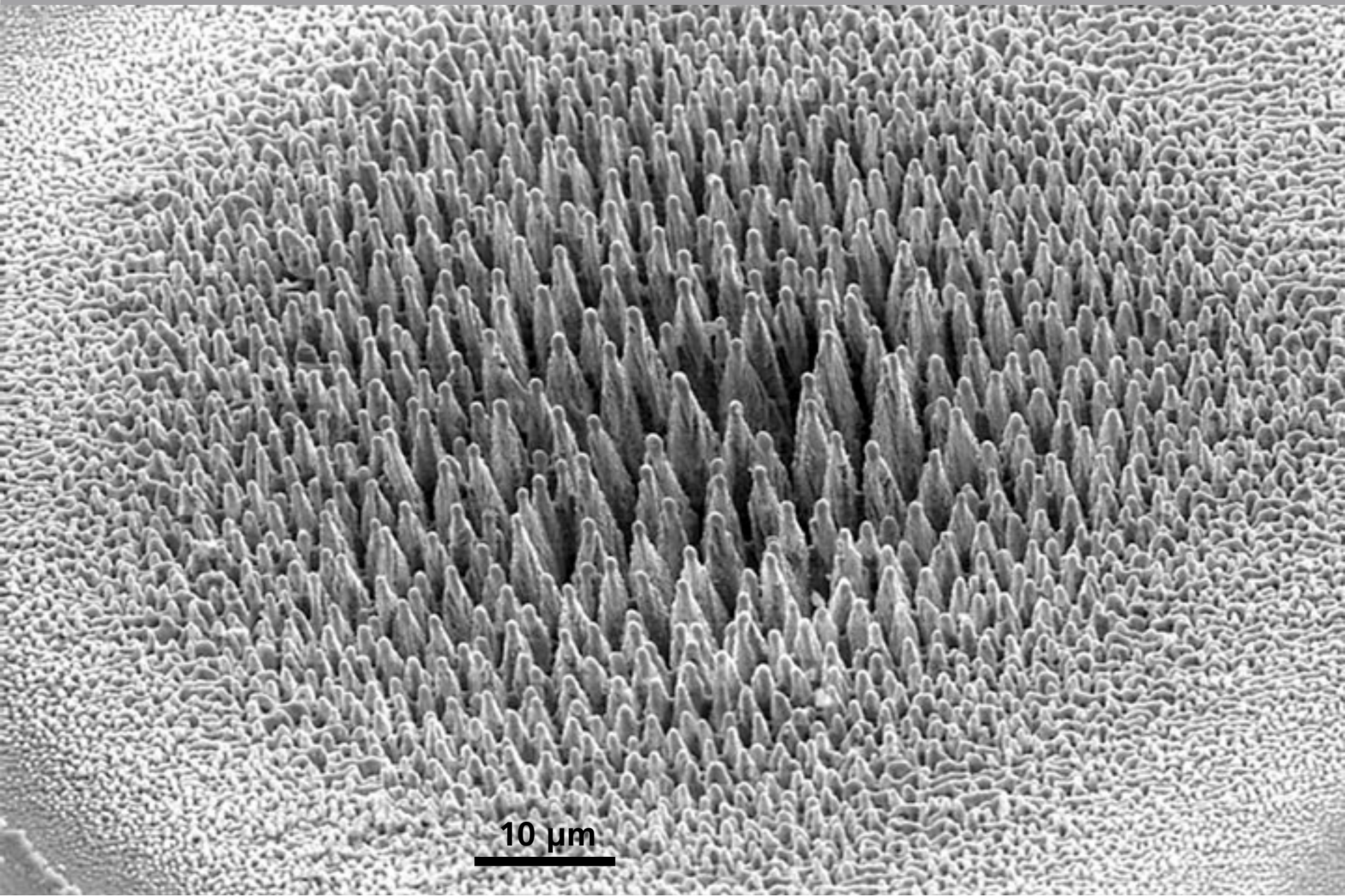


20 μm

Introduction

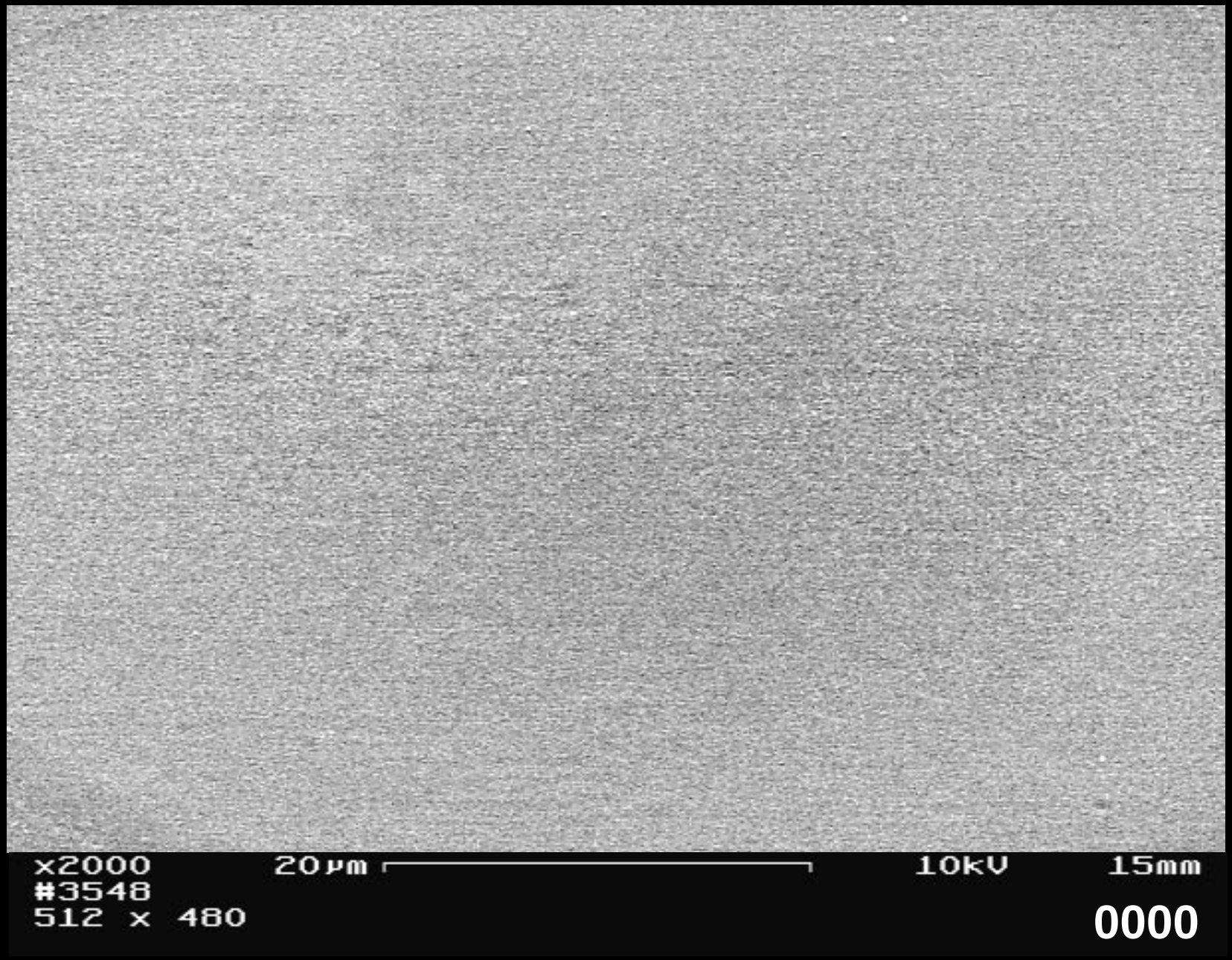


Introduction



Outline

- Background
- Results
- Discussion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10kV
15mm
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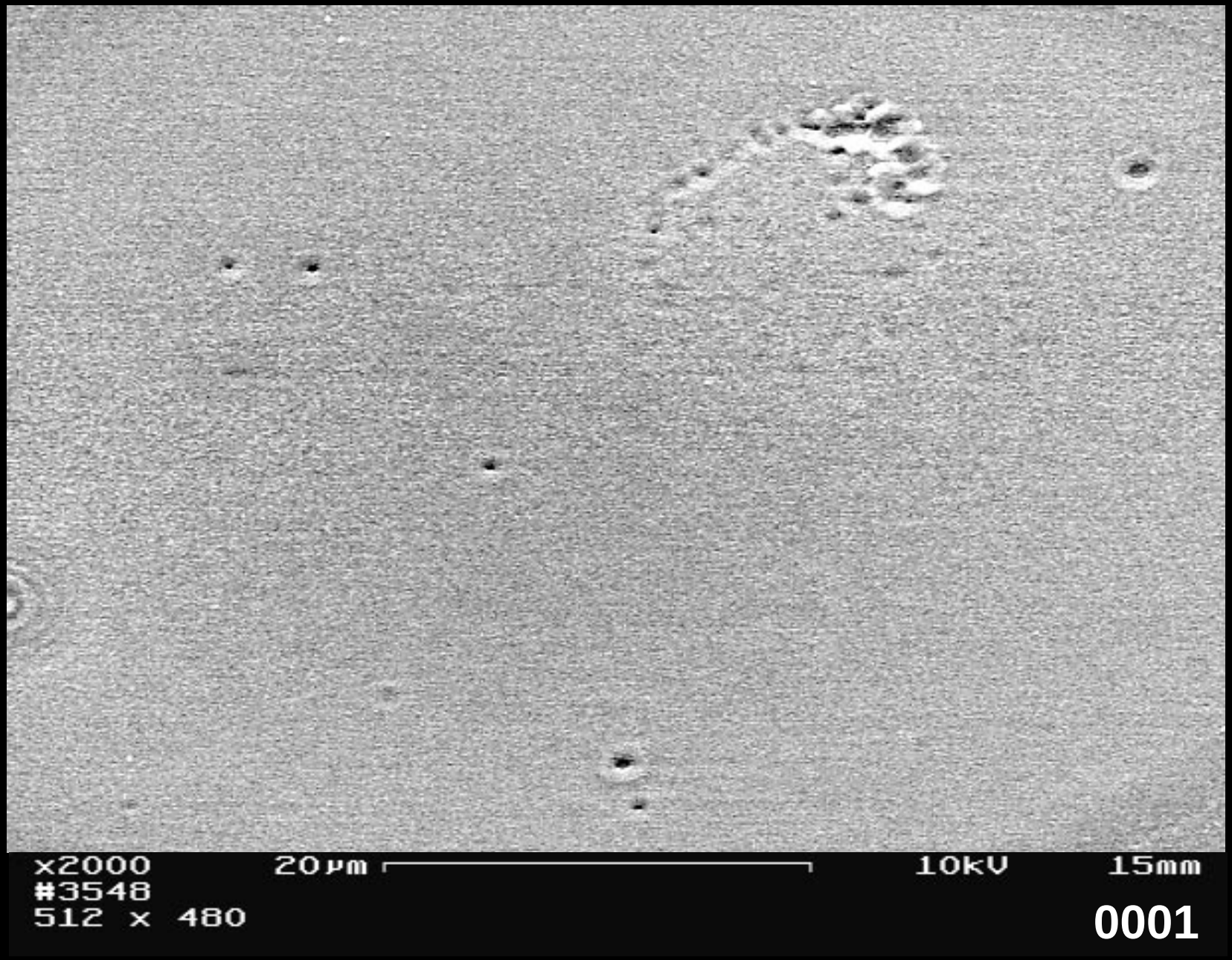
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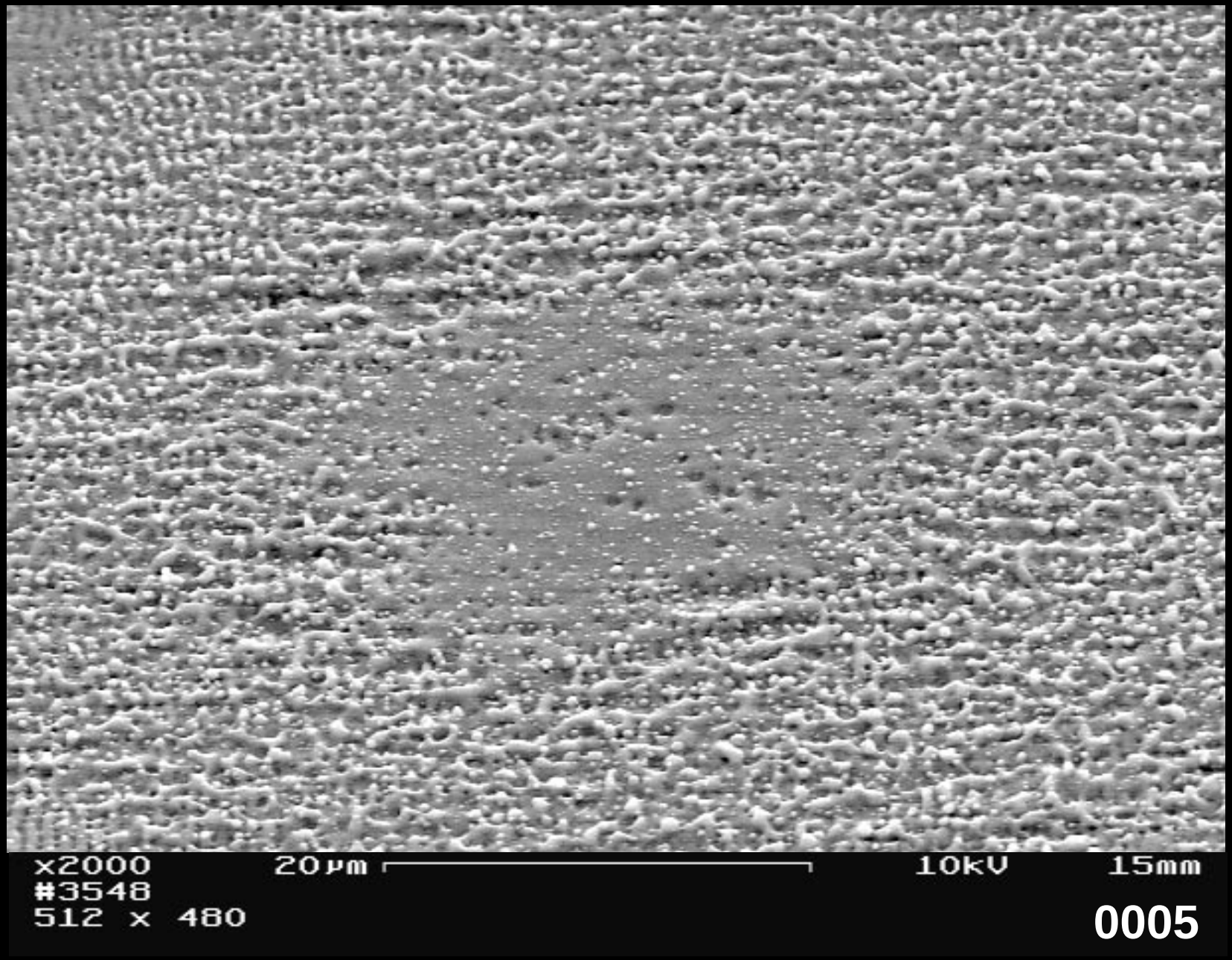
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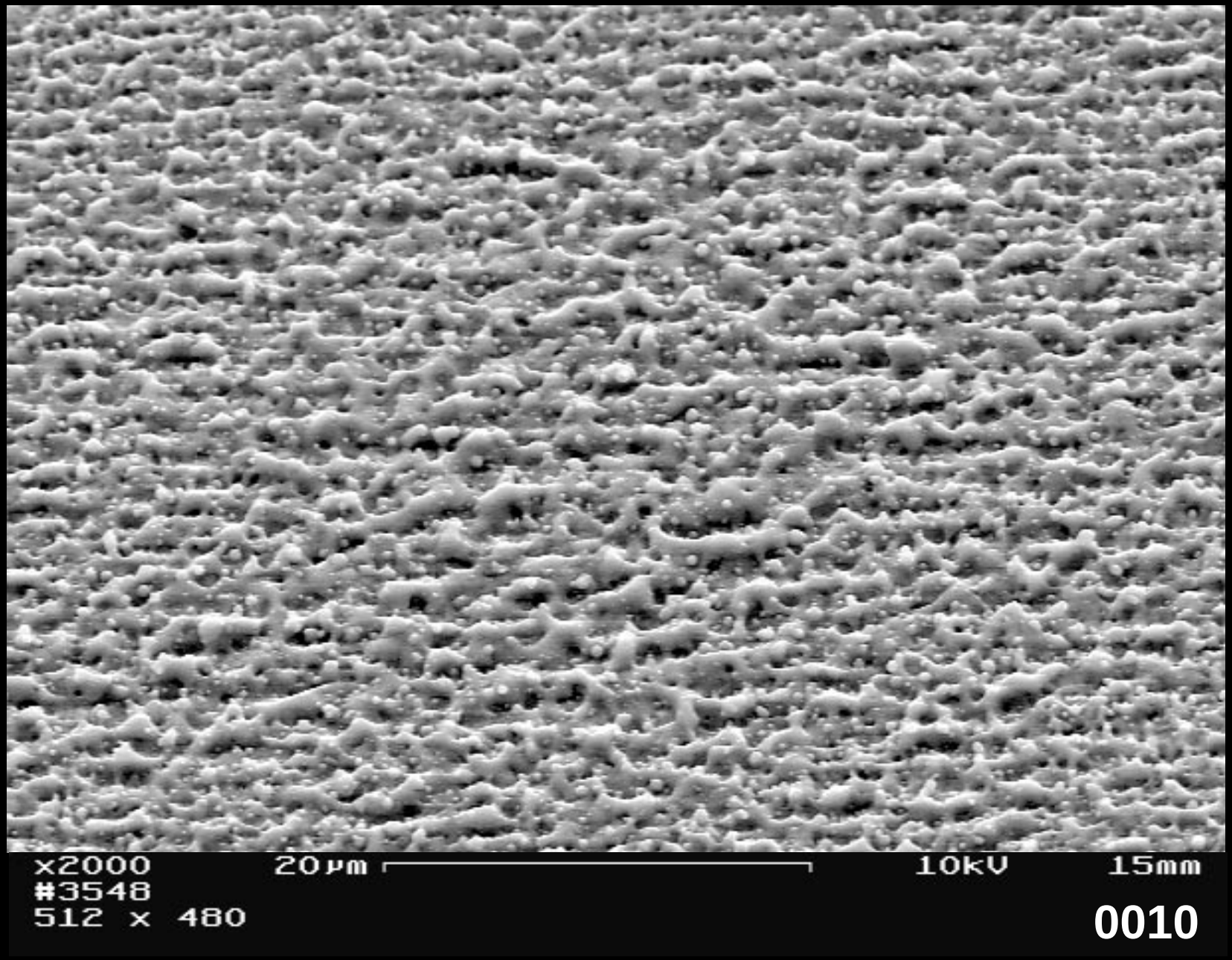
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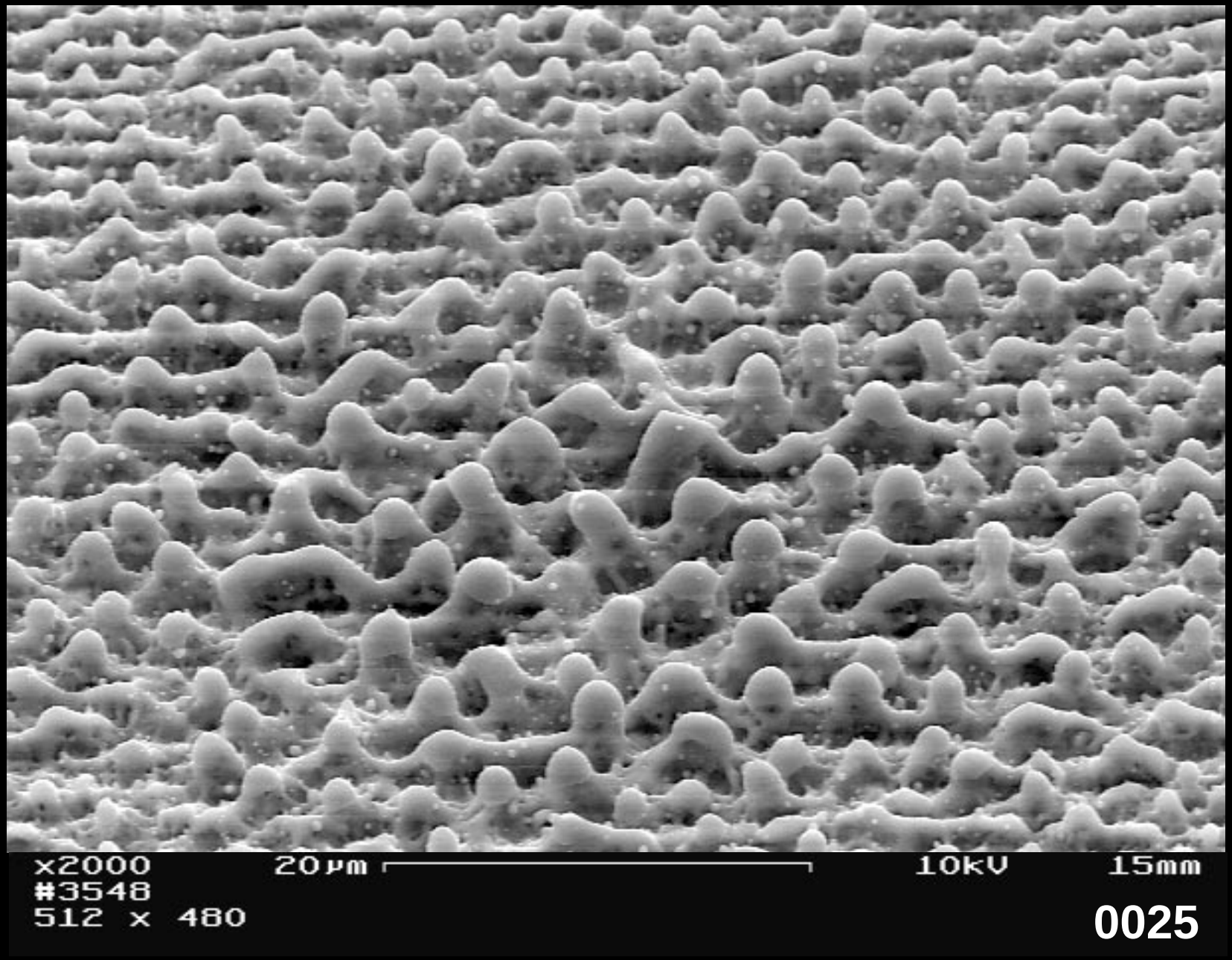
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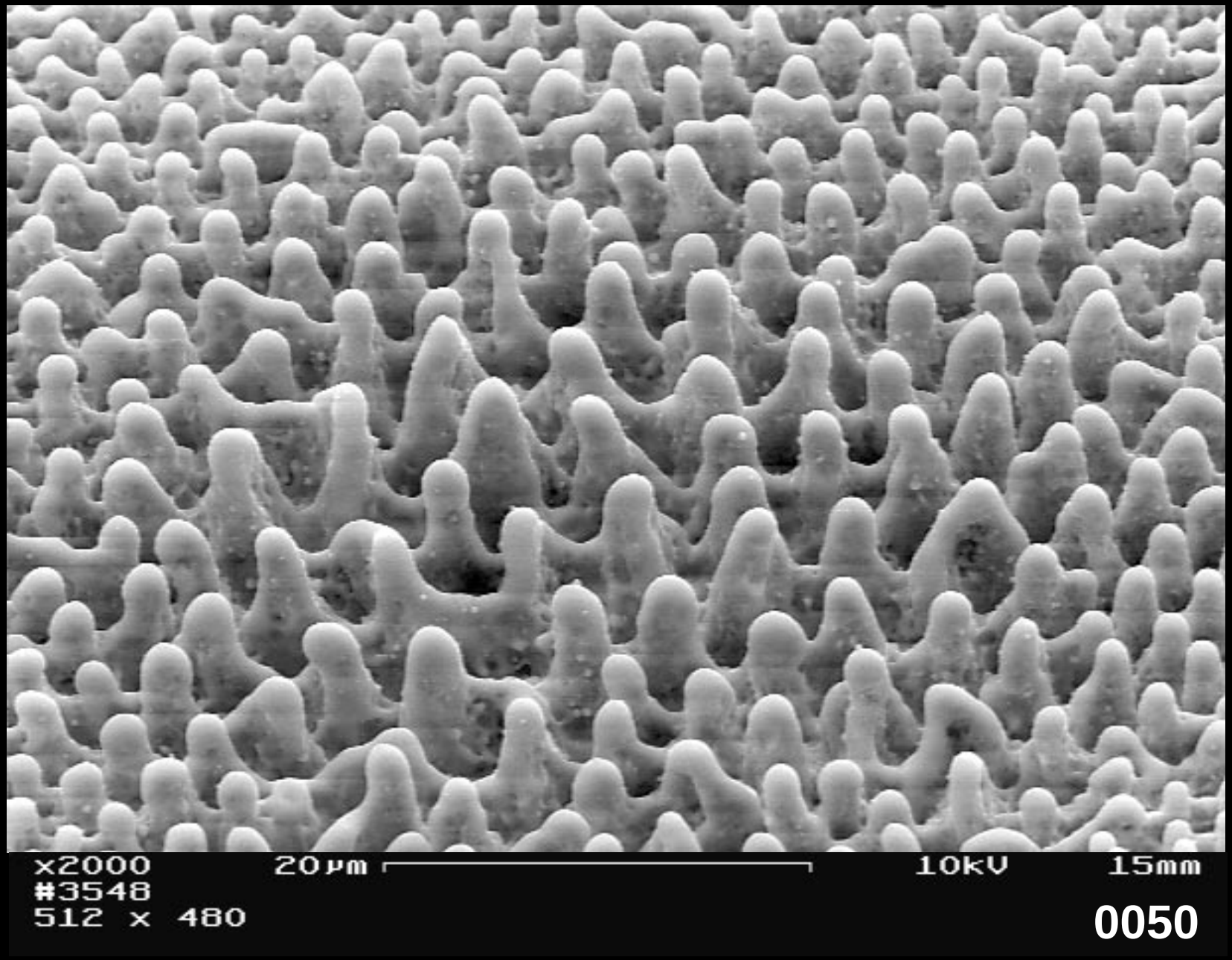
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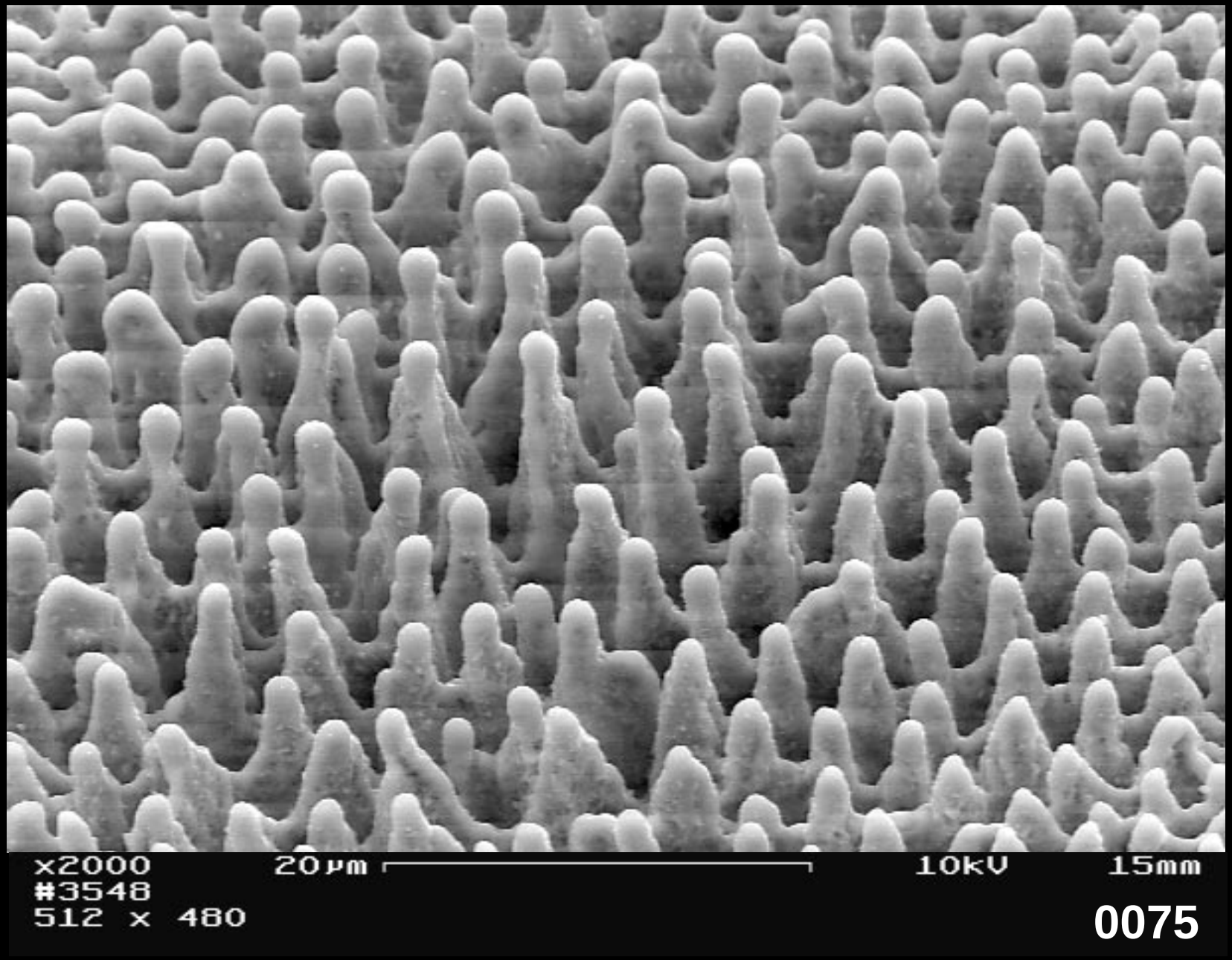
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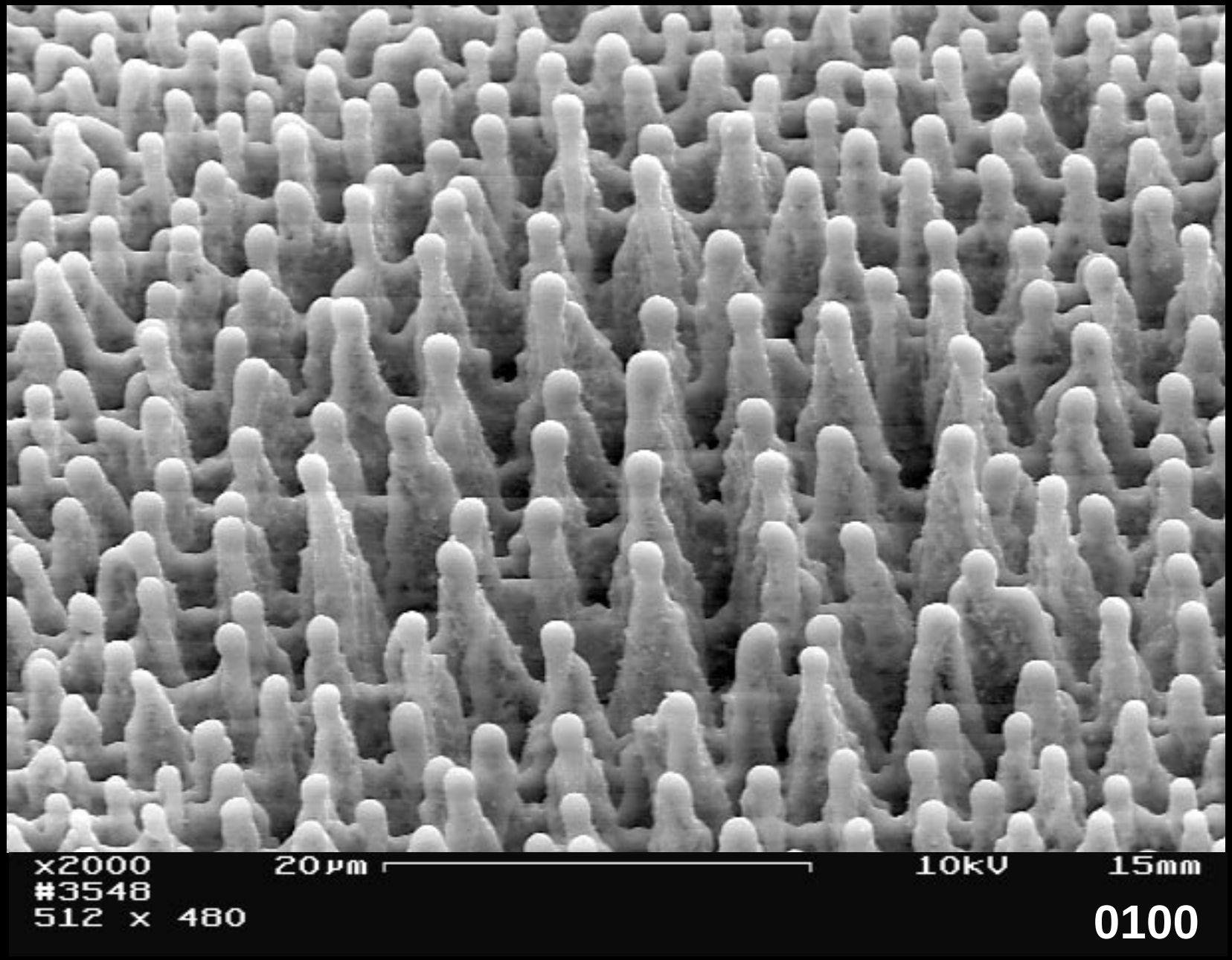
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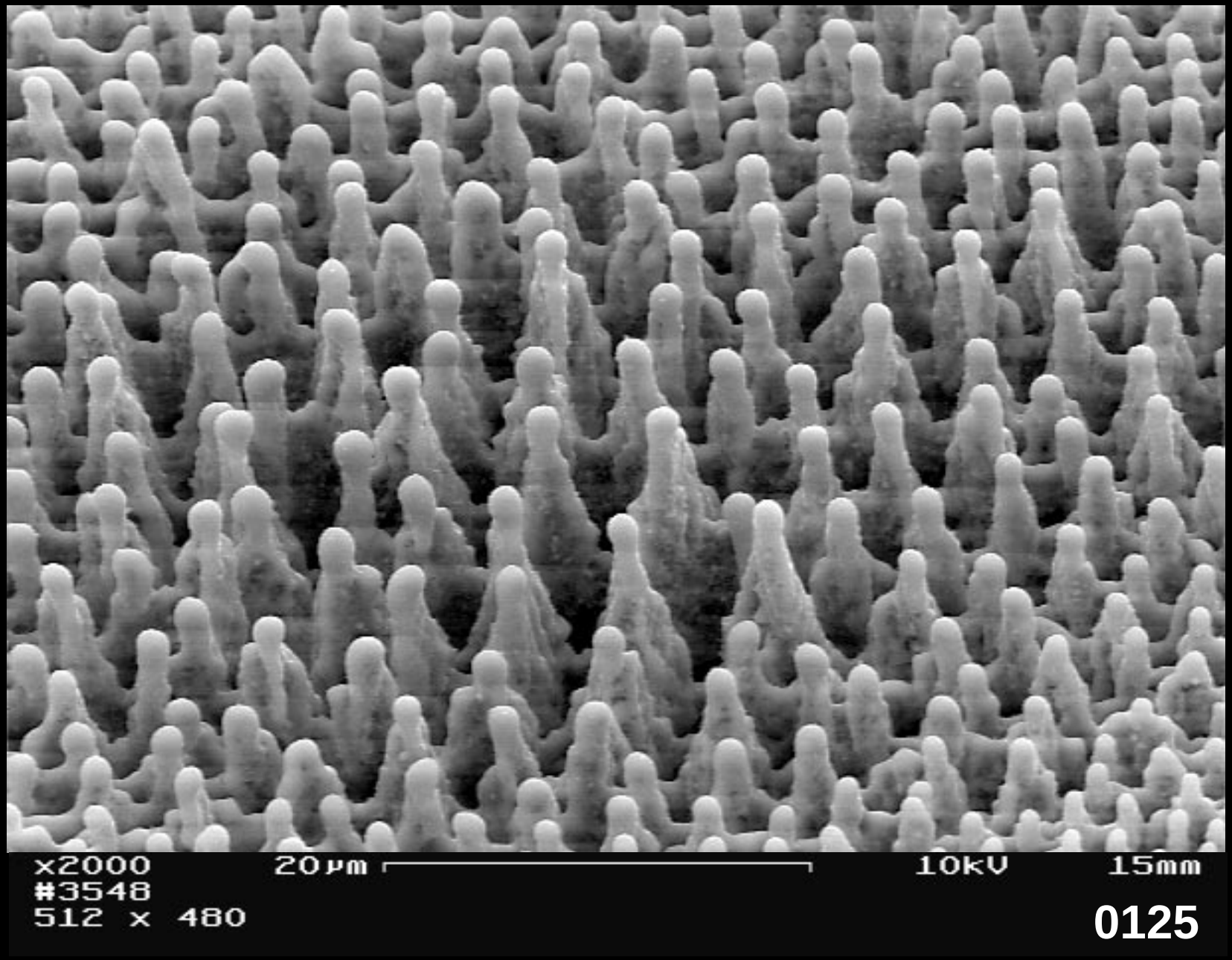
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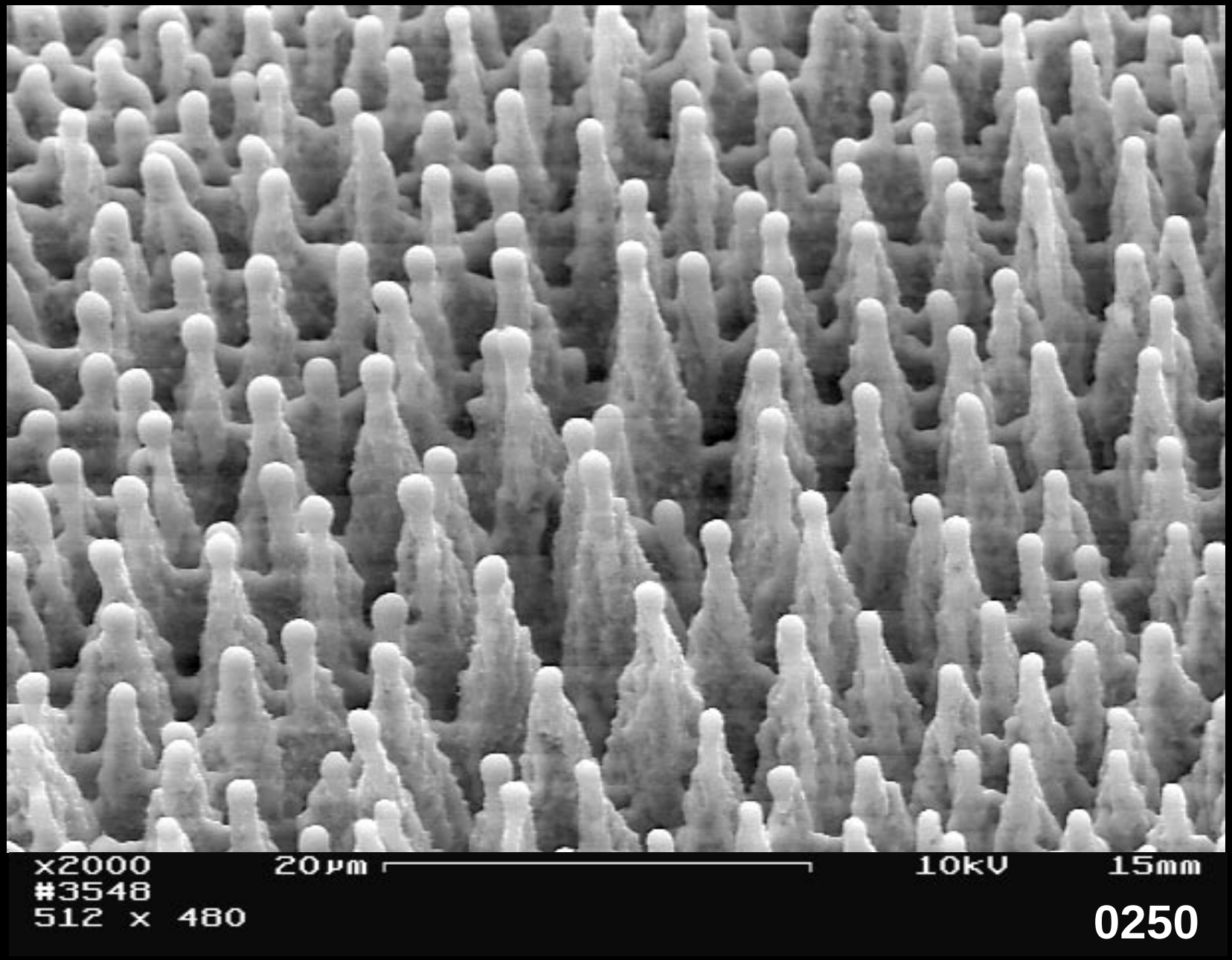
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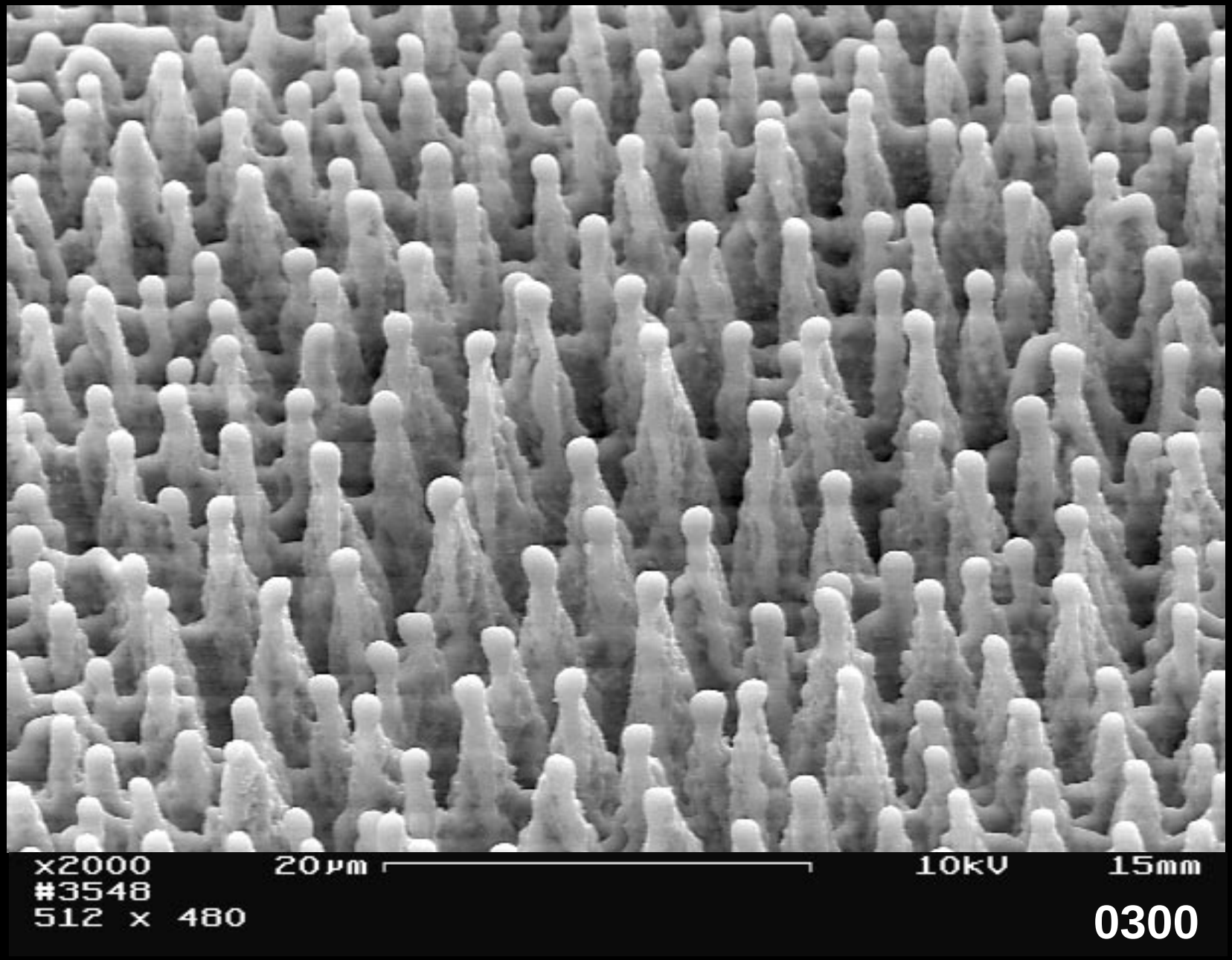
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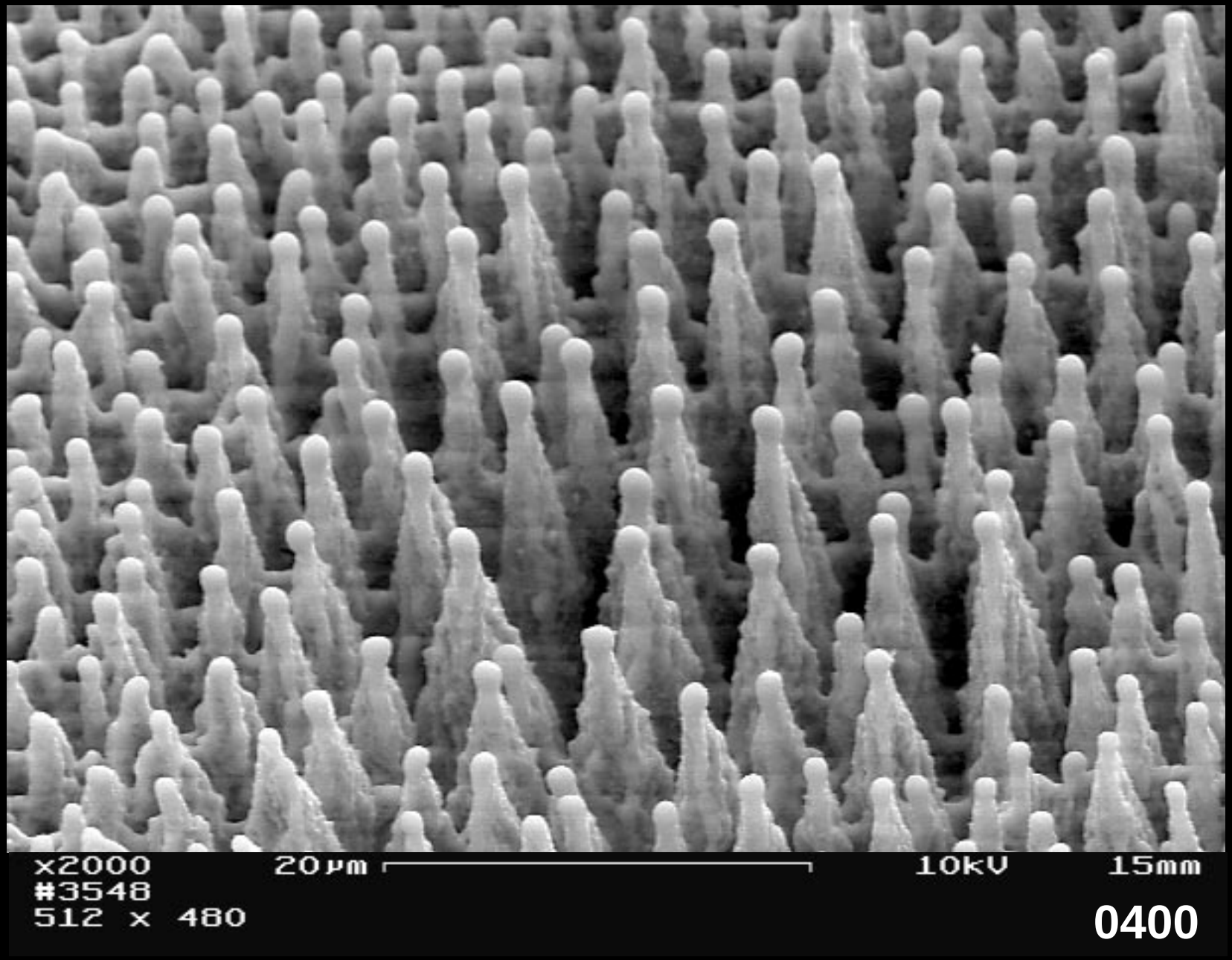
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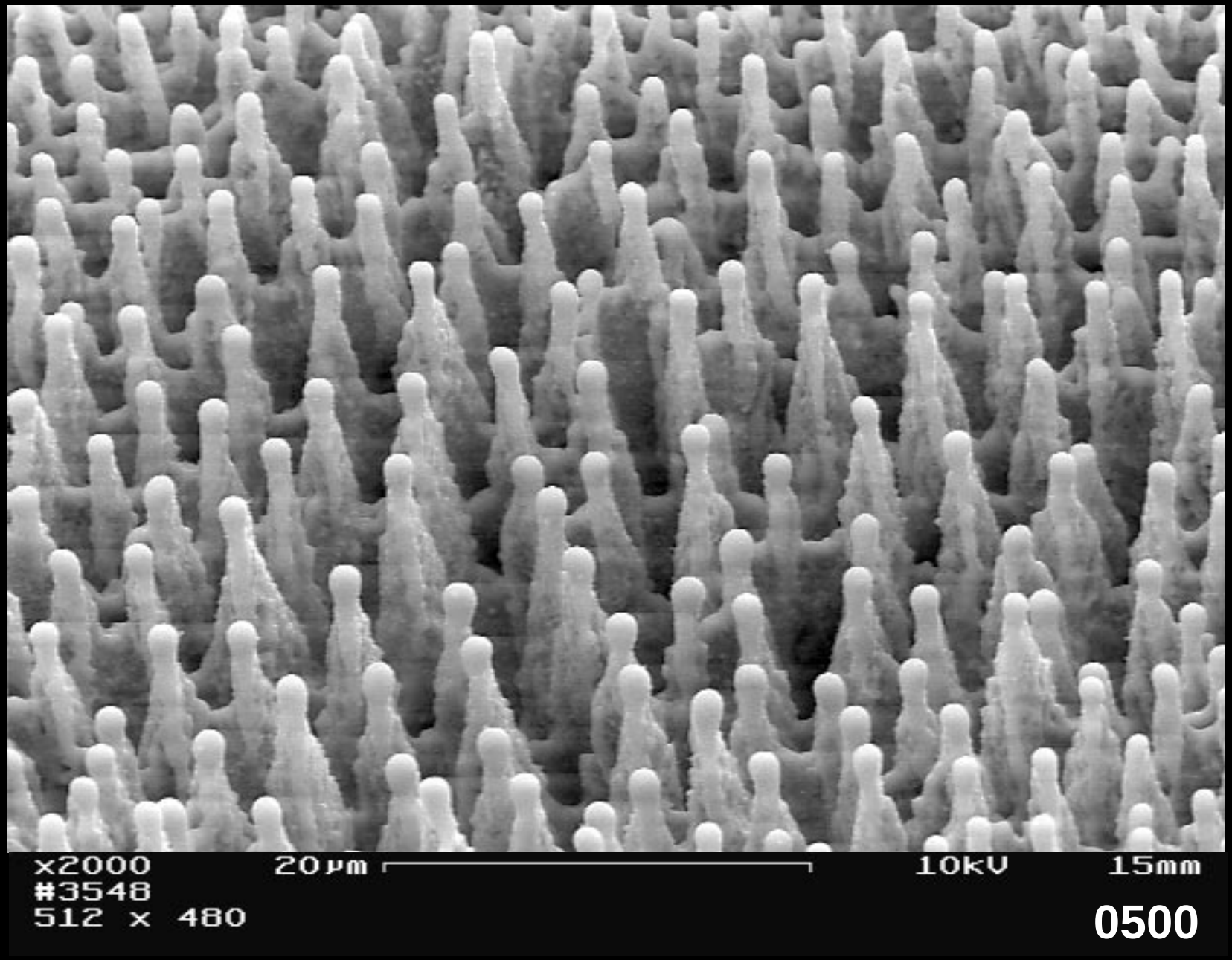
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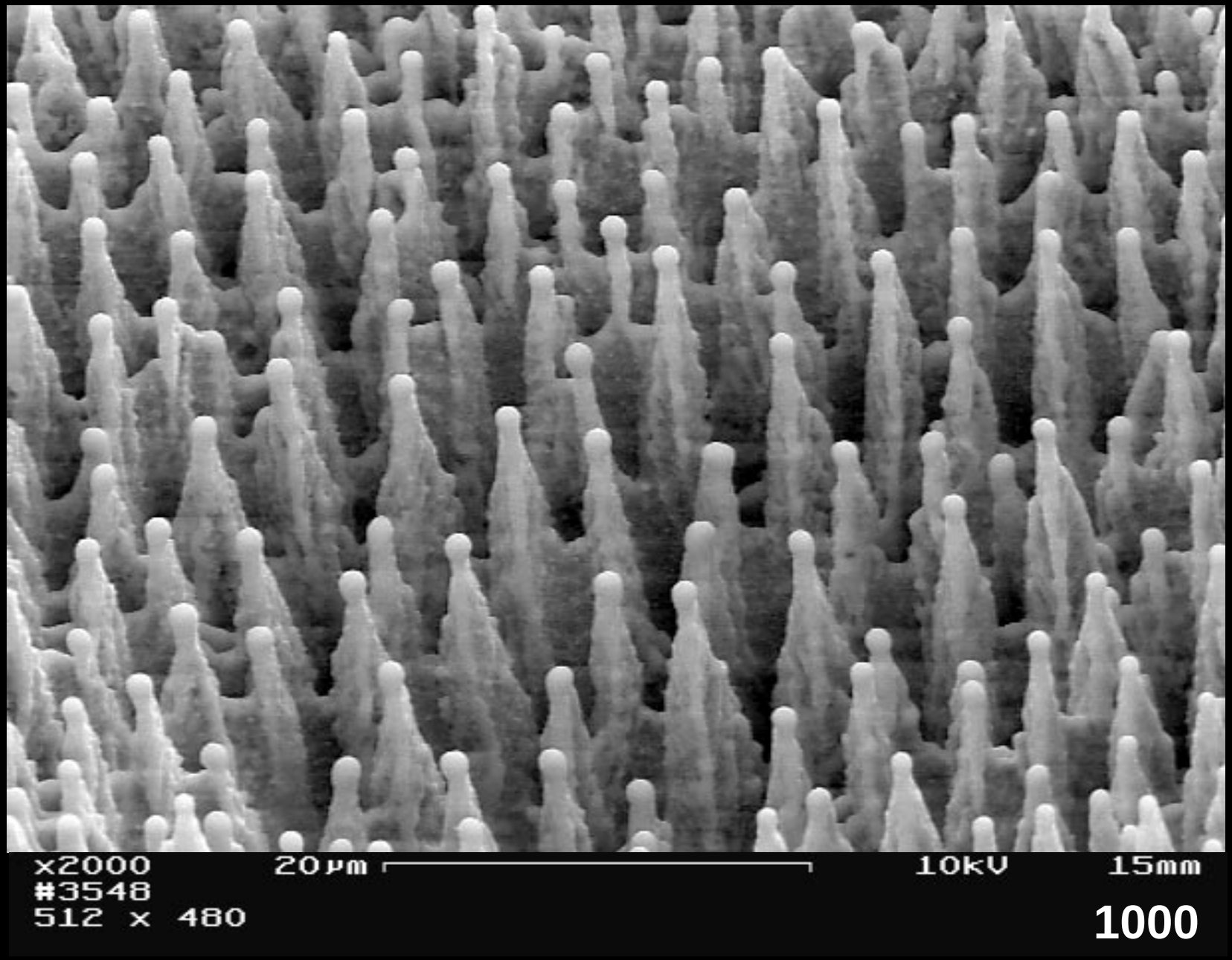
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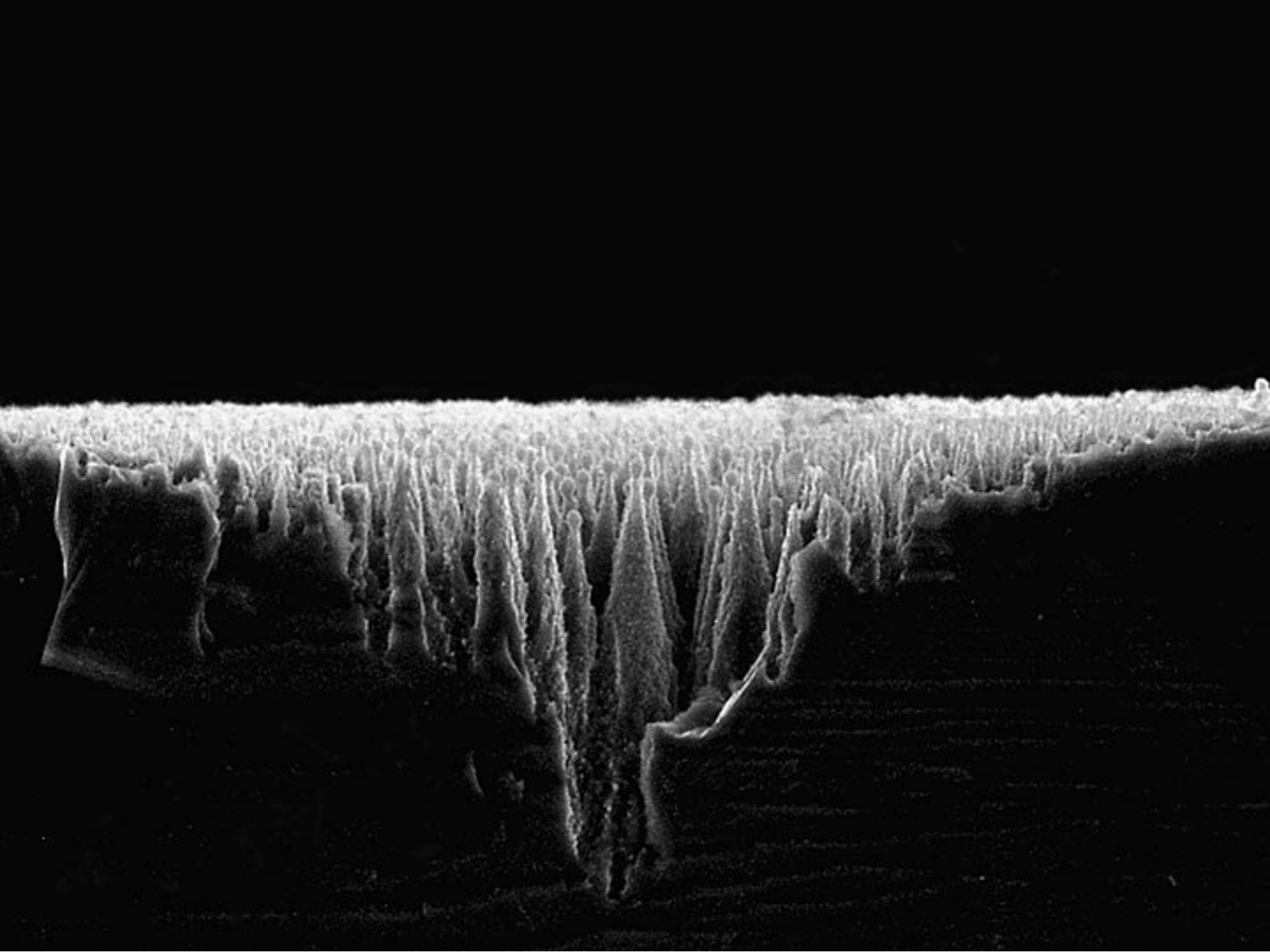

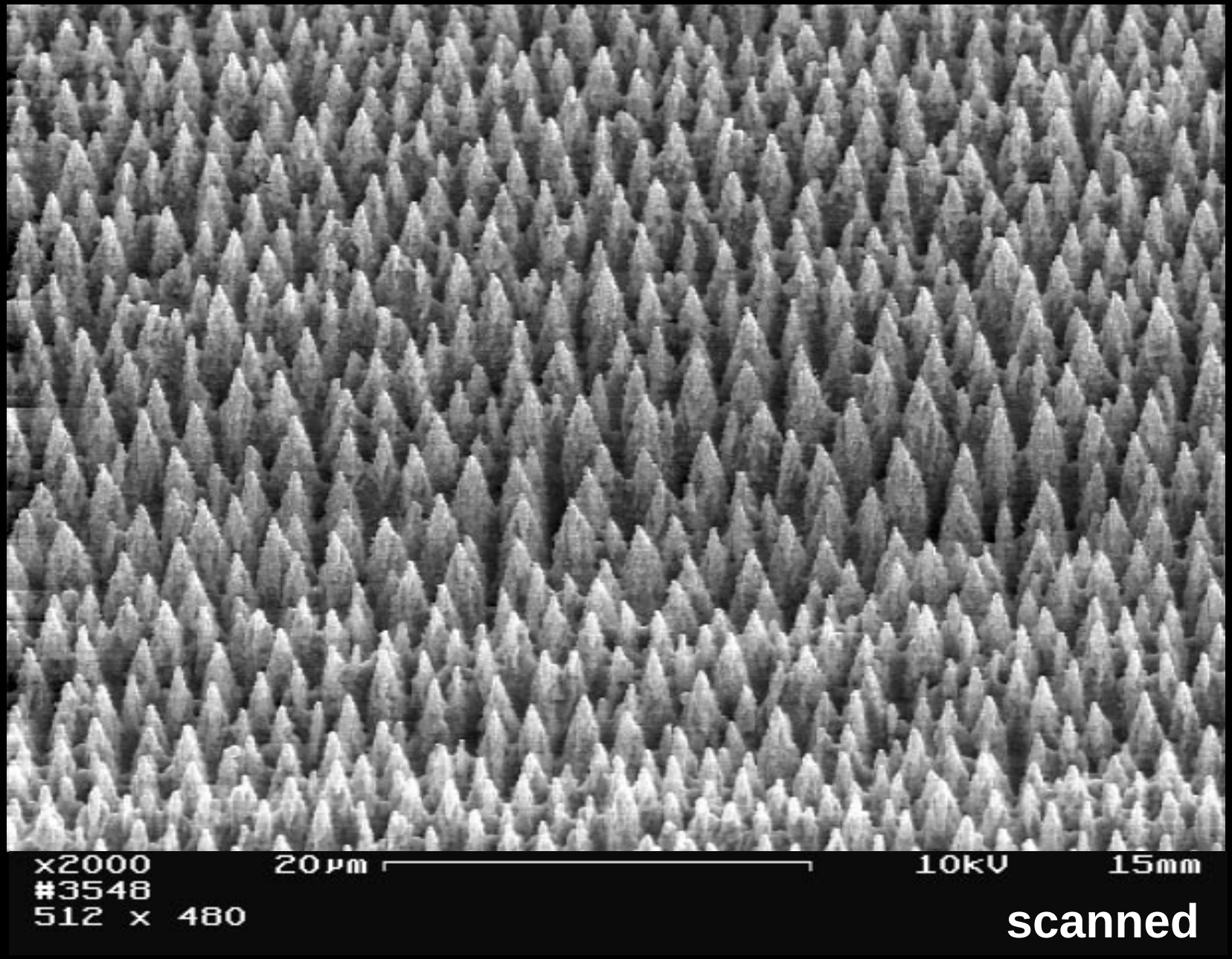
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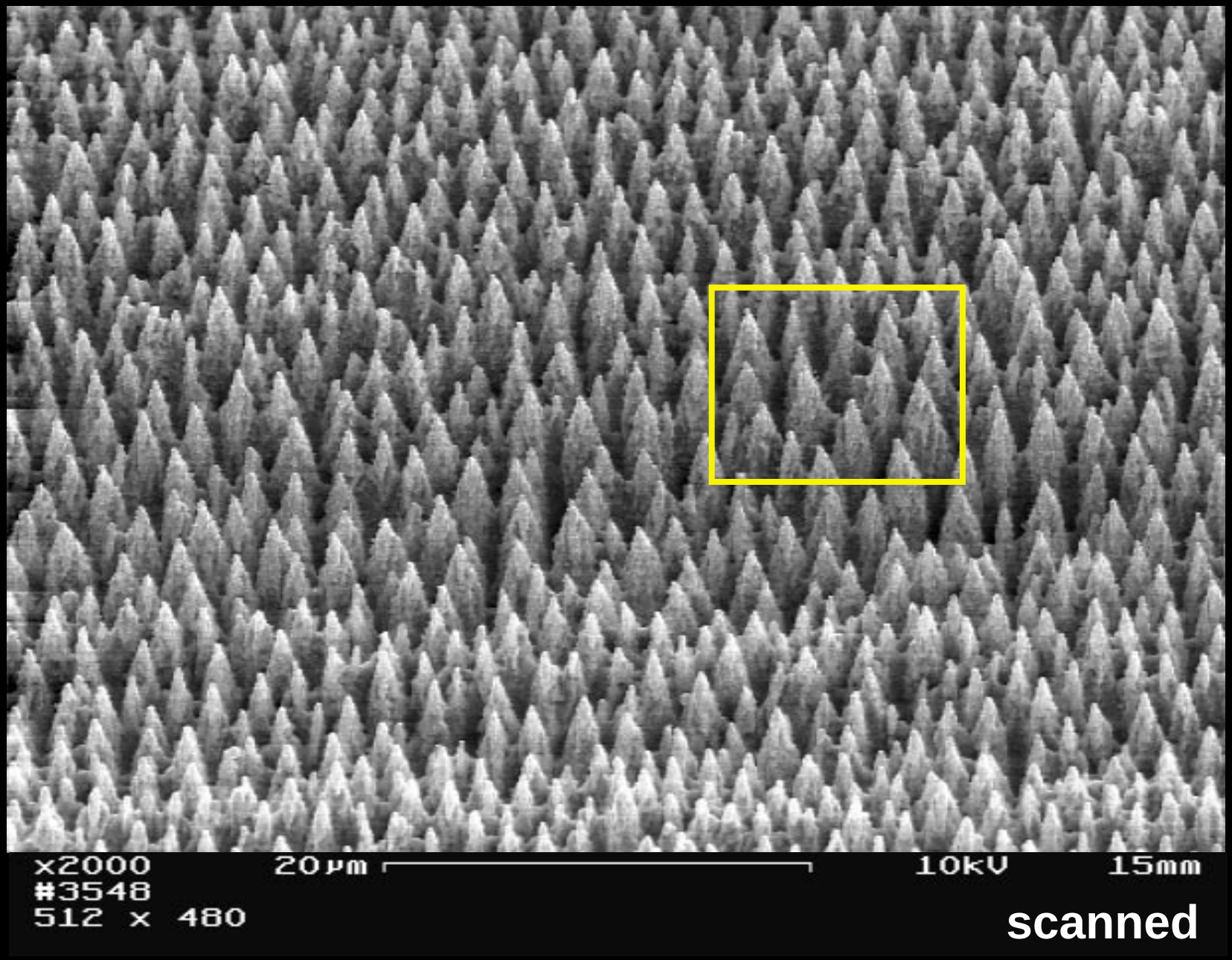
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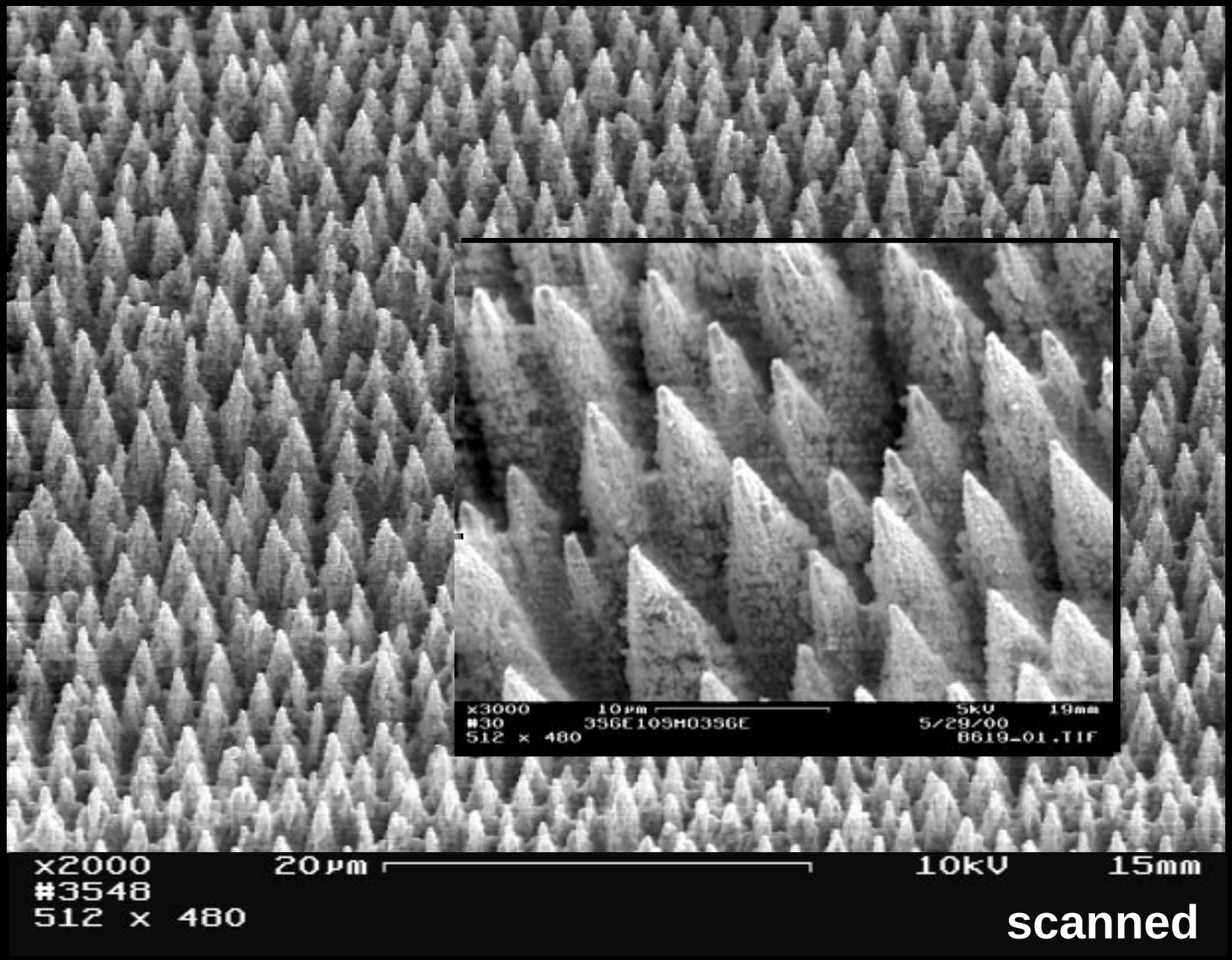
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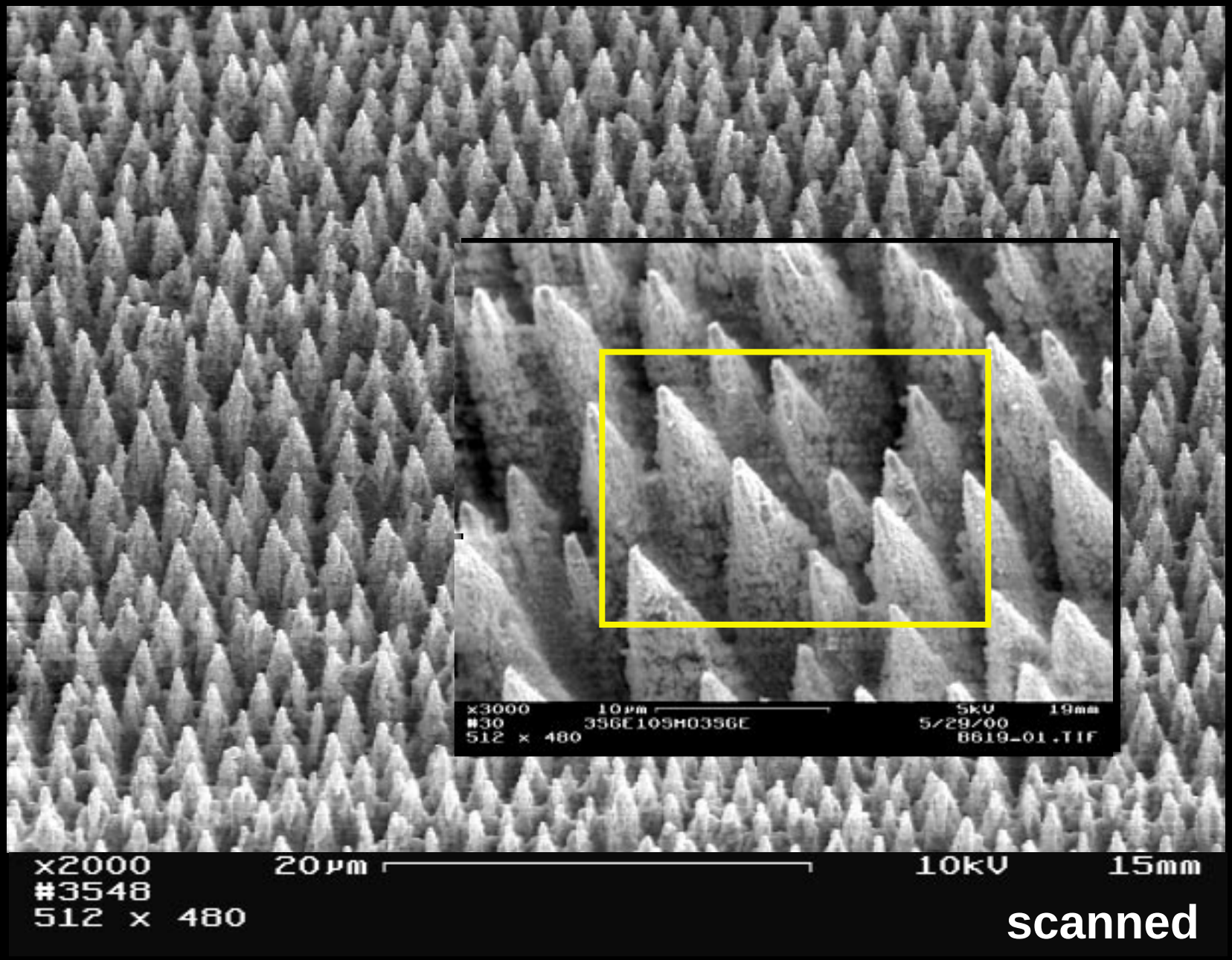
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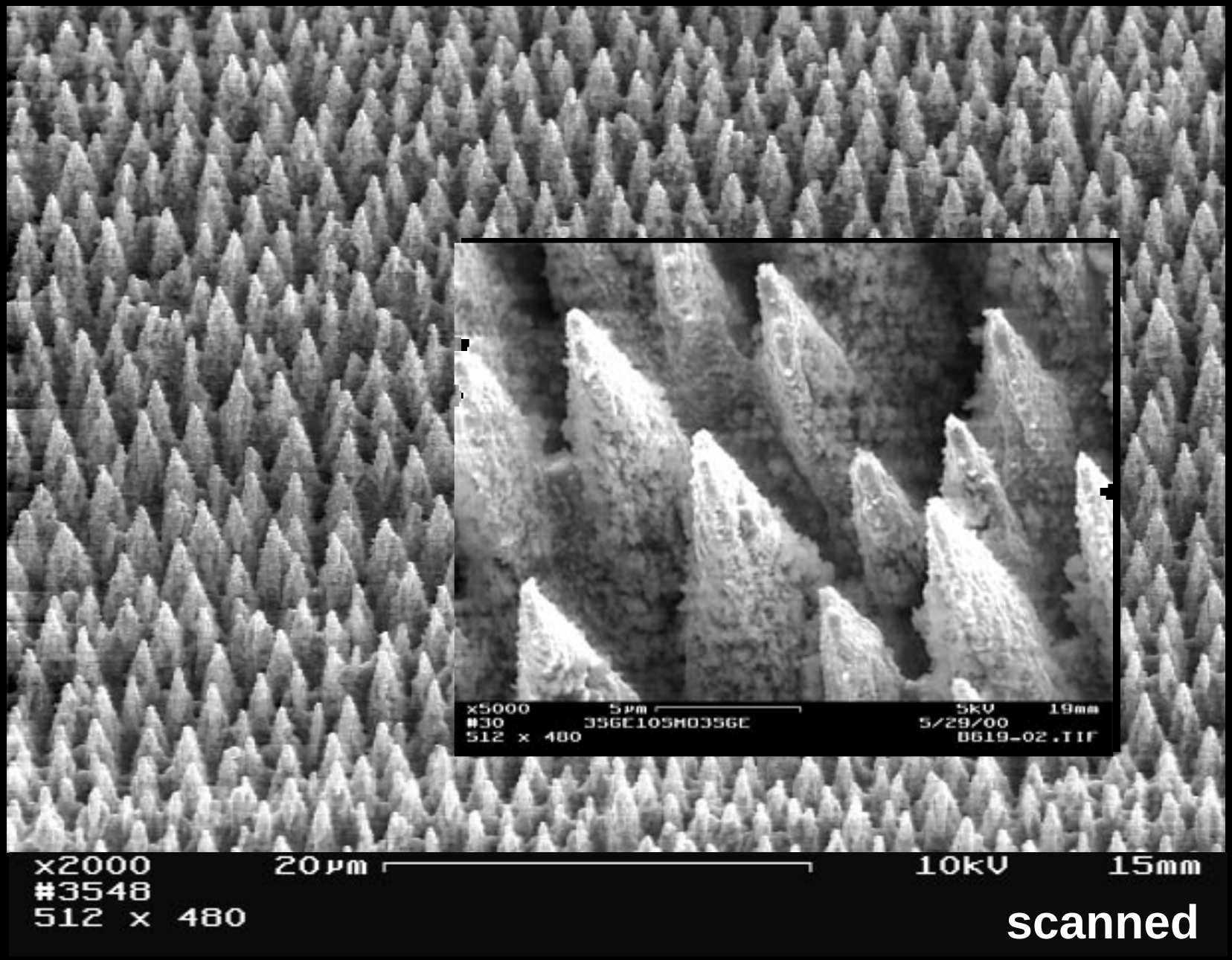
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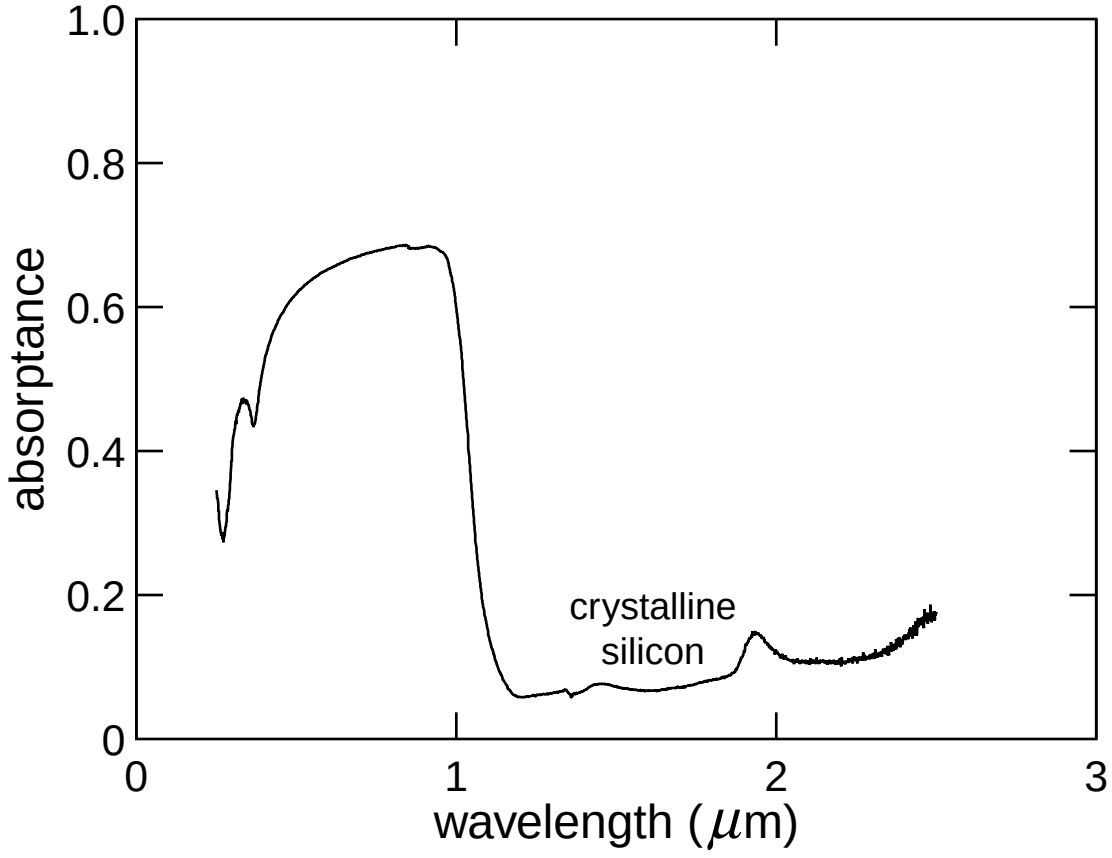
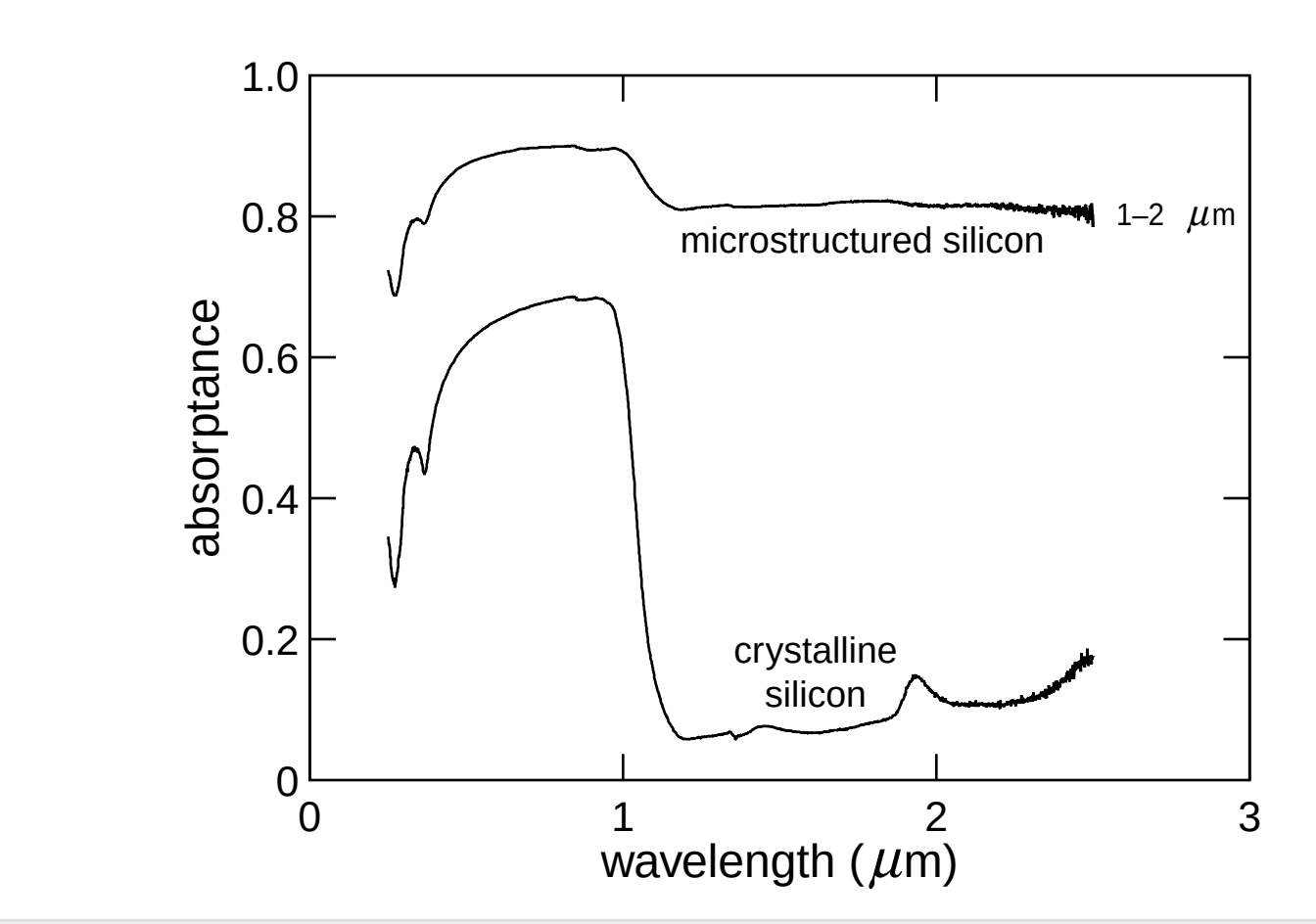
Background

absorptance



Background

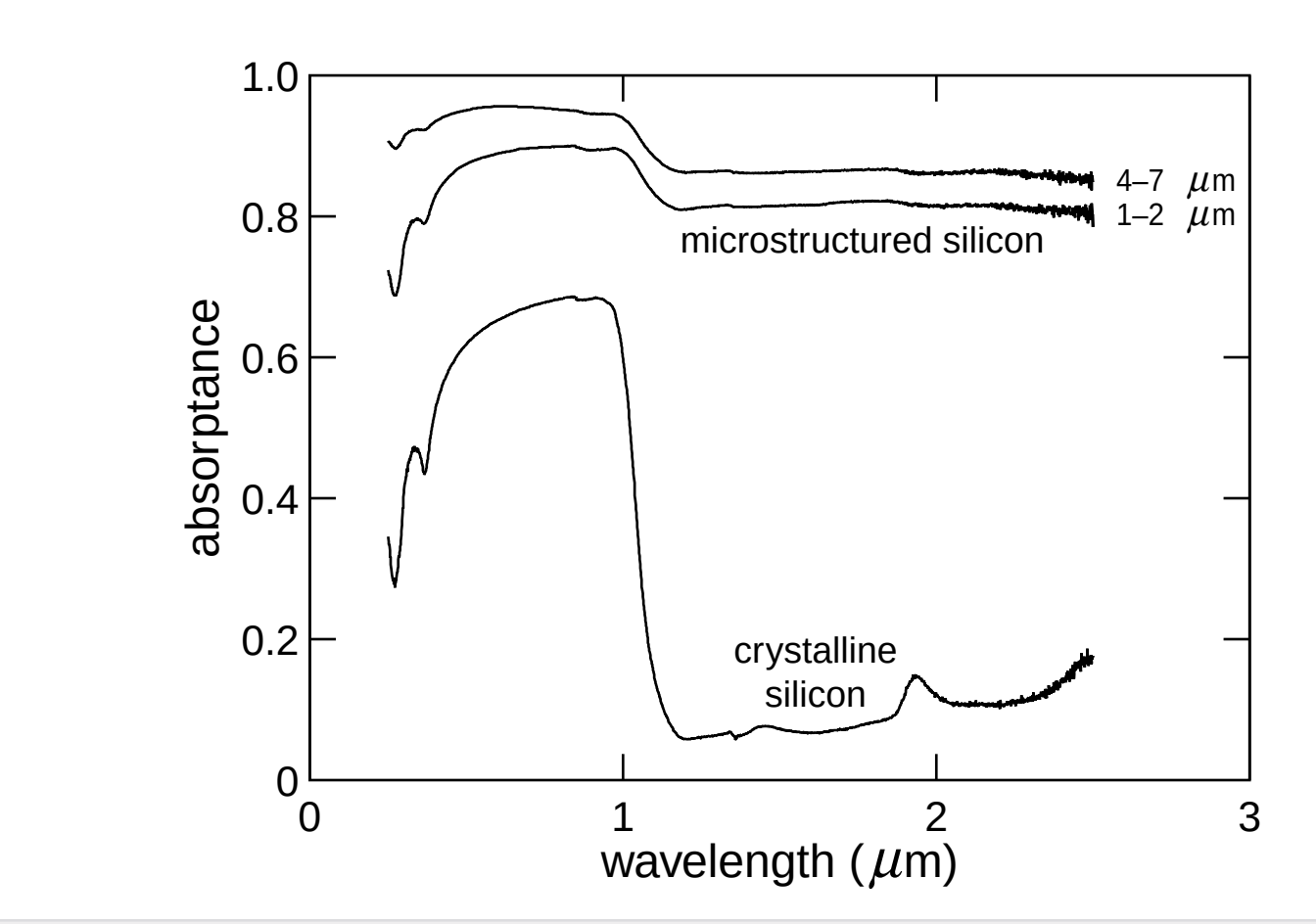
absorptance



C. Wu, *et al.*, *Appl. Phys. Lett*. 78, 1850 (2001)

Background

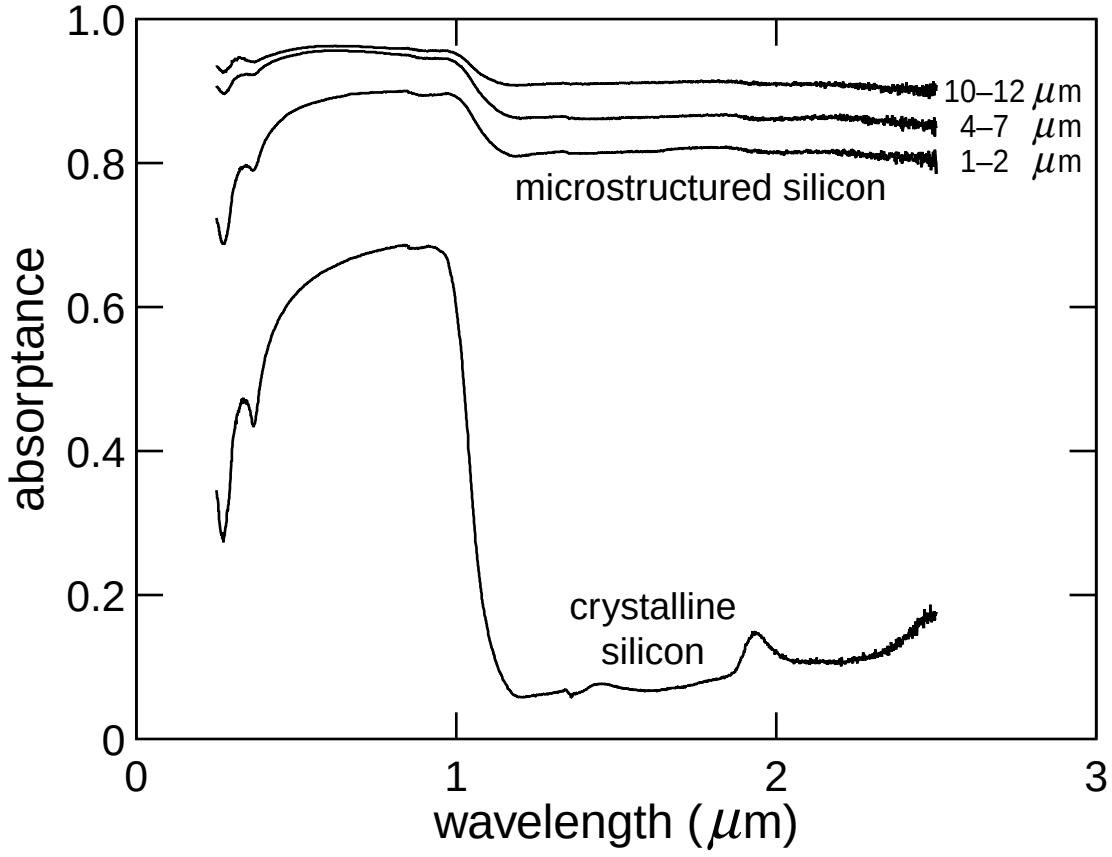
absorptance



C. Wu, *et al.*, *Appl. Phys. Lett.* **78**, 1850 (2001)

Background

absorptance



C. Wu, *et al.*, *Appl. Phys. Lett*. 78, 1850 (2001)

Background

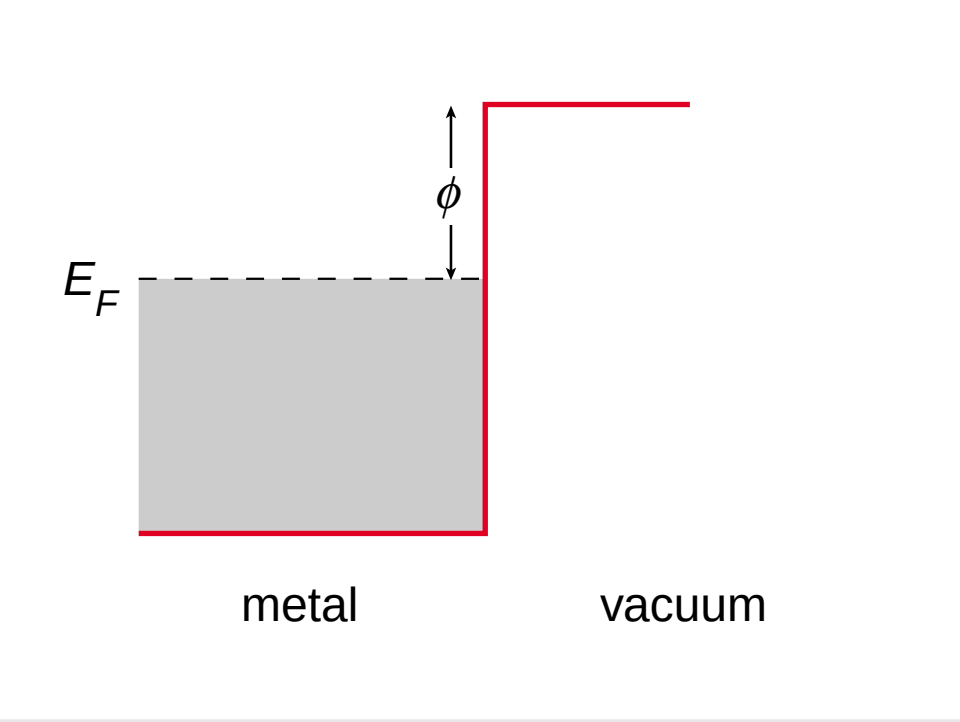
Points to keep in mind:

- **one-step, maskless process**
- **large area with uniform high density of spikes**
- **band structure change**

Outline

- Background
- **Results**
- Discussion

Field emission



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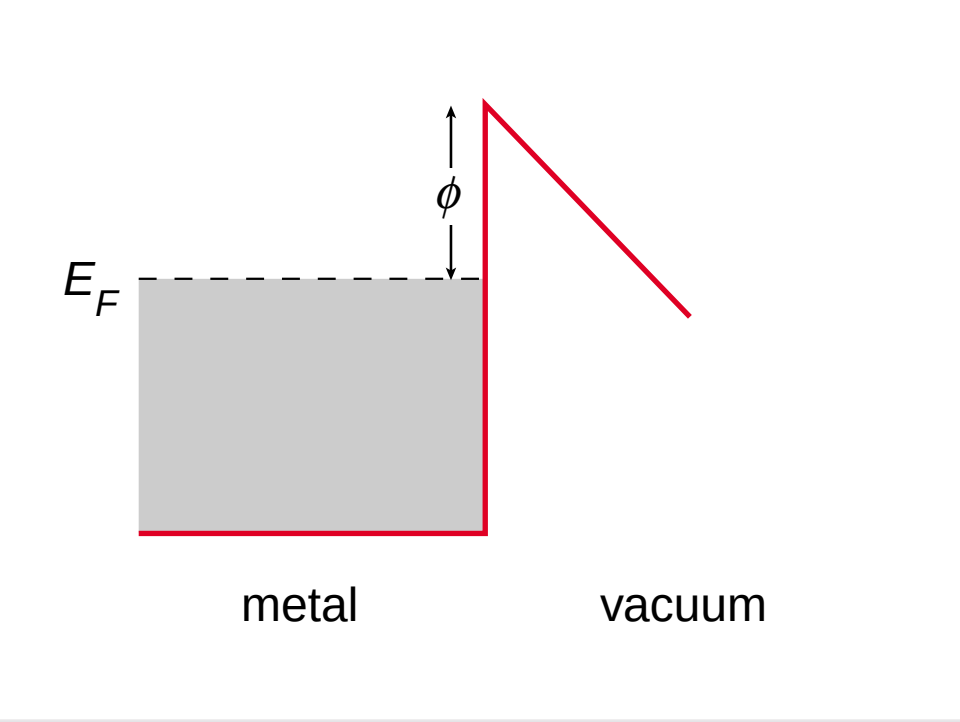

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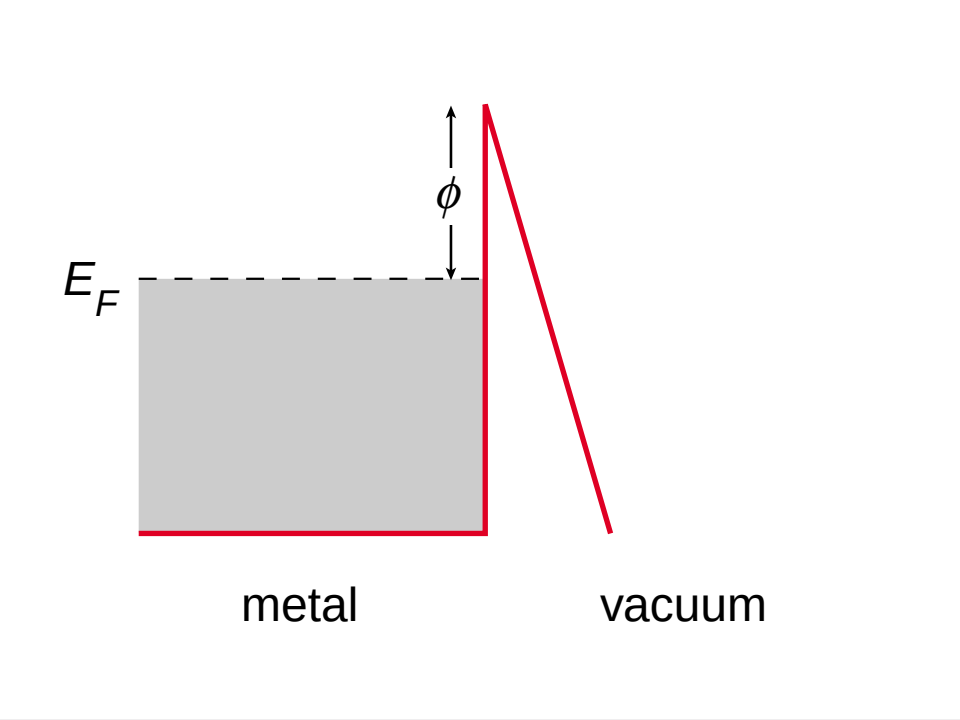

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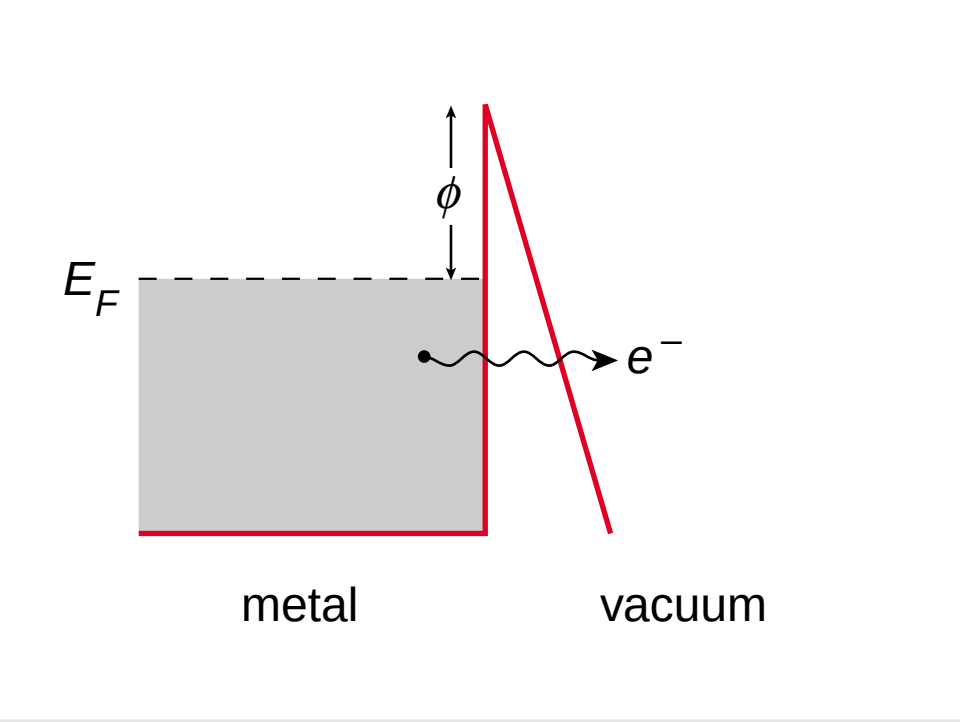

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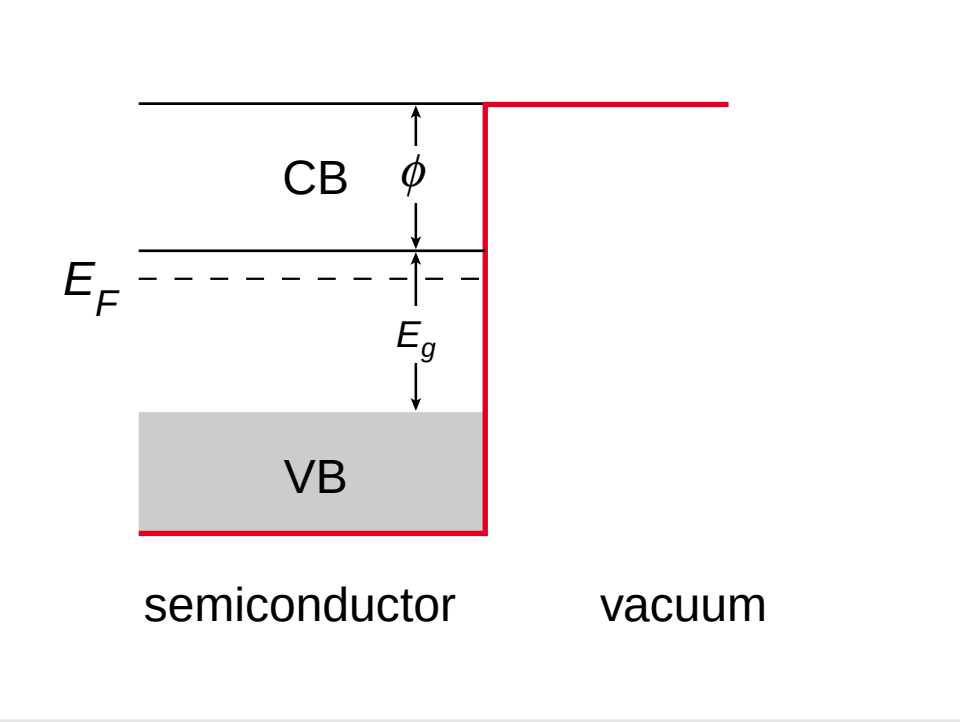

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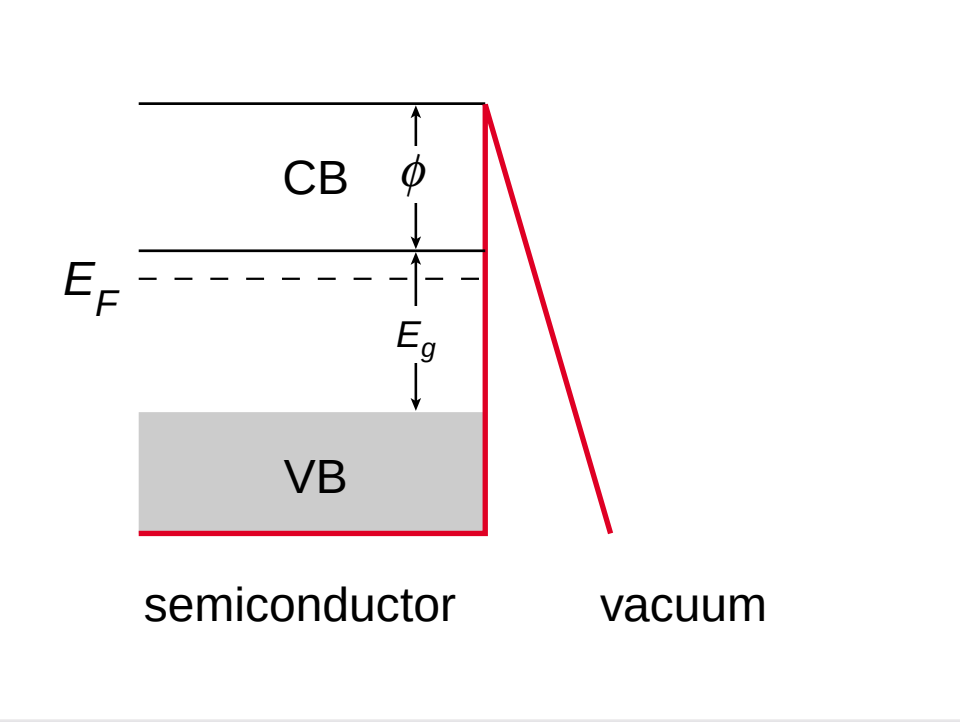

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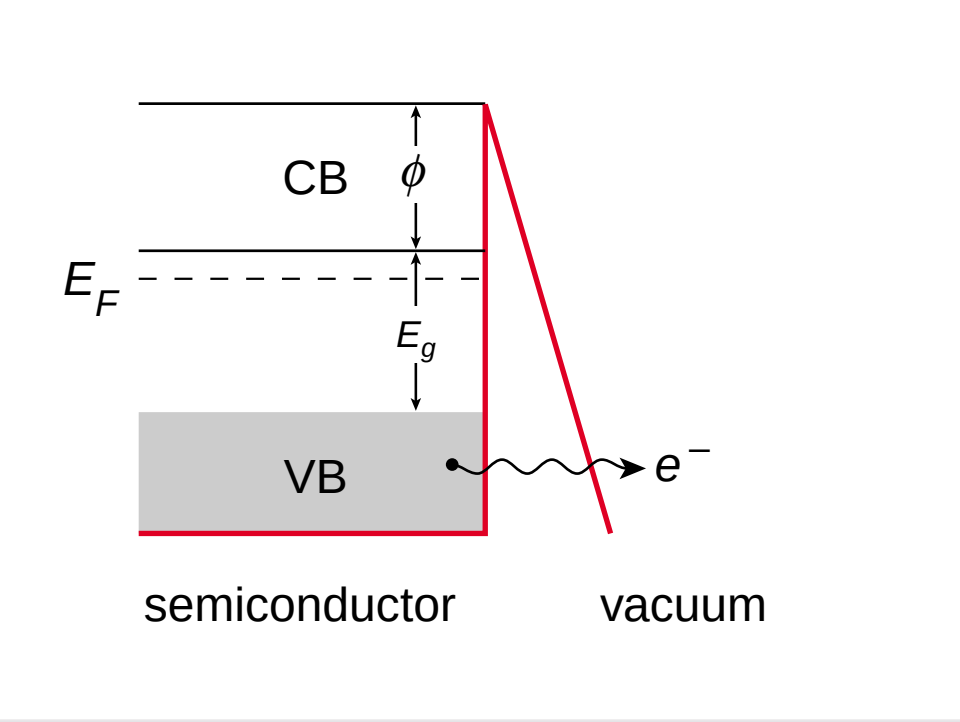

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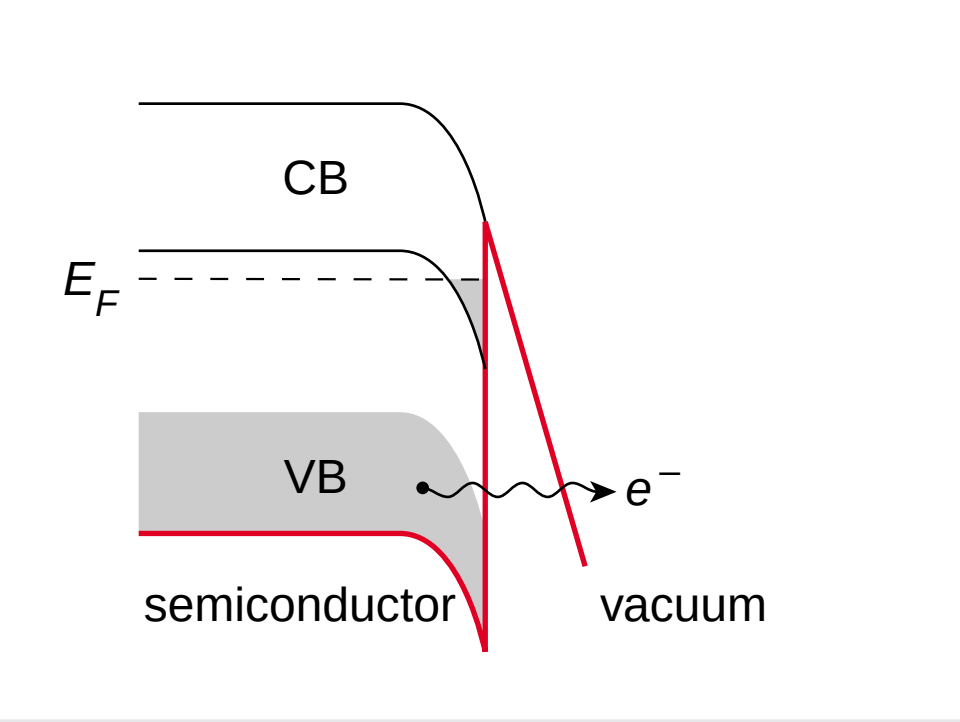

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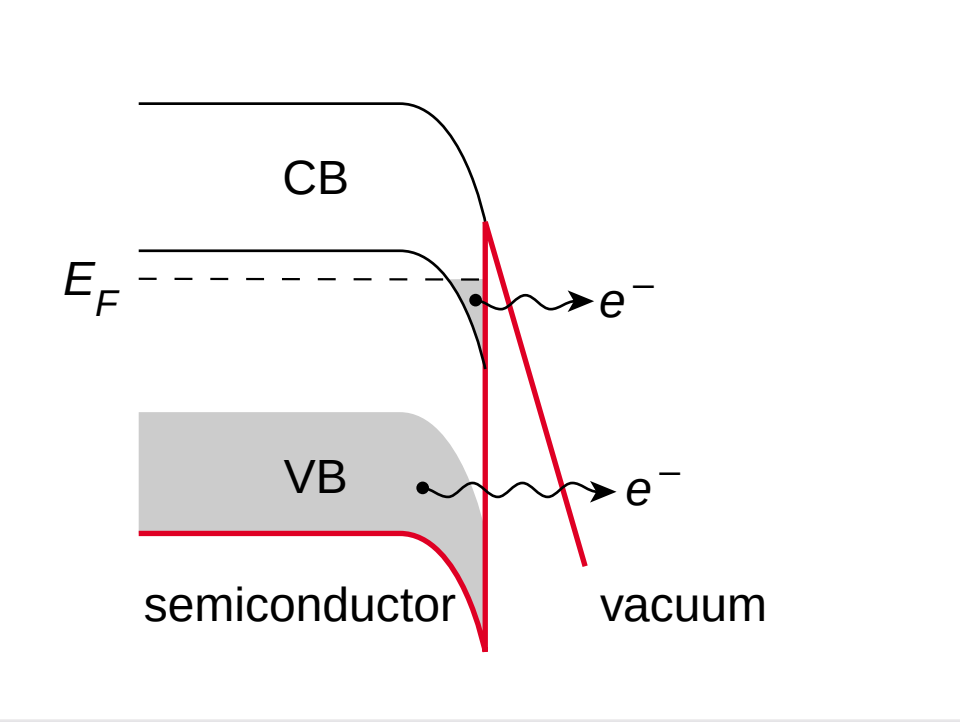
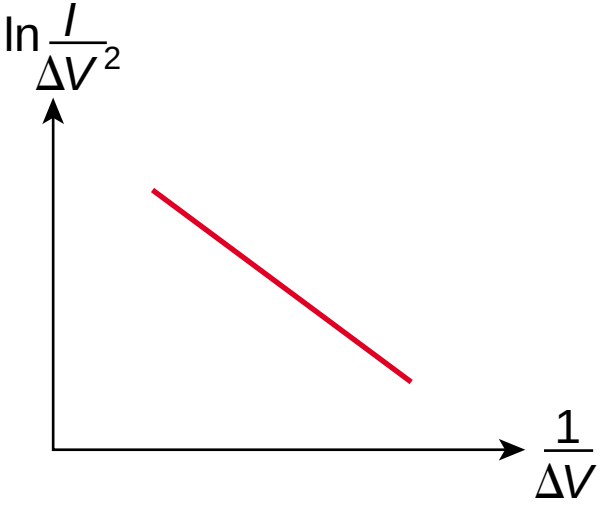


Field emission

$$\ln \frac{I}{\Delta V^2} = \ln a - b\frac{1}{\Delta V}$$



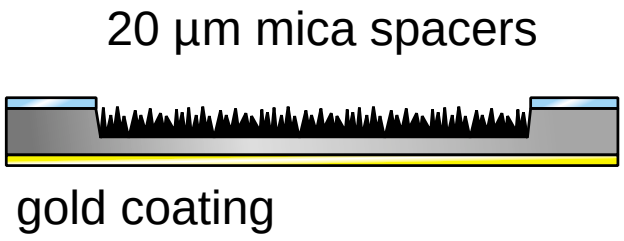
R.H. Fowler and L. Nordheim, *Proc. R. Soc. Lond. A* (1928)

Setup

Setup

gold coating

Setup



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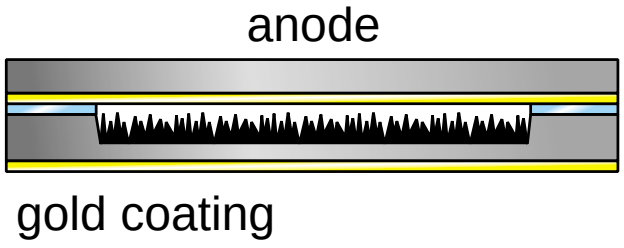

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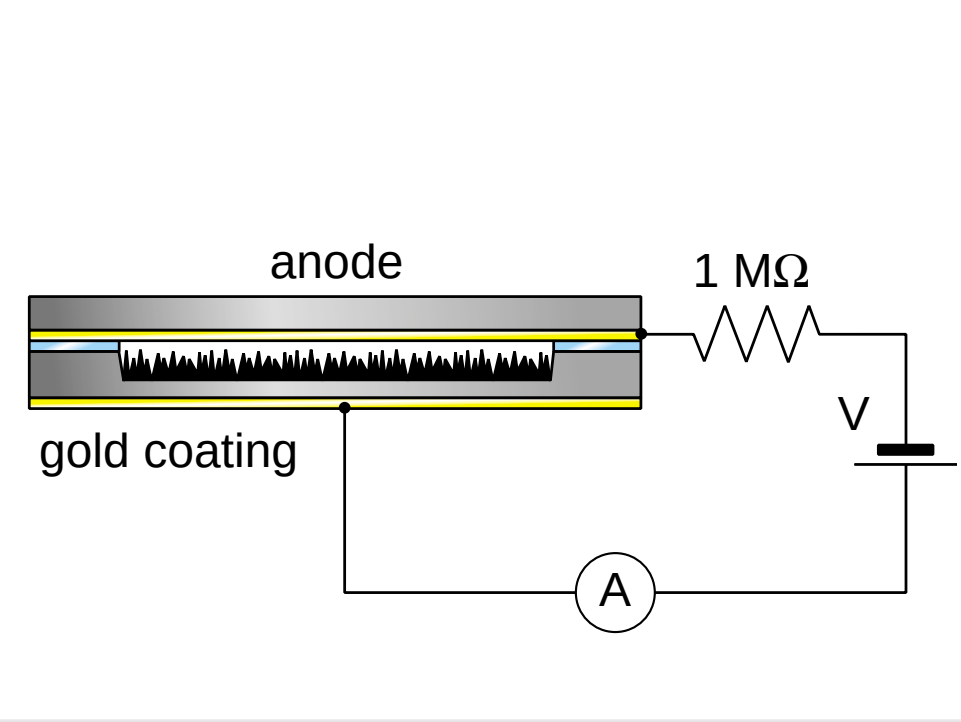
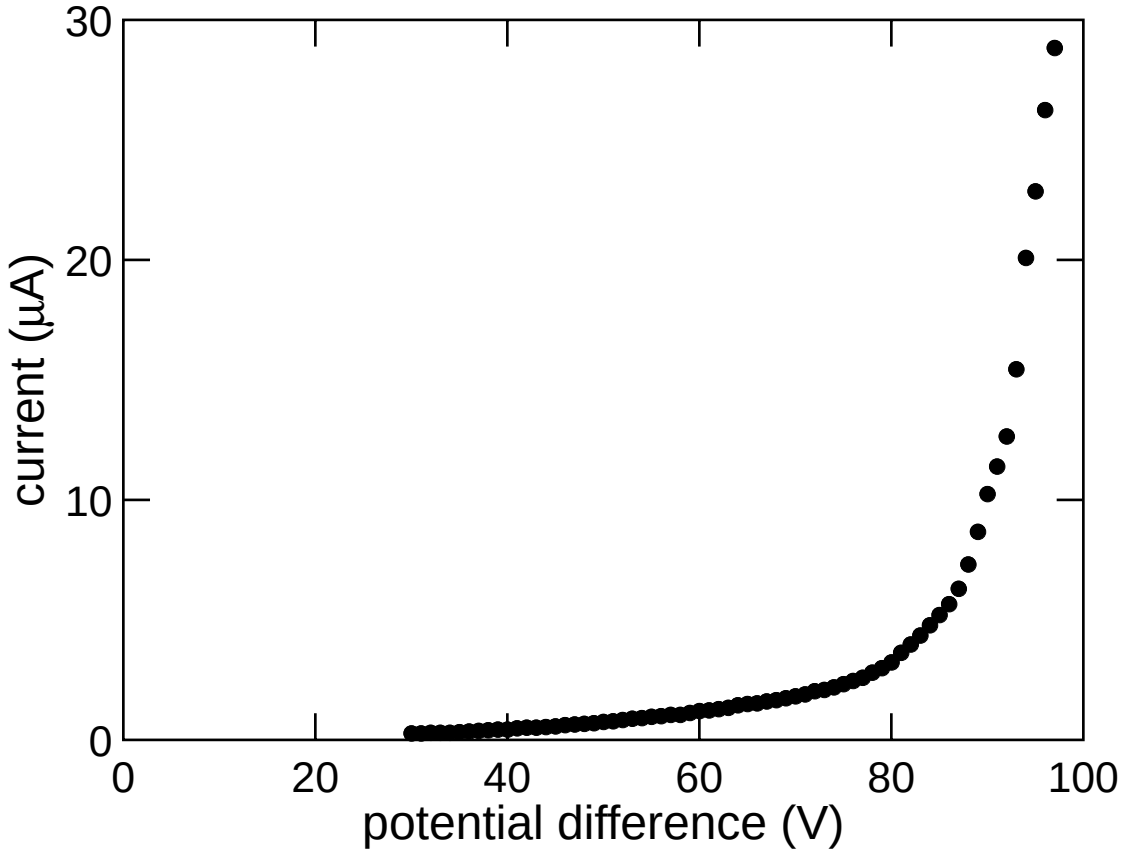


Results



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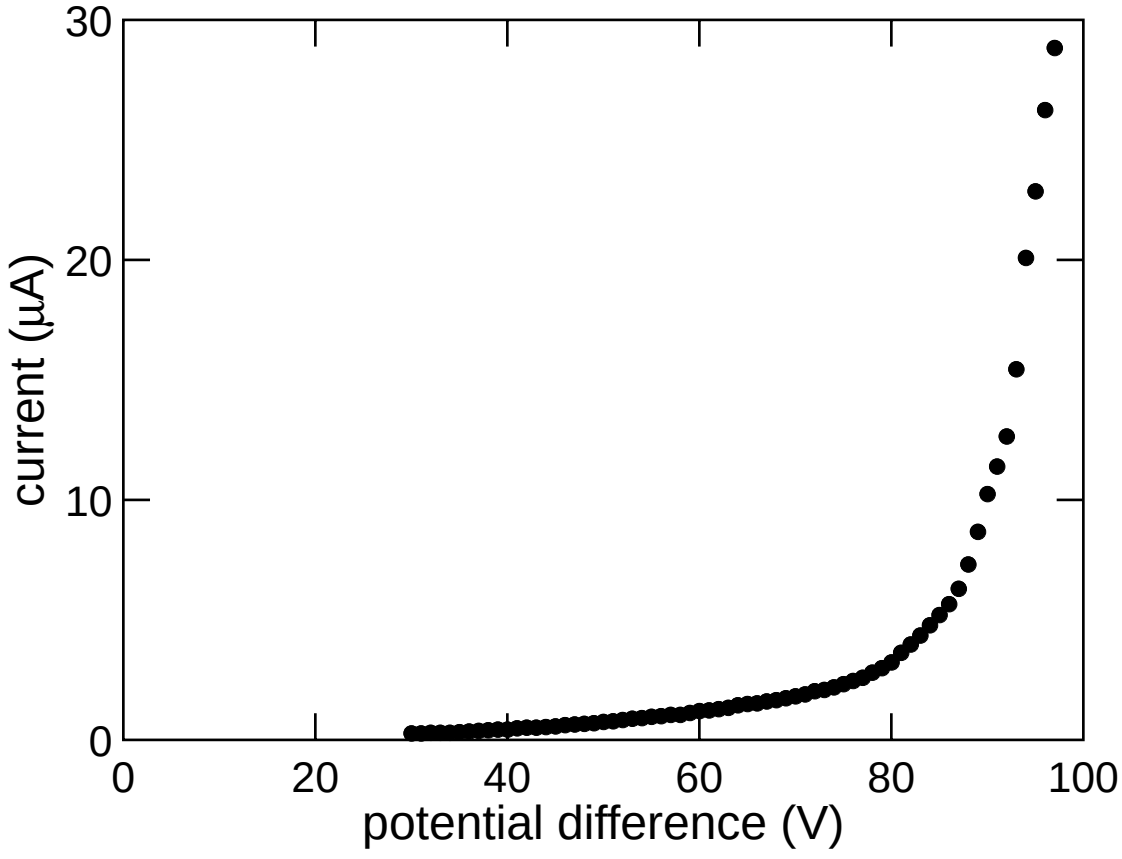
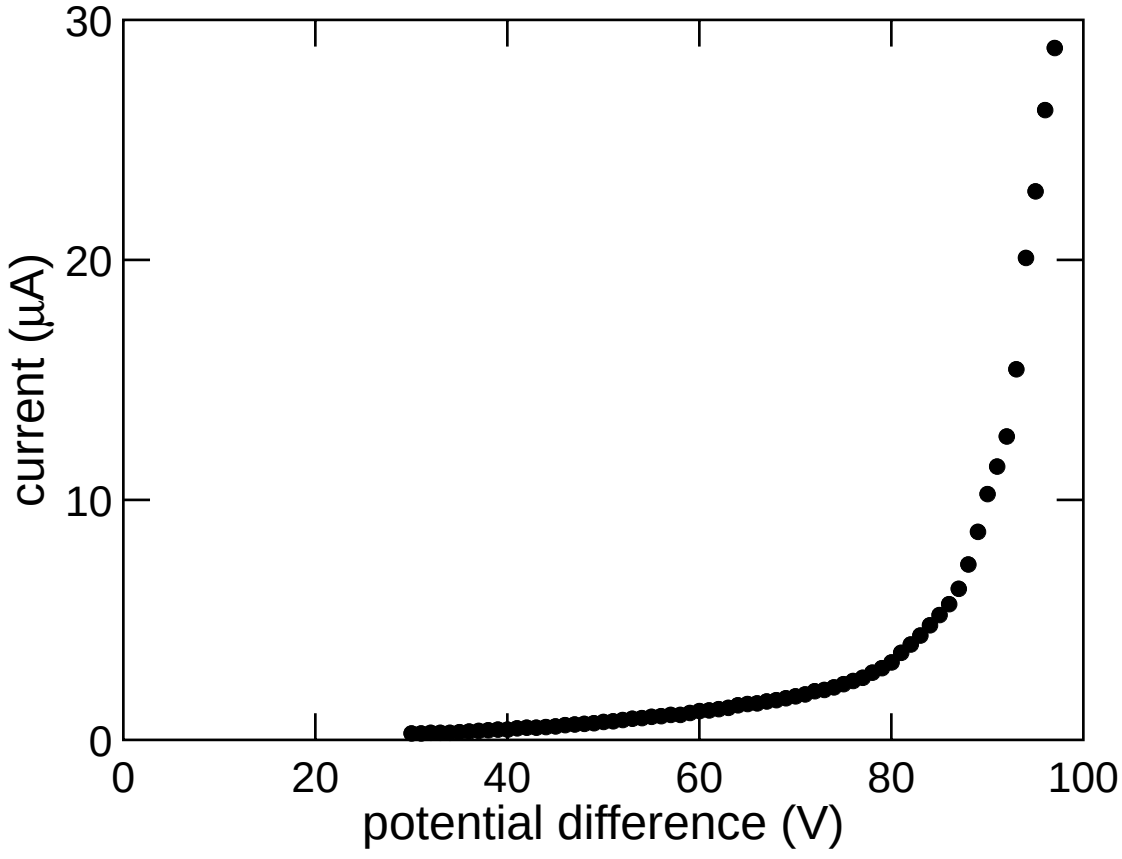


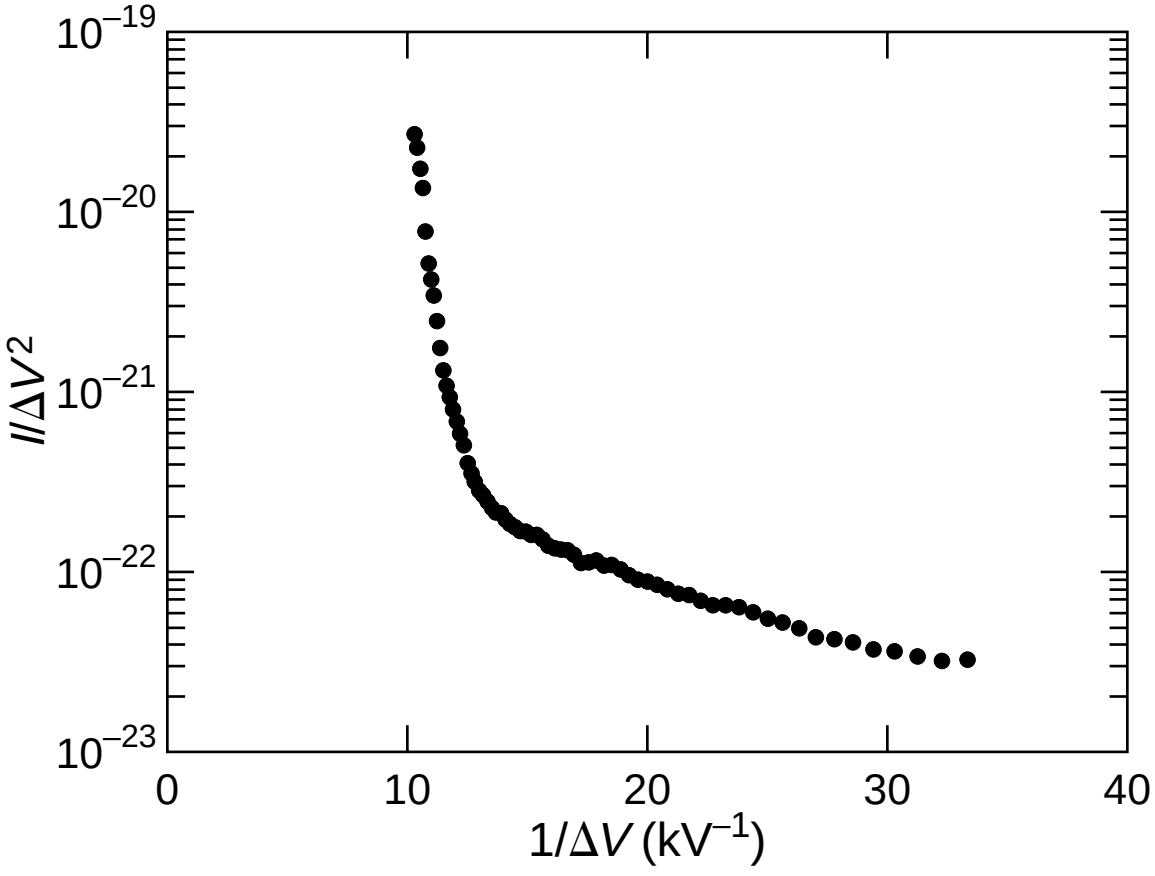
turn-on field (1 μA/cm^2): 1.3 V/μm

Results



threshold field (10 μA/cm^2): 2.15 V/μm

Results



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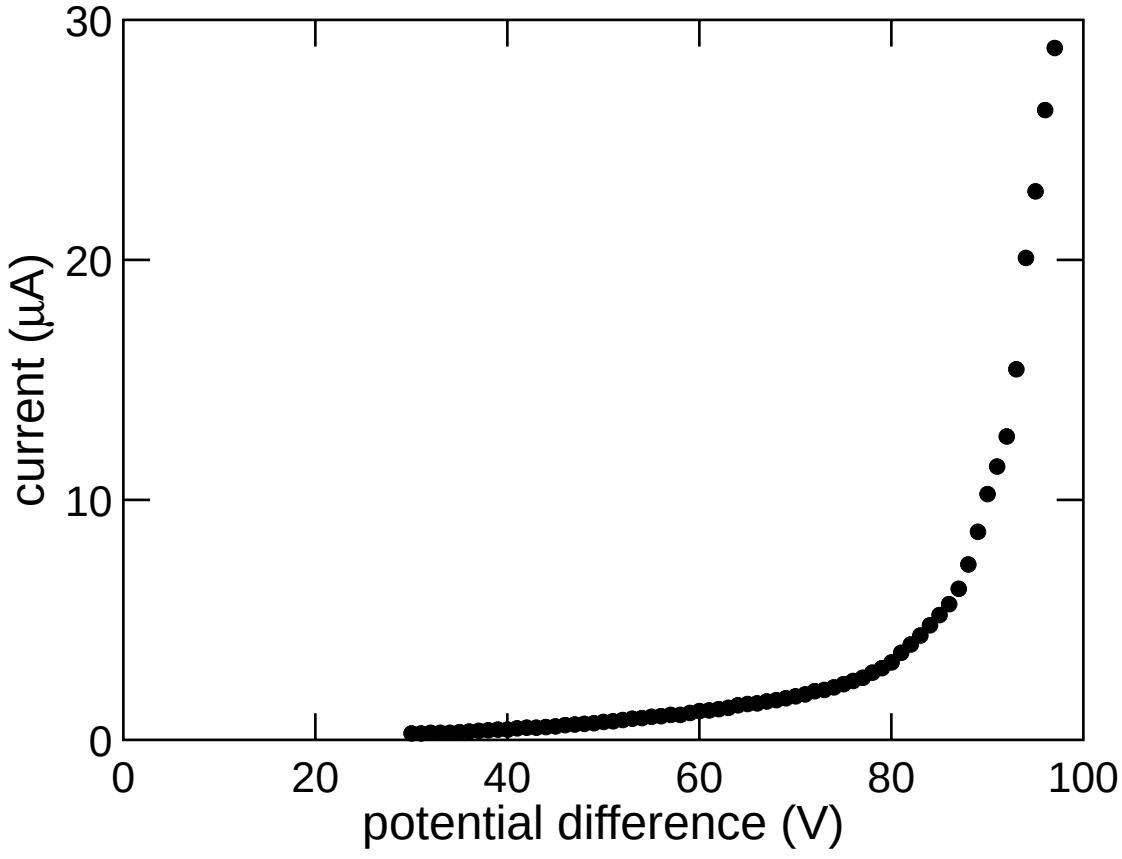

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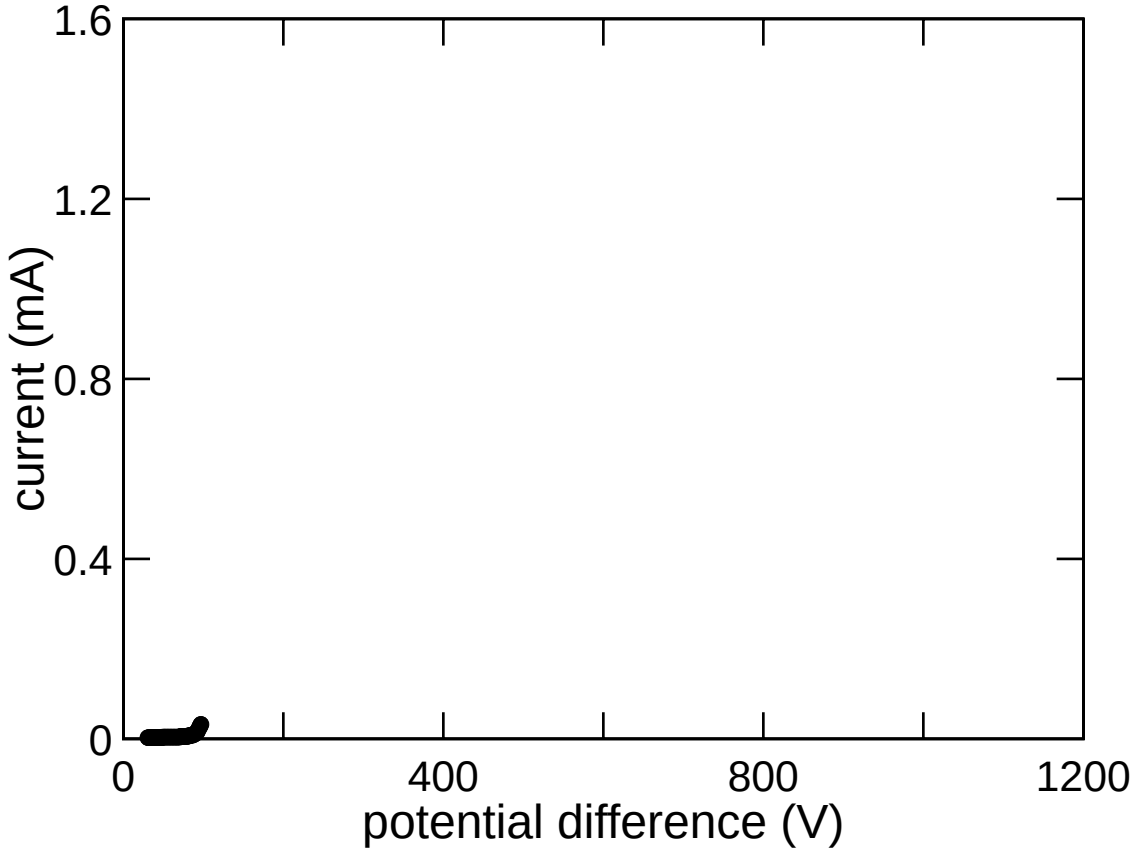

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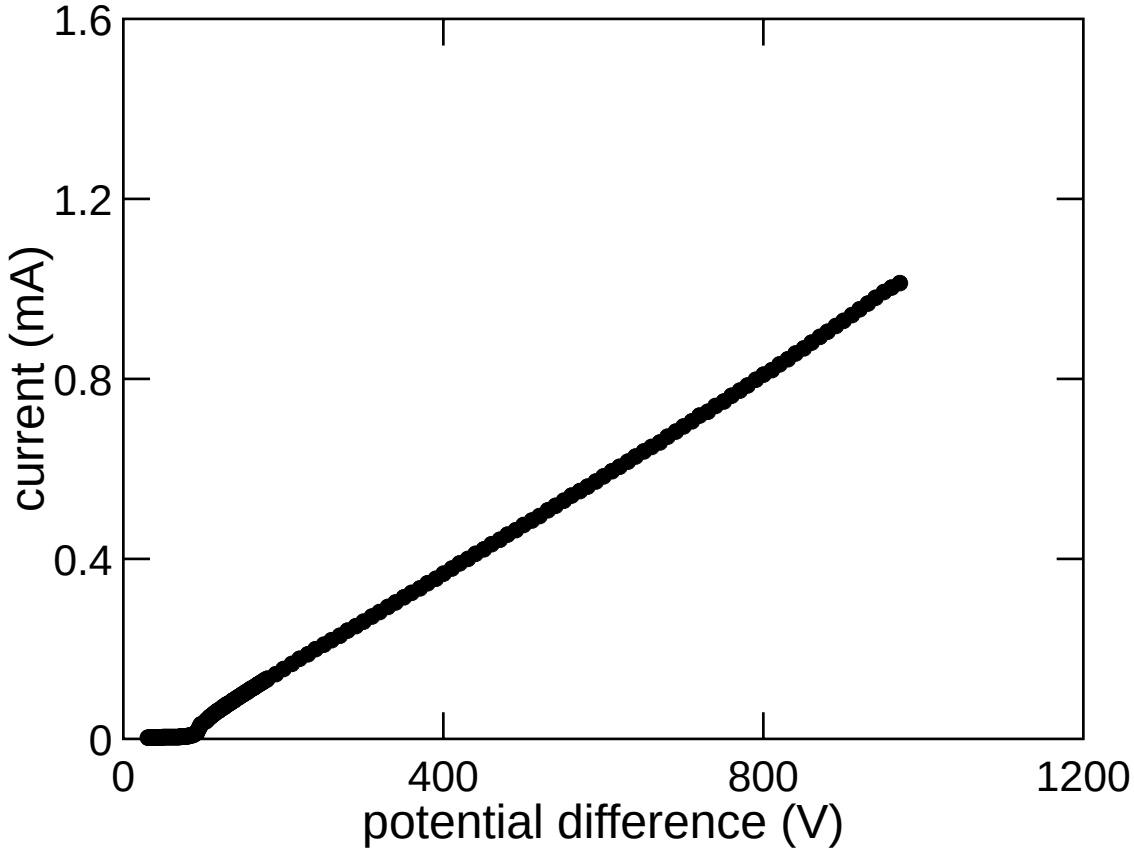
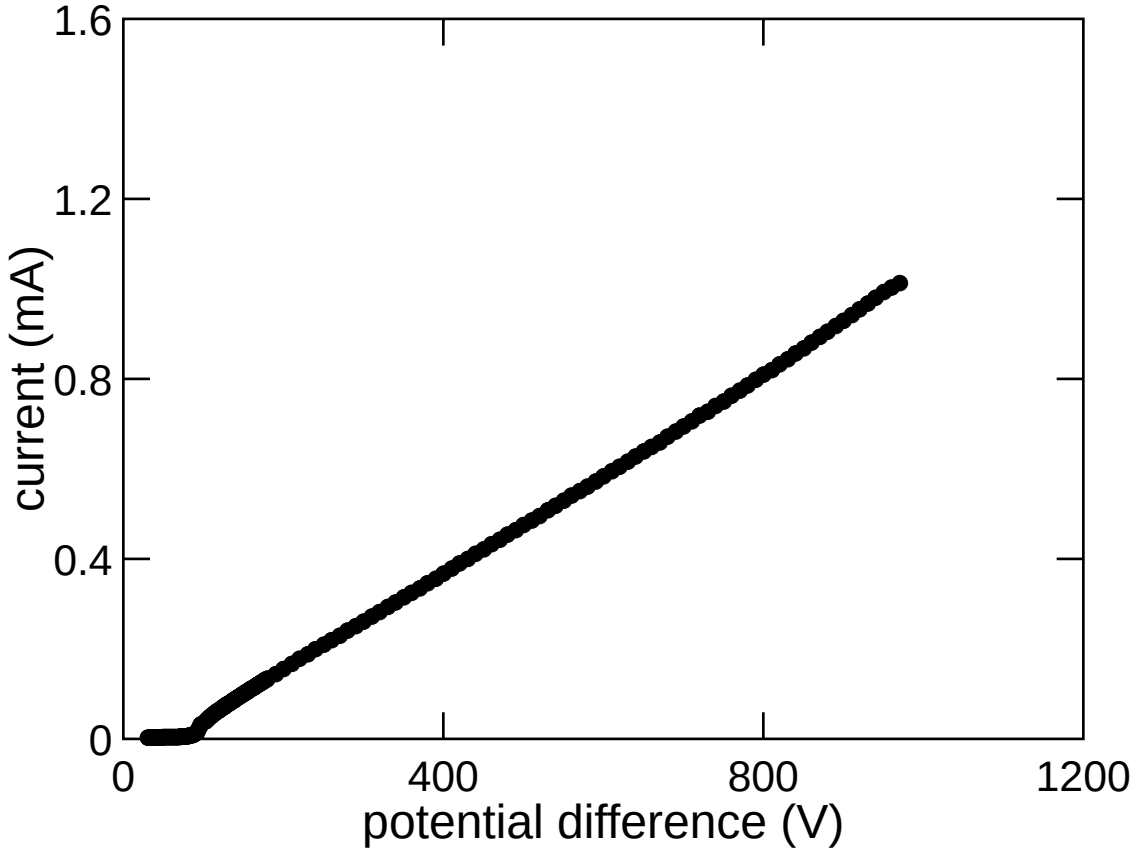
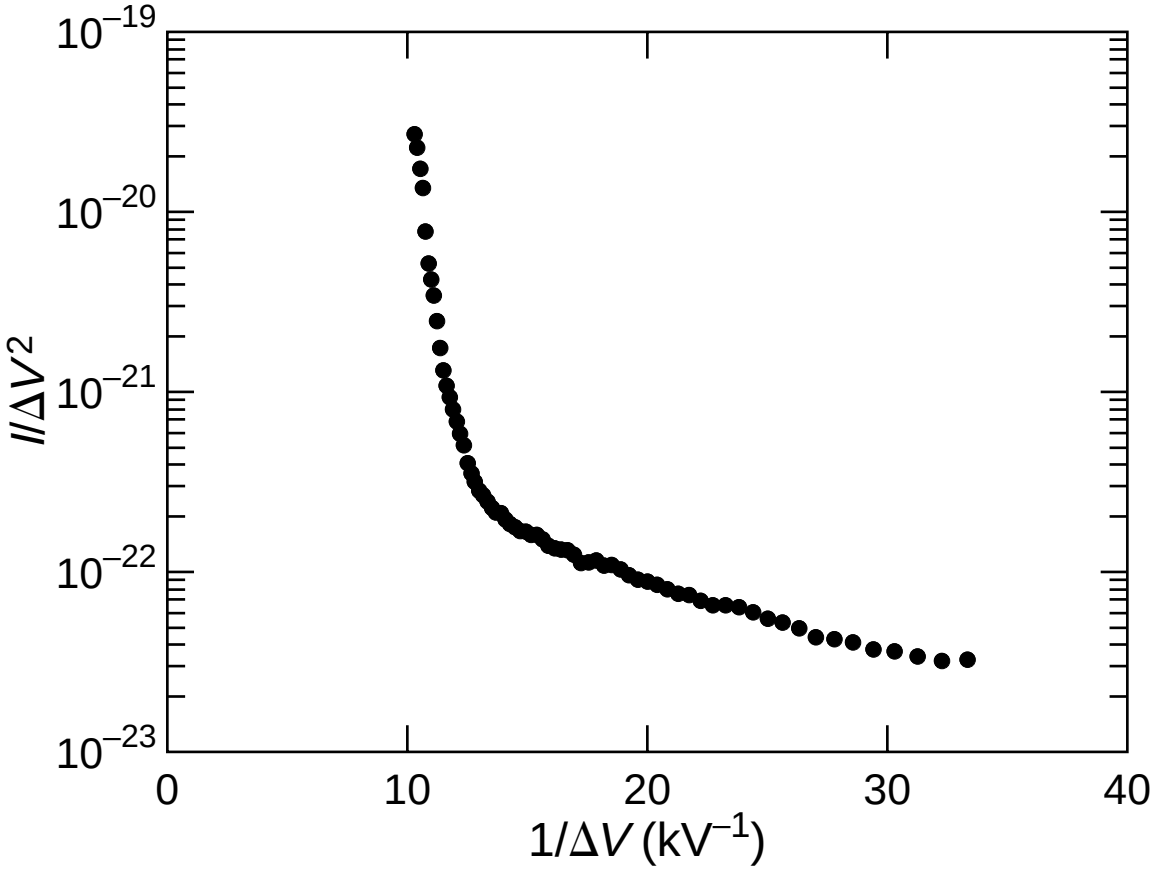


Results



maximum current: 2 mA (4 mm^2 sample)

Results



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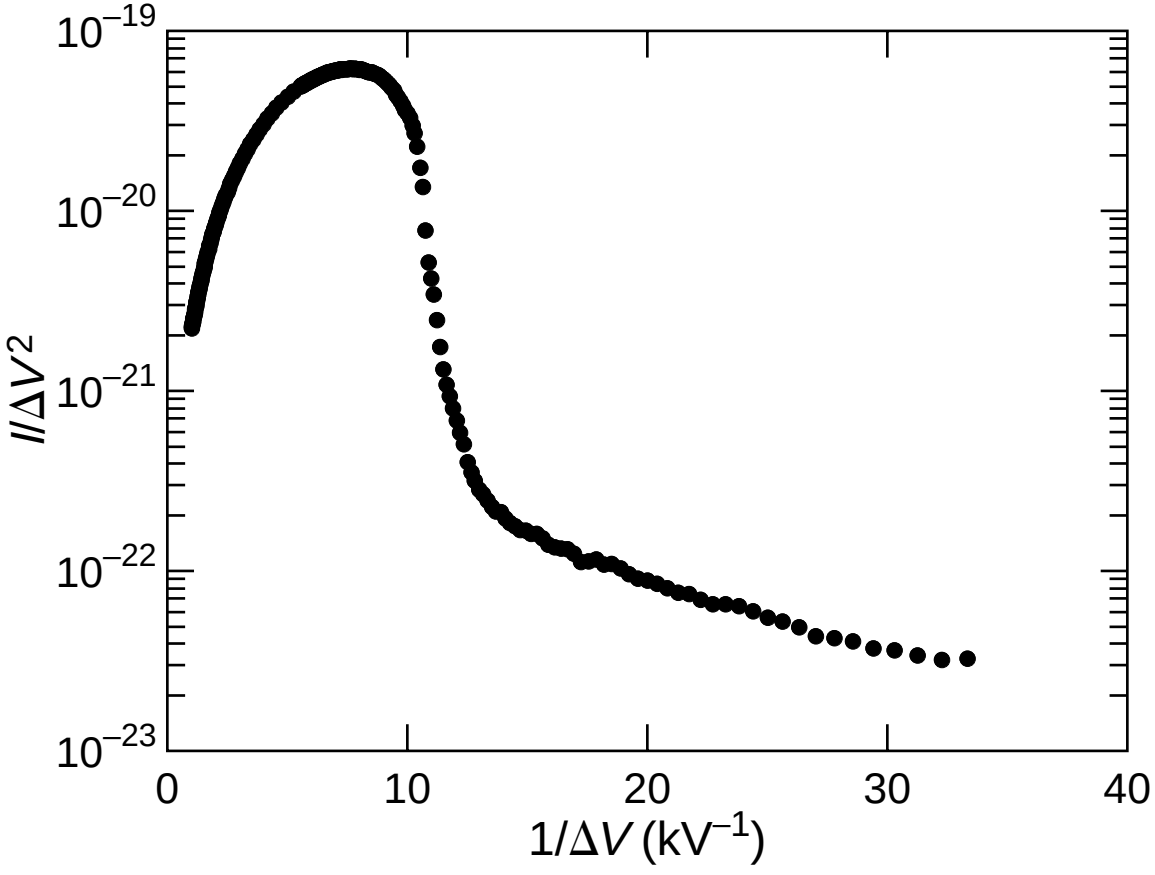
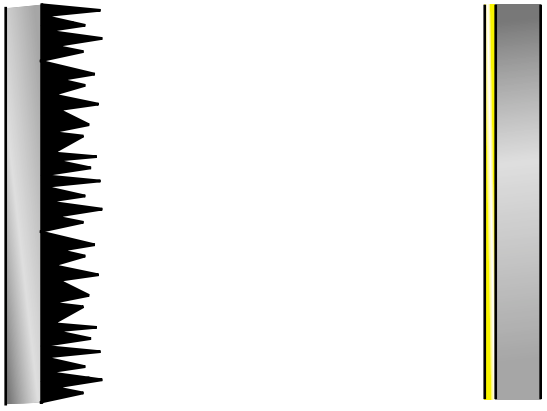
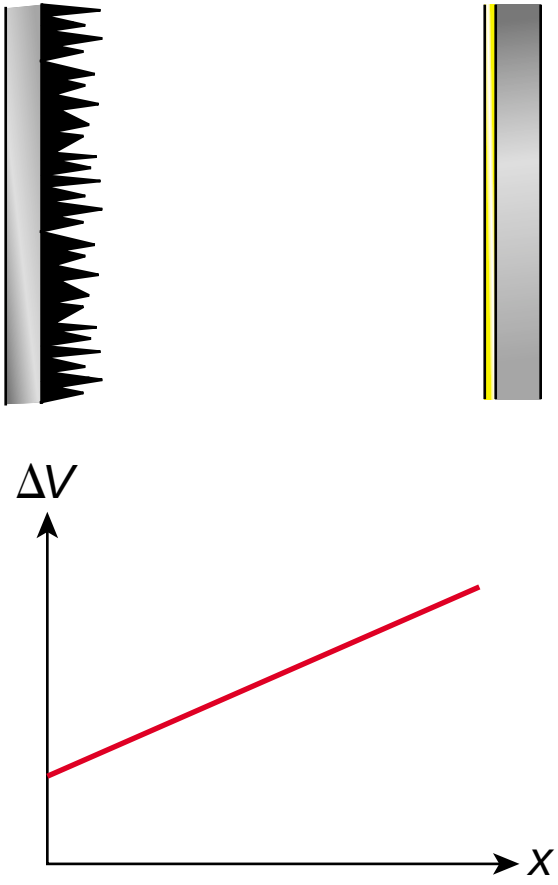


Space charge effect



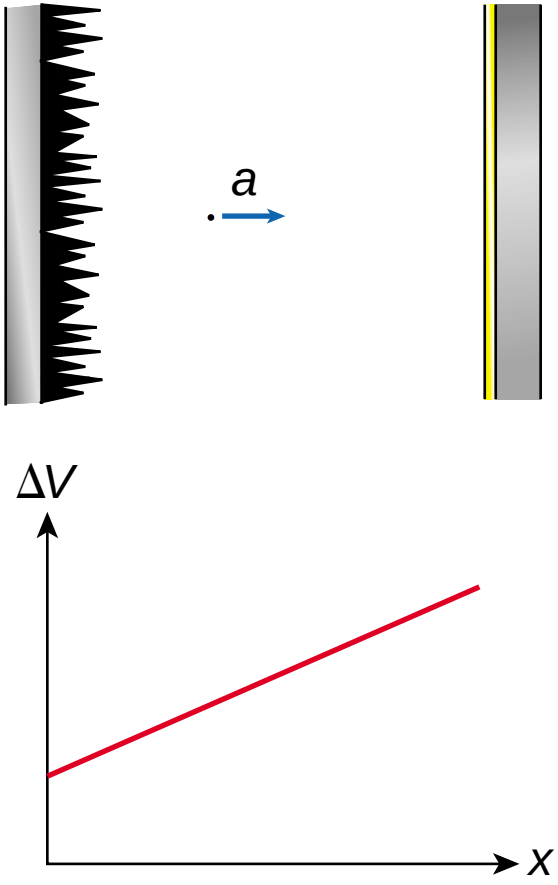
Y.Y. Lau *et al*., *Phys. Plasmas* 1, 2082 (1994)

Space charge effect



Y.Y. Lau *et al.*, *Phys. Plasmas* 1, 2082 (1994)

Space charge effect



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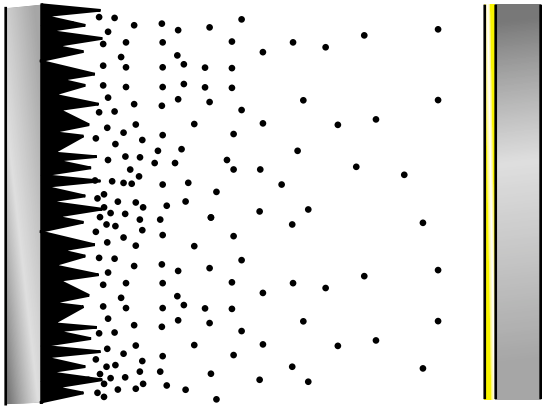

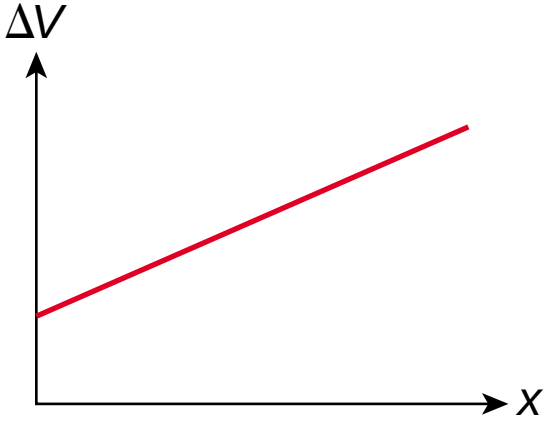

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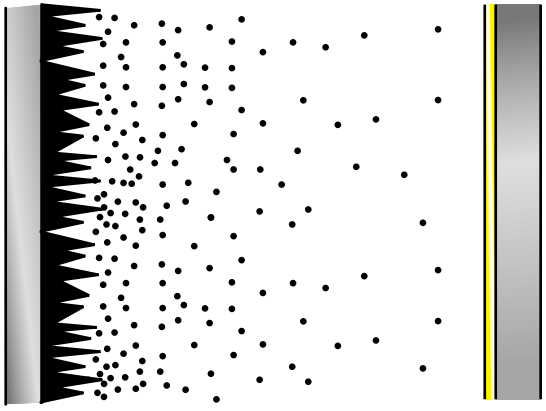

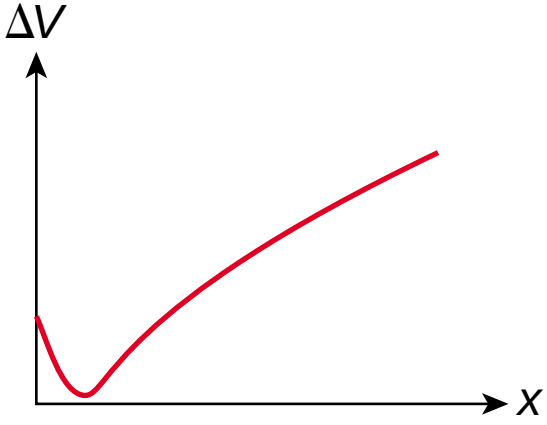

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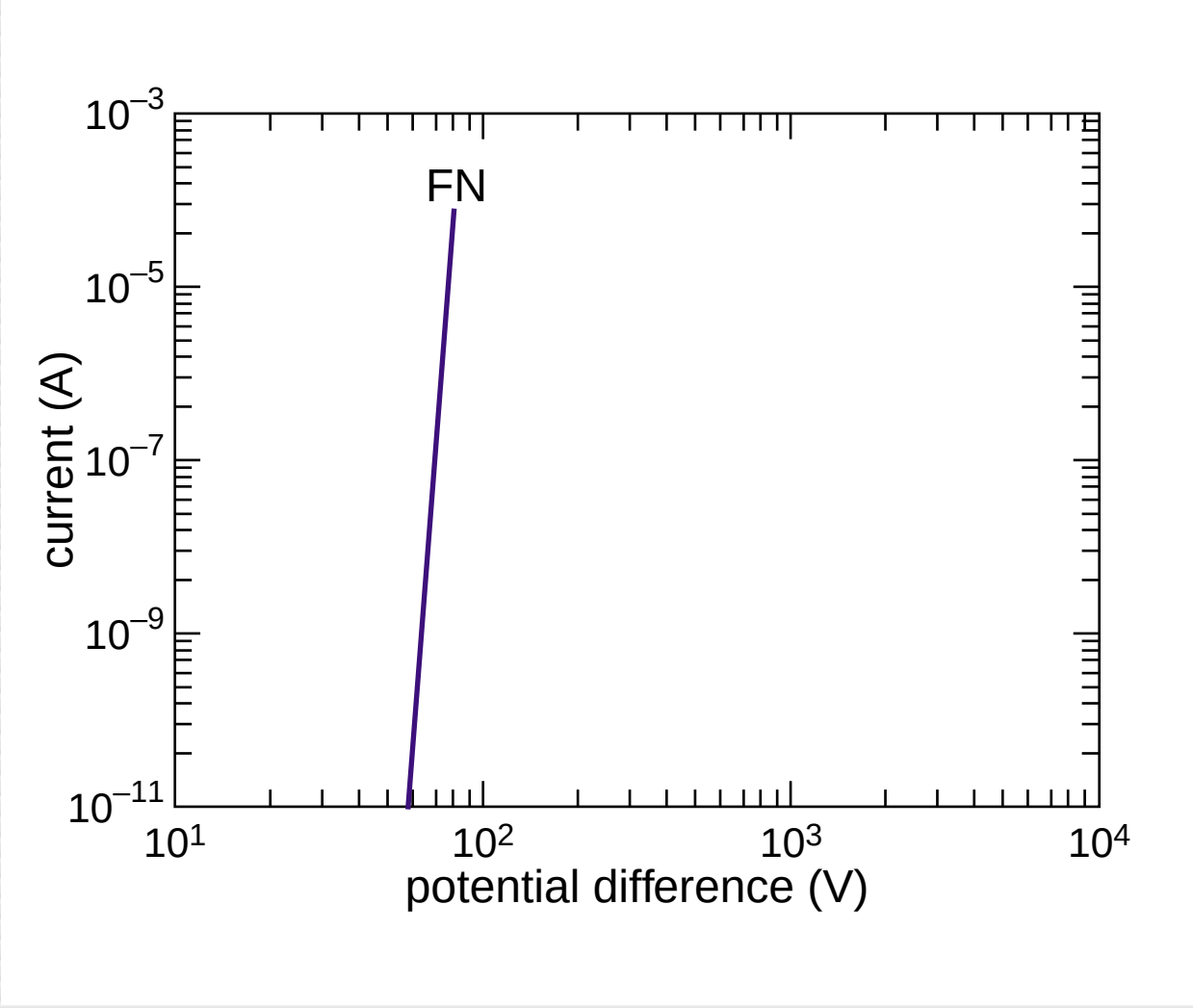

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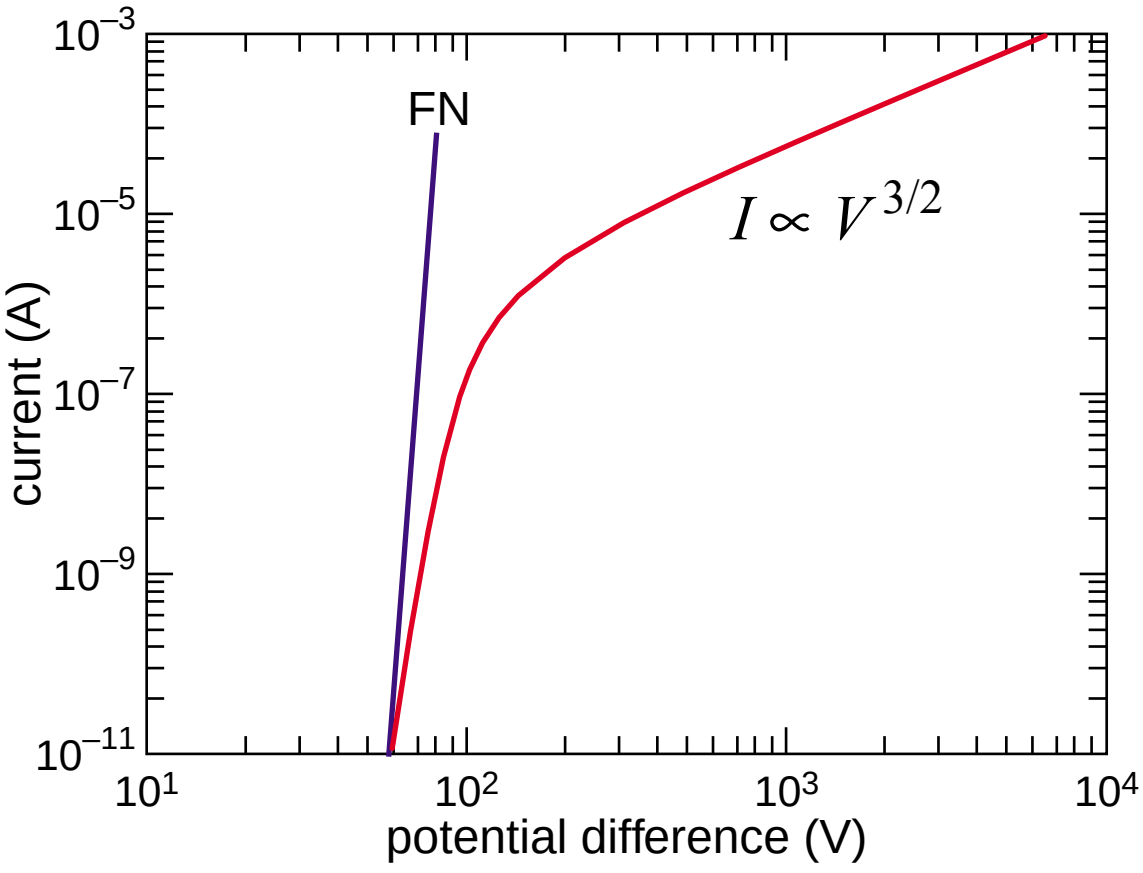

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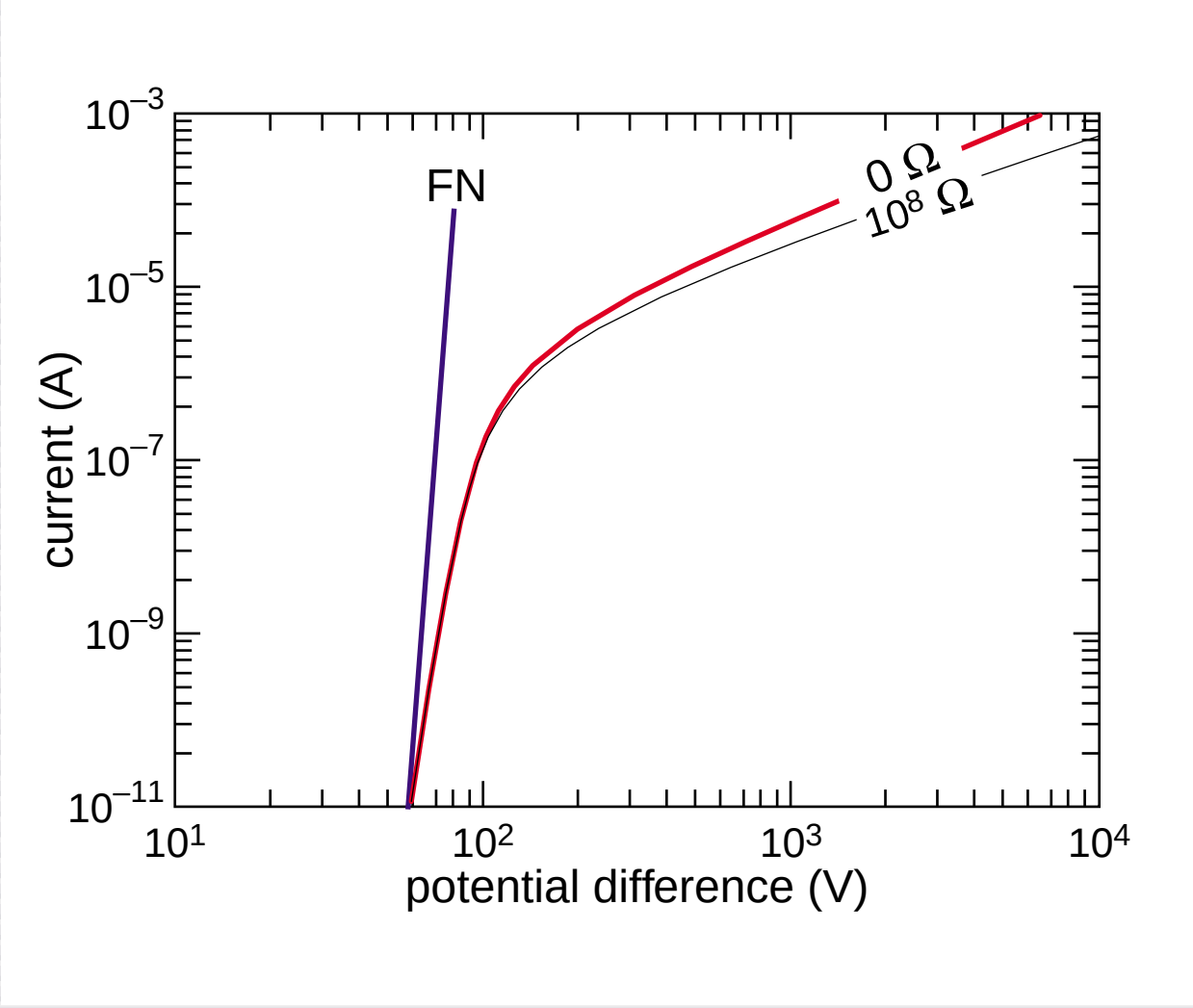

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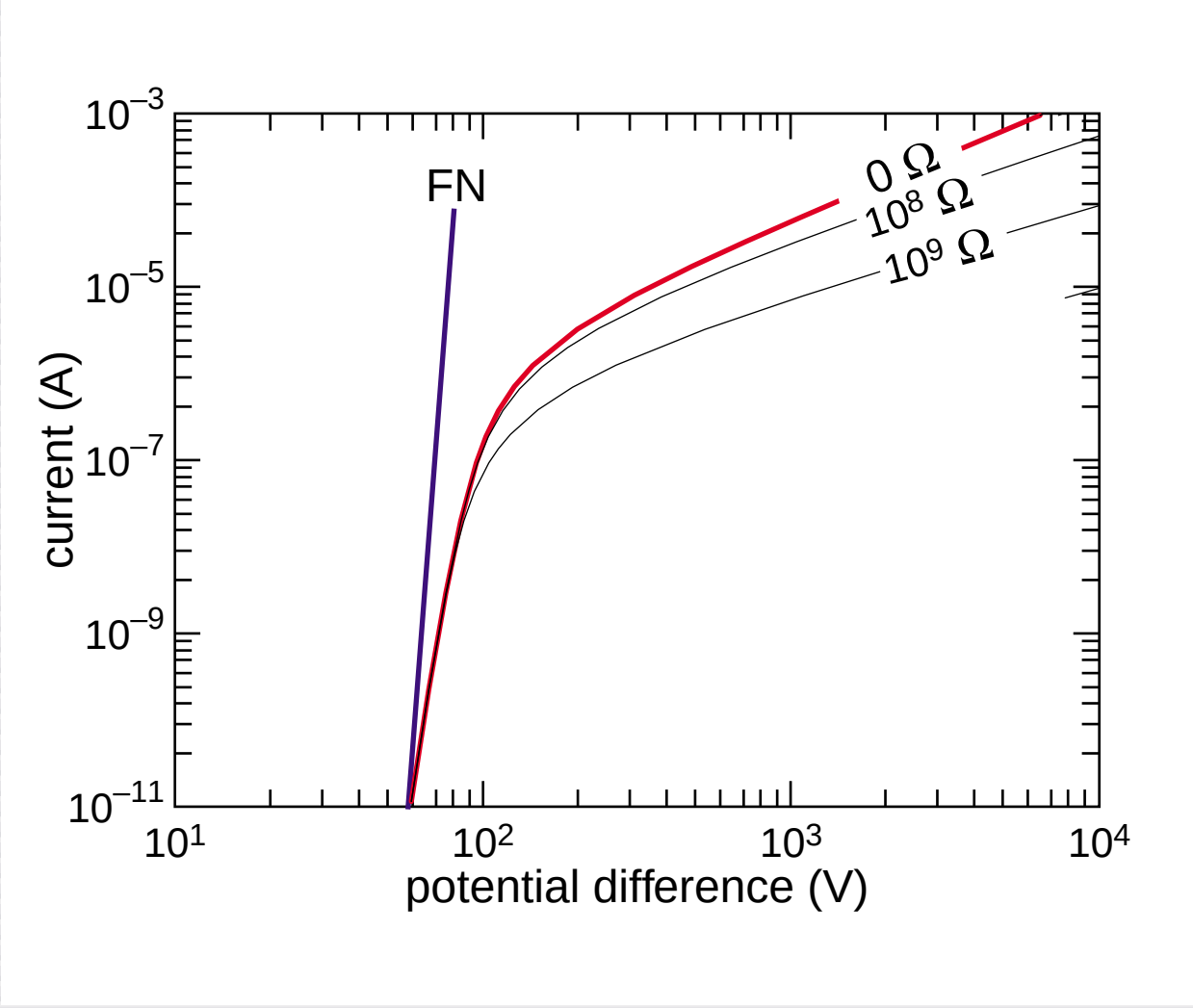

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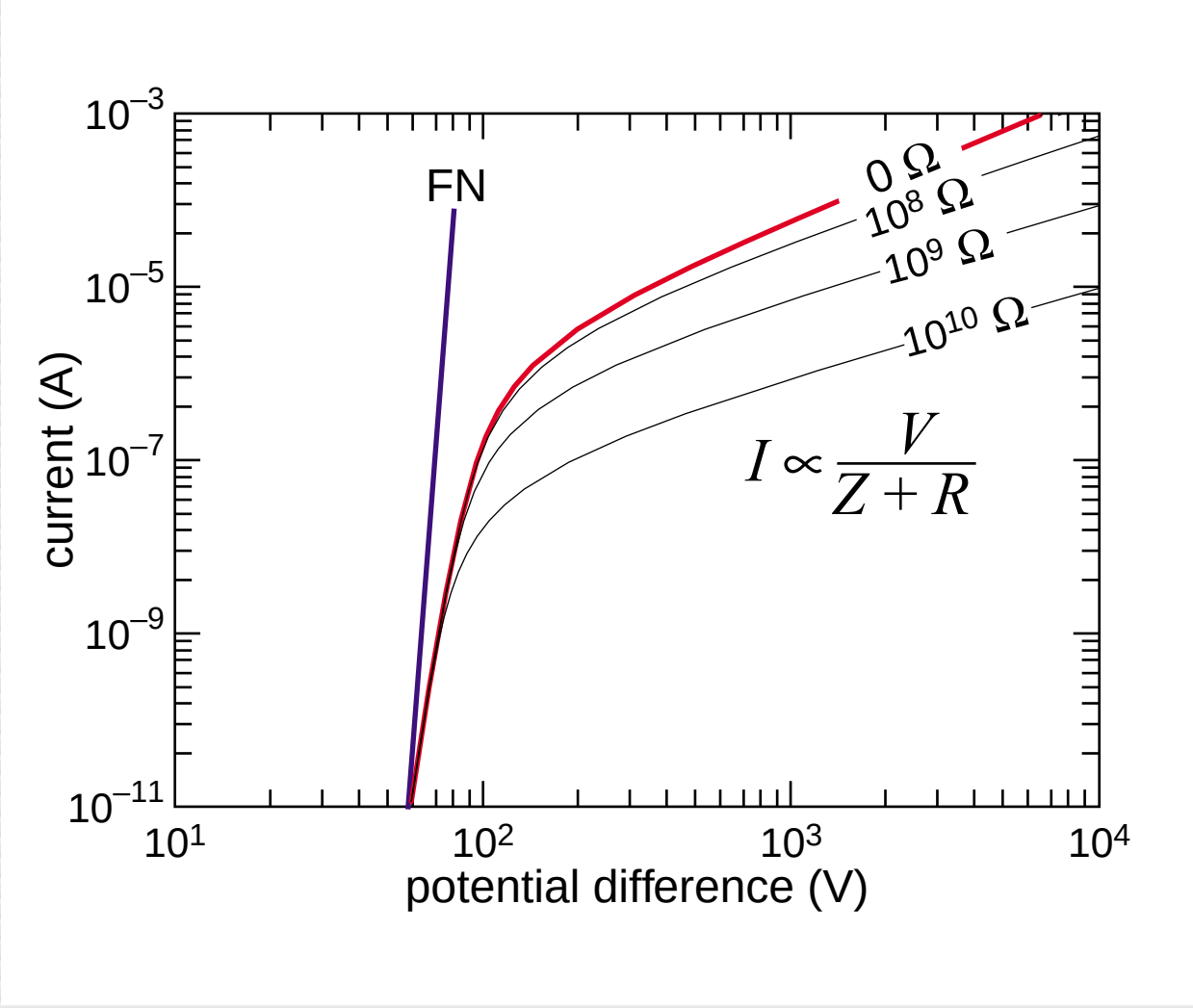

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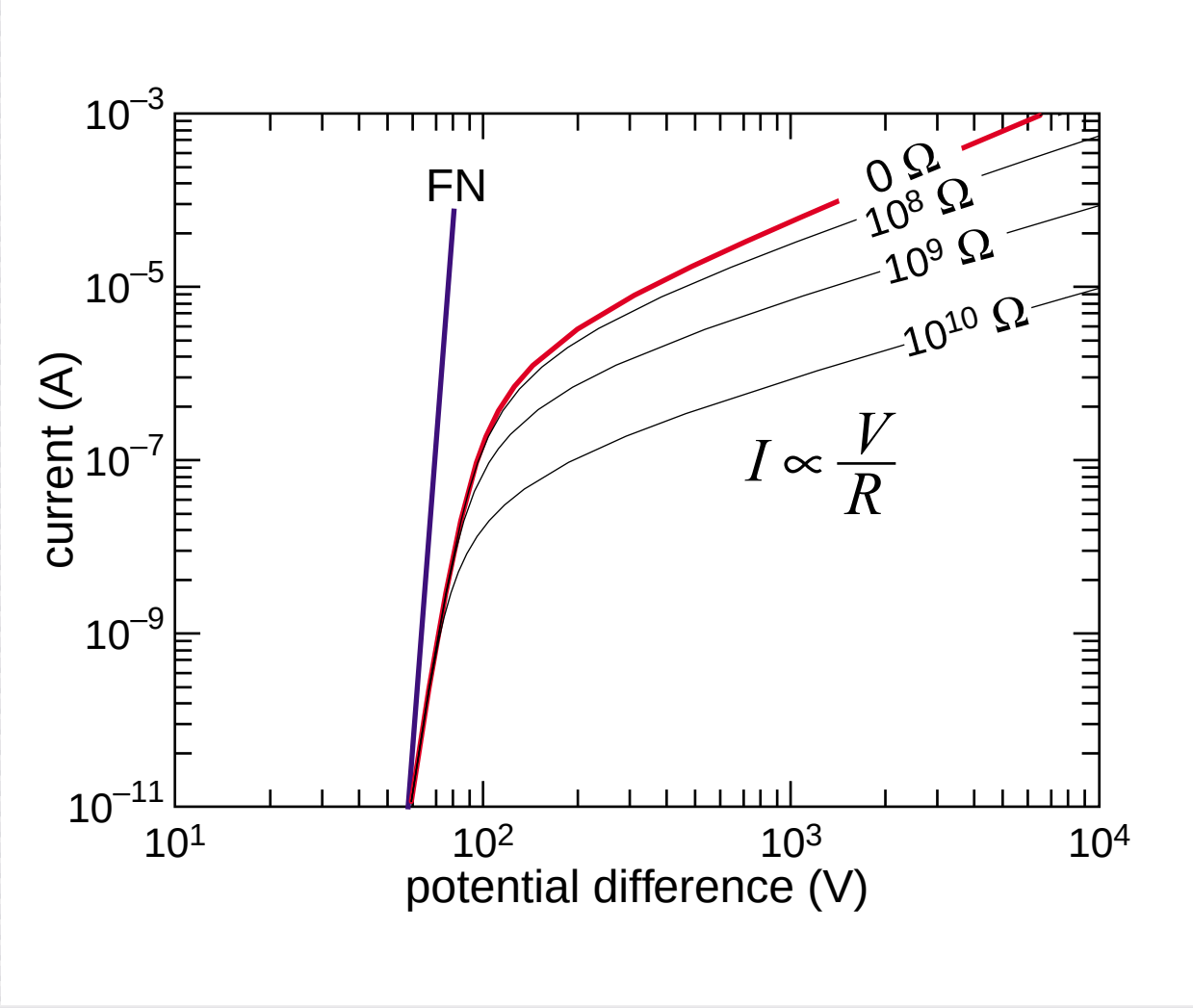

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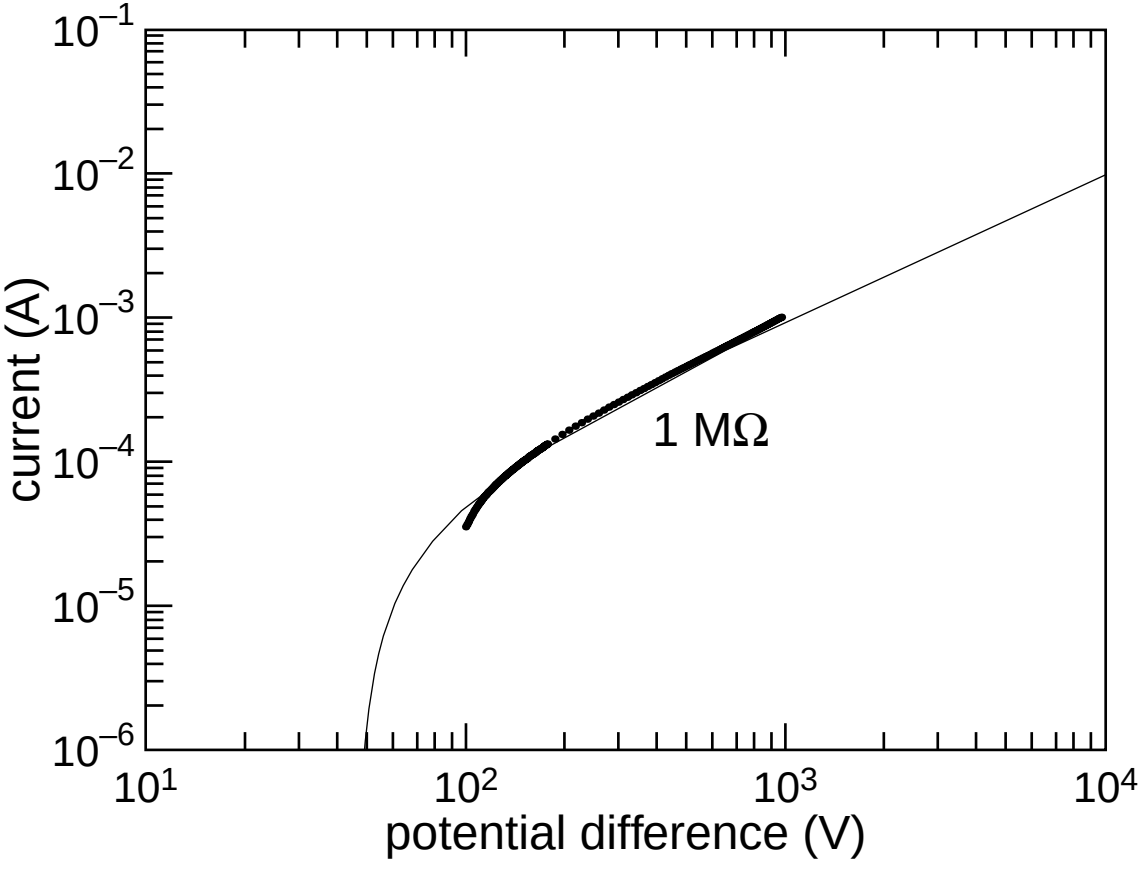

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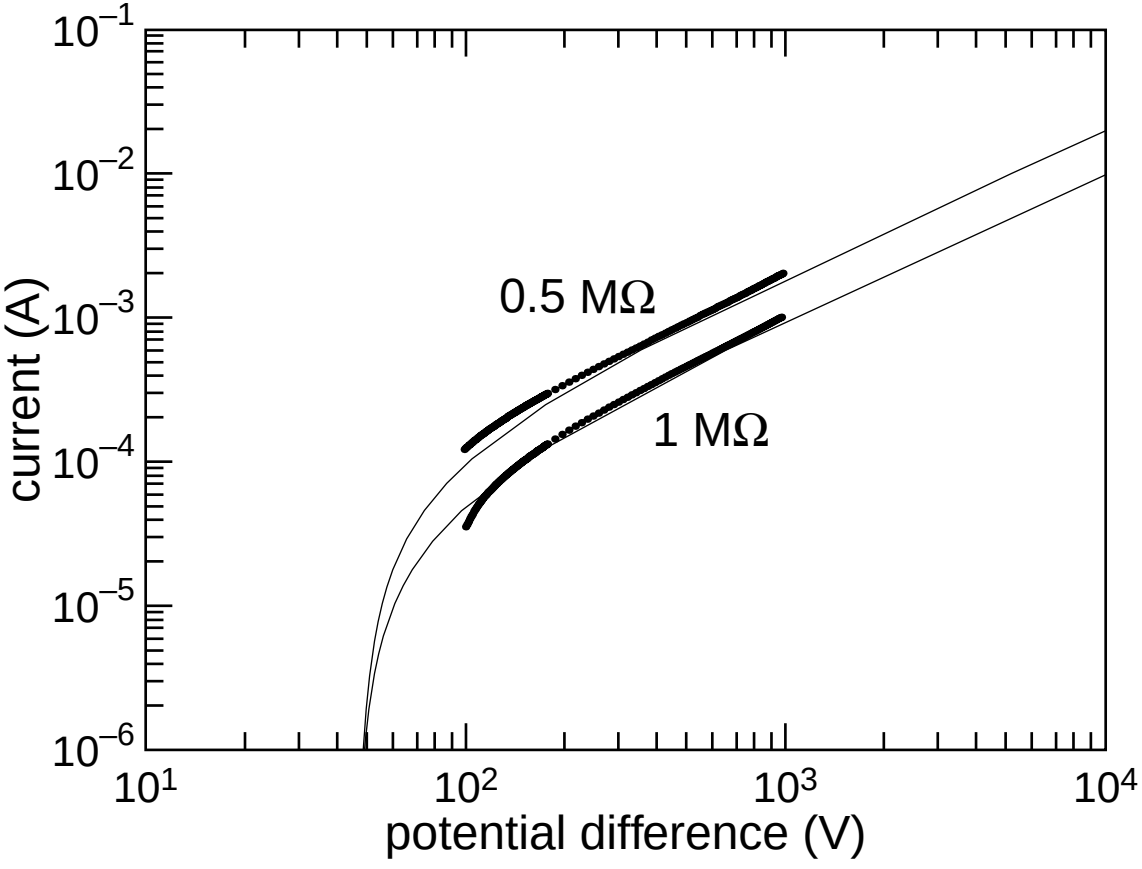


Outline

- Background
- Results
- **Discussion**

Discussion

Ion channeling and electron backscattering

- **spikes retain crystalline order**
- **high density of defects**

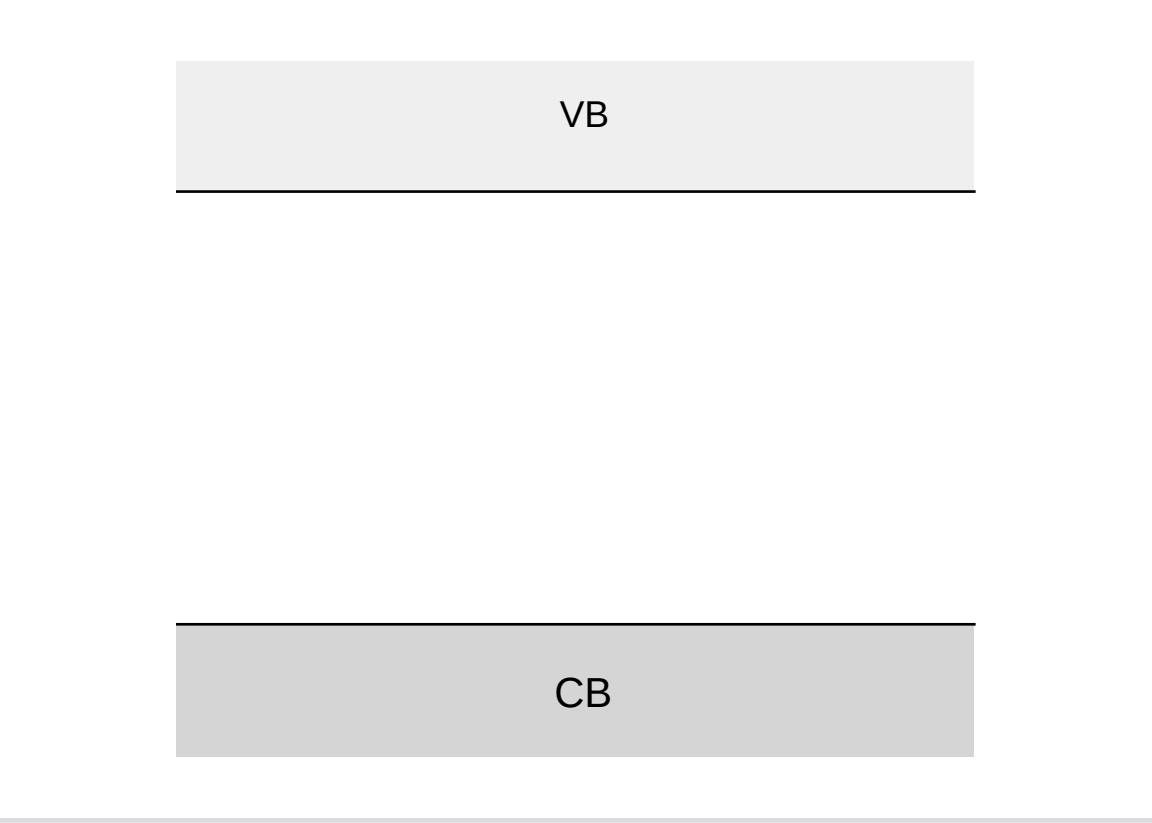
Discussion

Secondary ion mass spectrometry:

- 10^{20} cm^{-3} sulfur
- 10^{17} cm^{-3} fluorine

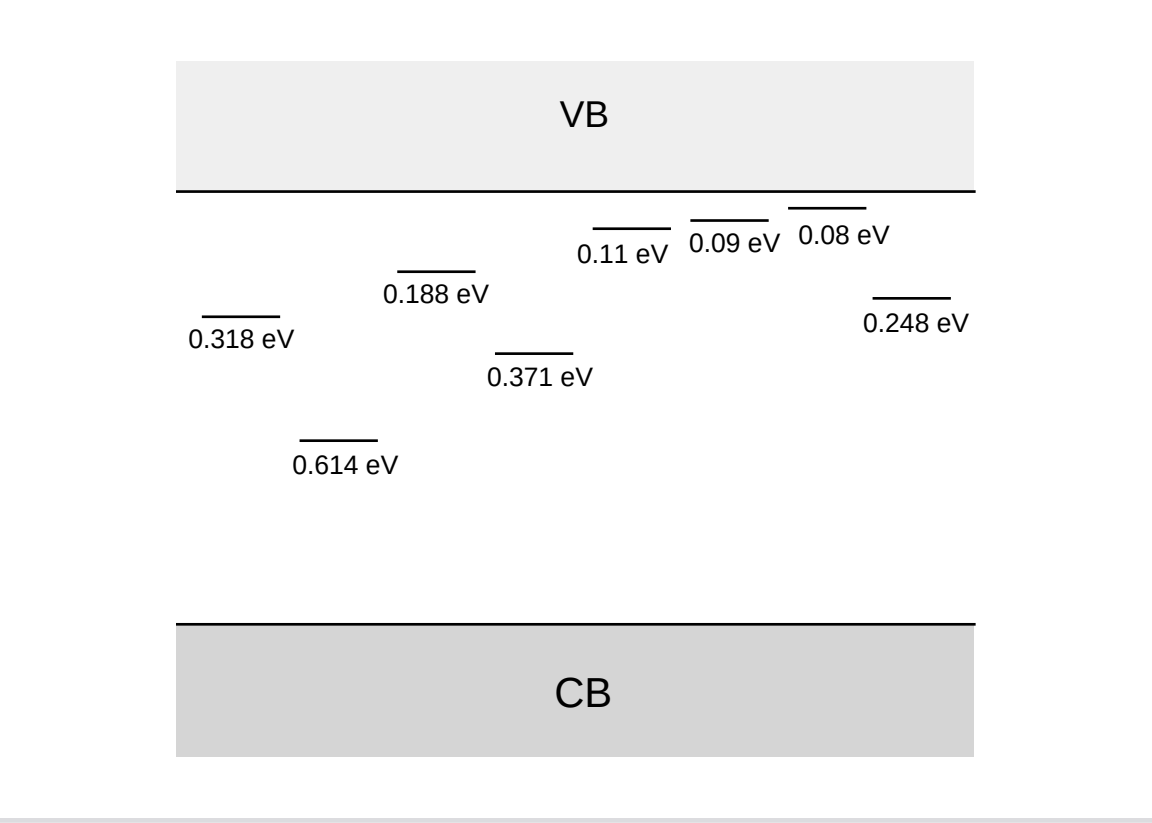
Discussion

sulfur introduces states in the gap



Discussion

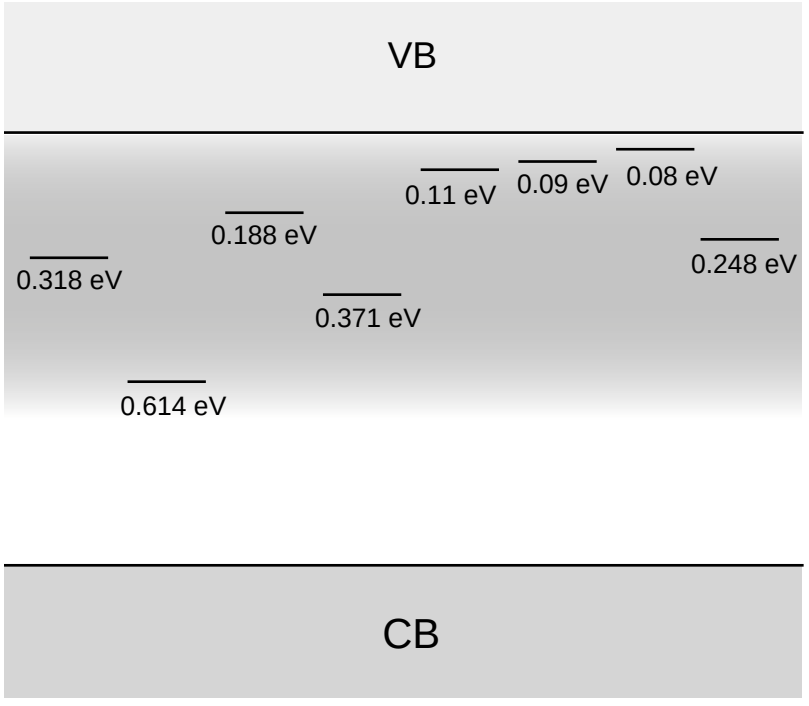
sulfur introduces states in the gap



Janzén, *et al.*, *Phys. Rev. B* **29**,1907 (1984)

Discussion

states broaden into a band



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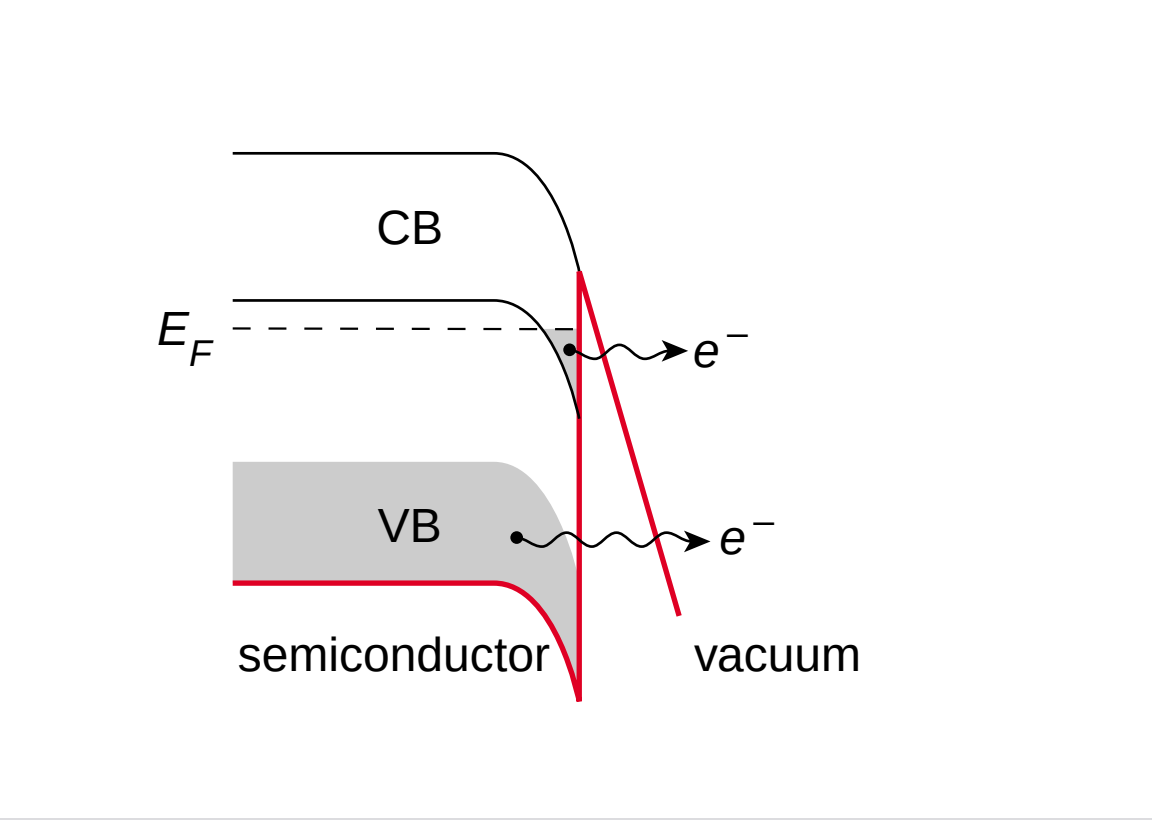
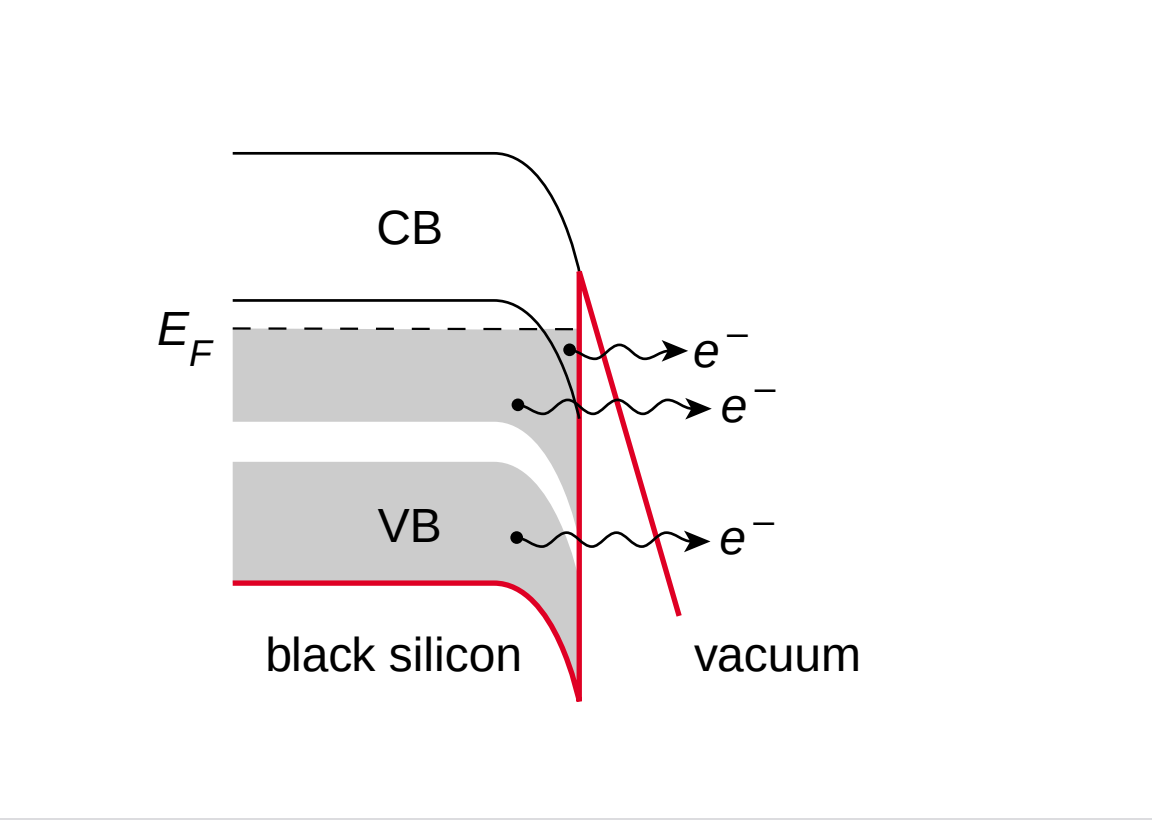


Discussion

sulfur band provides additional electrons



Summary

Microstructured silicon

- **fabricated by simple, maskless process**

Summary

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- **fabricated by simple, maskless process**
- **can be integrated with microelectronics**

Summary

Microstructured silicon

- **fabricated by simple, maskless process**
- **can be integrated with microelectronics**
- **provides stable, high field-emission current**

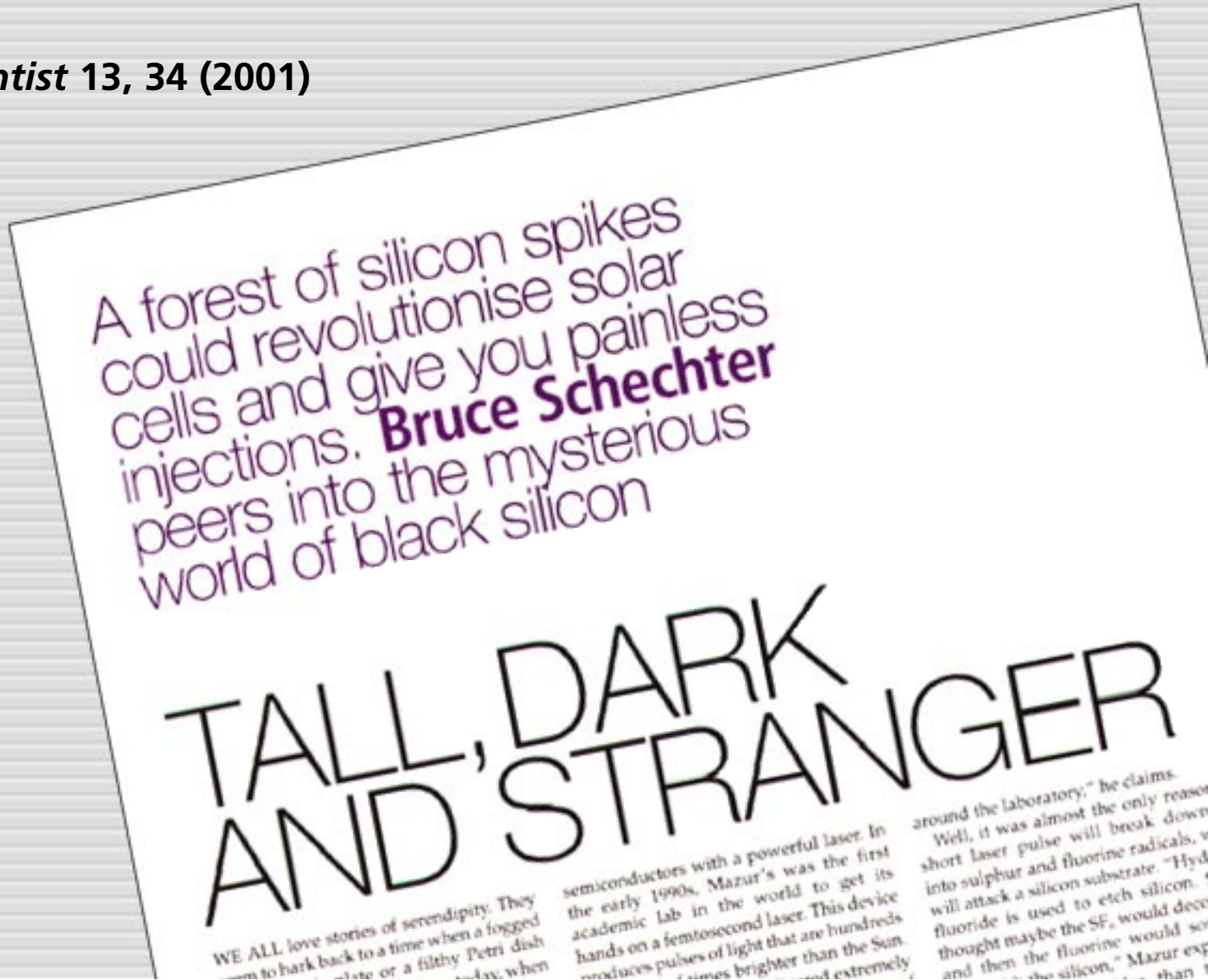
Summary

Microstructured silicon

- **fabricated by simple, maskless process**
- **can be integrated with microelectronics**
- **provides stable, high field-emission current**
- **is durable**

Summary

***New Scientist* 13, 34 (2001)**



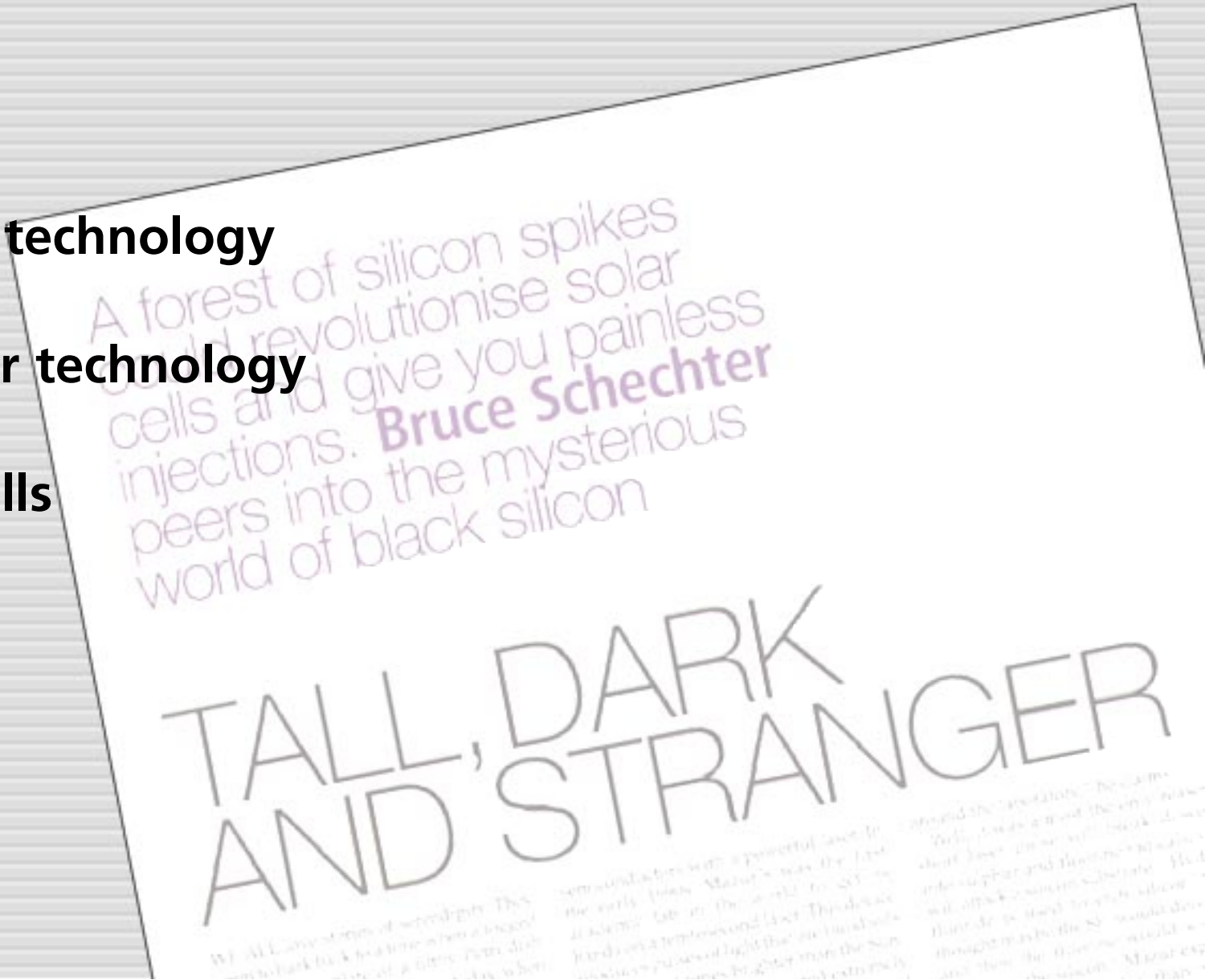
A forest of silicon spikes could revolutionise solar cells and give you painless injections. **Bruce Schechter** peers into the mysterious world of black silicon

TALL, DARK AND STRANGER

WE ALL love stories of serendipity. They
semiconductors with a powerful laser. In
the early 1990s, Mazur's was the first
academic lab in the world to get its
hands on a femtosecond laser. This device
produces pulses of light that are hundreds
around the laboratory," he claims.
Well, it was almost the only reason
short laser pulse will break down
into sulphur and fluorine radicals,
will attack a silicon substrate. "Hyd
fluoride is used to etch silicon.
thought maybe the SF_6 would deco
and then the fluorine would so
the silicon," Mazur exp

Applications

- display technology
- detector technology
- solar cells



Applications

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Prof. Li Zhao (Fudan University)
Prof. Mike Aziz (Harvard University)

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