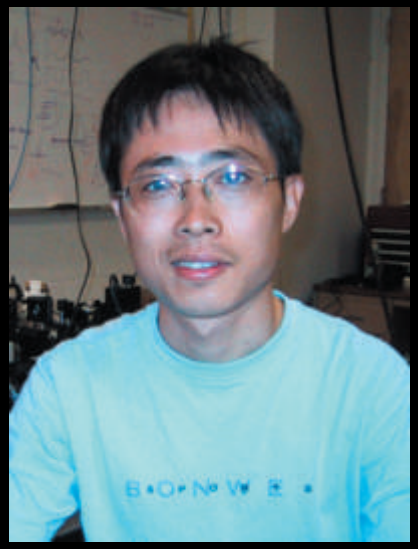
Wrapping light around a hair: Optical sensing at the nanoscale

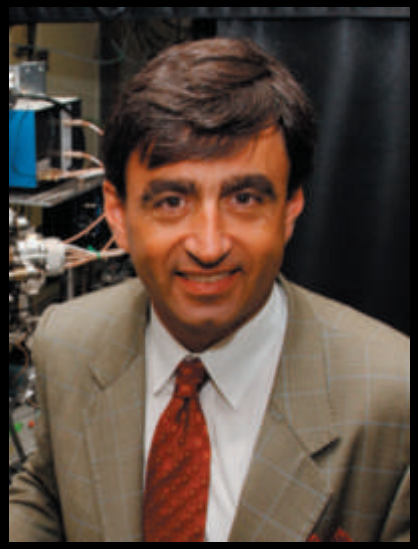
Working Together:
R&D Partnerships in Homeland Security
Boston, MA, 27 April 2005



Limin Tong

Rafael Gattass

Geoff Svacha



Eric Mazur

and also....

at Harvard:

Jonathan Aschom
Mengyan Shen
Iva Maxwell
James Carey
Brian Tull
Dr. Yuan Lu
Dr. Richard Schalek
Prof. Federico Capasso
Prof. Cynthia Friend

at Zhejiang University:

Dr. Sailing He
Dr. Jingyi Lou
Xuewen Chen
Liu Liu
Zhanghua Han

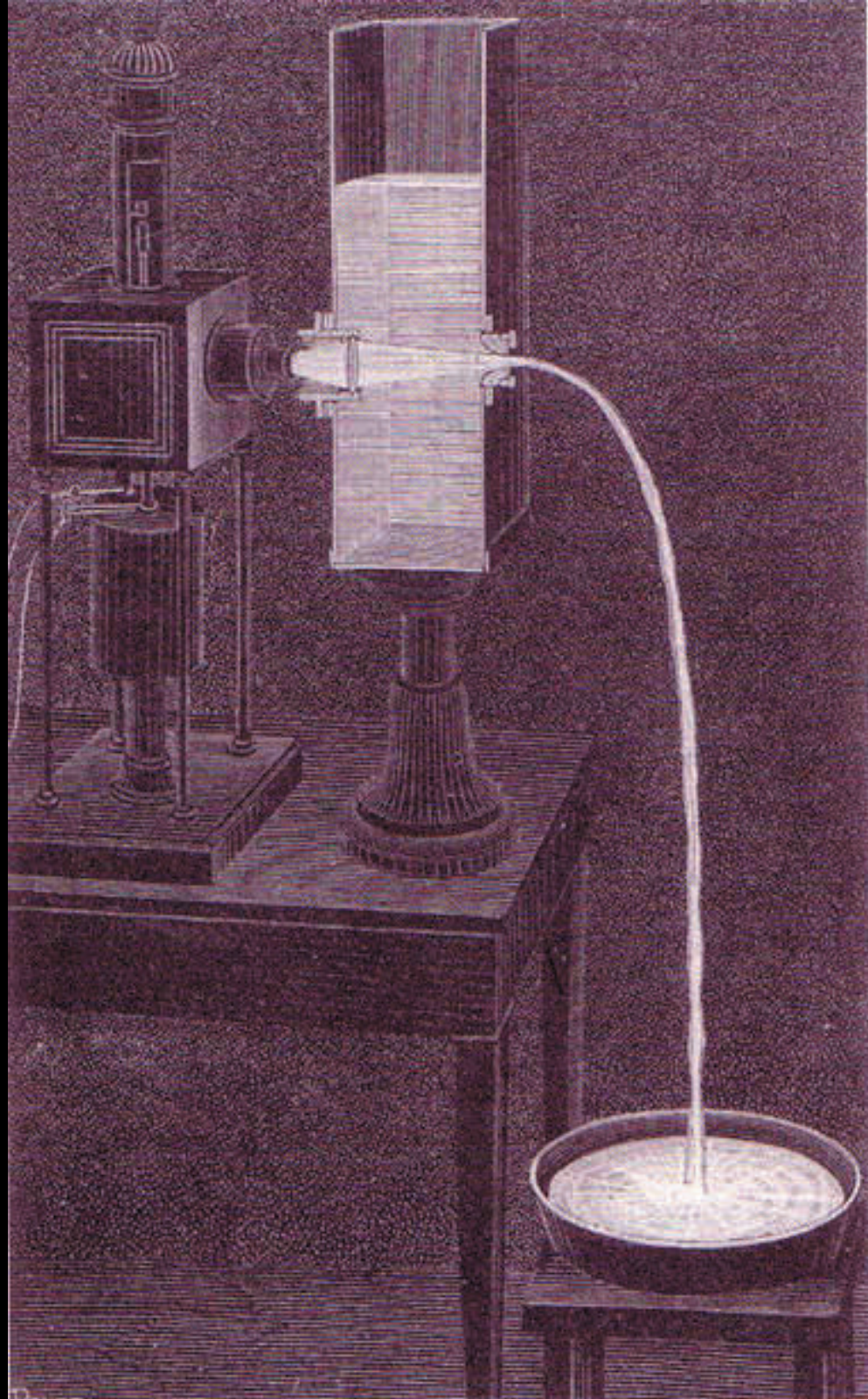
Dr. Ray Mariella (LLNL)

Outline

- waveguiding
- nanowire fabrication
- optical properties

“I managed to illuminate the interior of a stream in a dark space. I have discovered that this strange arrangement offers one of the most beautiful, and most curious experiments that one can perform in a course on Optics.”

Daniel Colladon, *Comptes Rendus*, 15, 800–802 (1842)



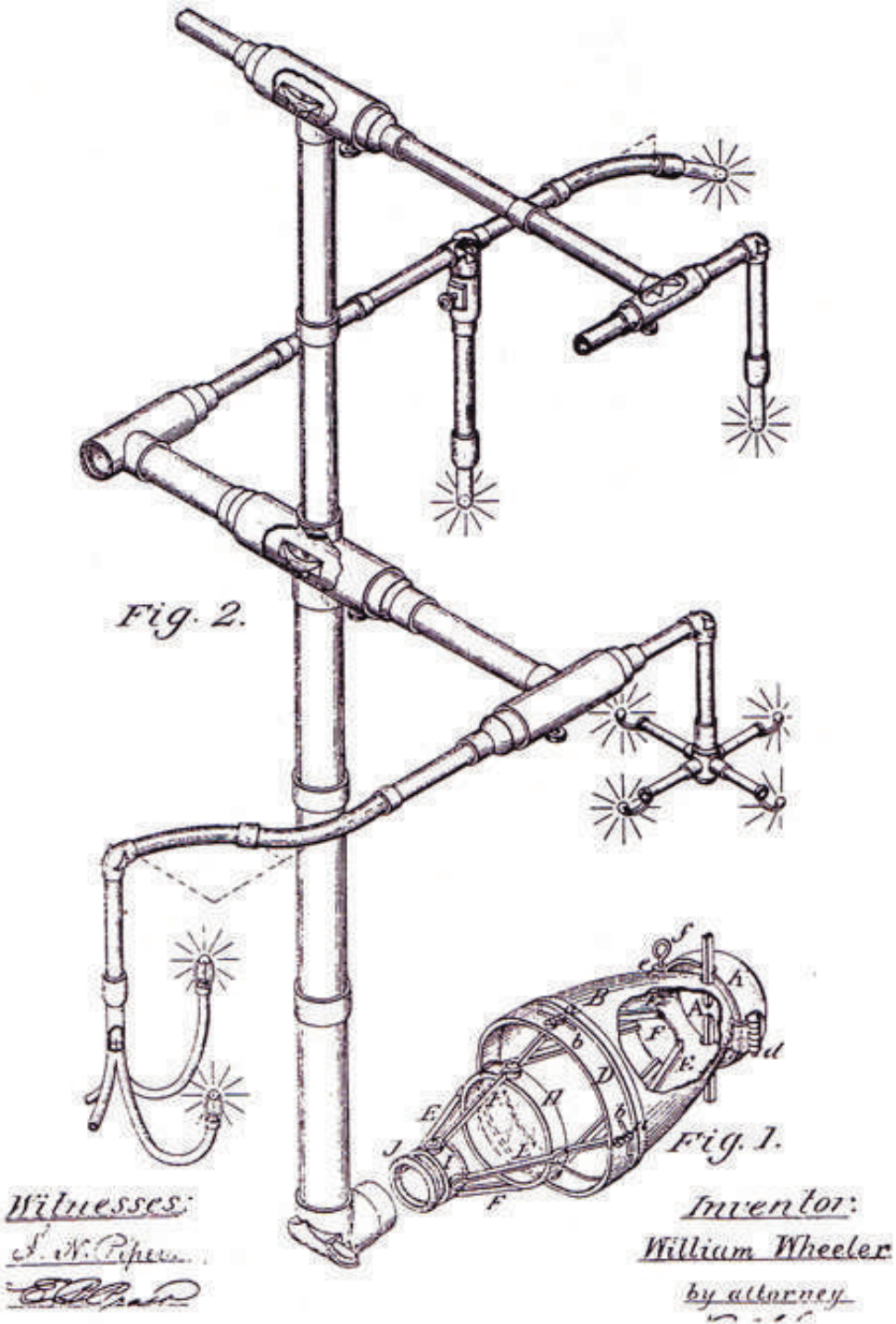
D. Colladon, *La Nature*, 325 (1884)

(No model.) 4 Sheets—Sheet

W. WHEELER.

APPARATUS FOR LIGHTING DWELLINGS OR OTHER STRUCTURES.

No. 247,229. Patented Sept. 20, 1881.

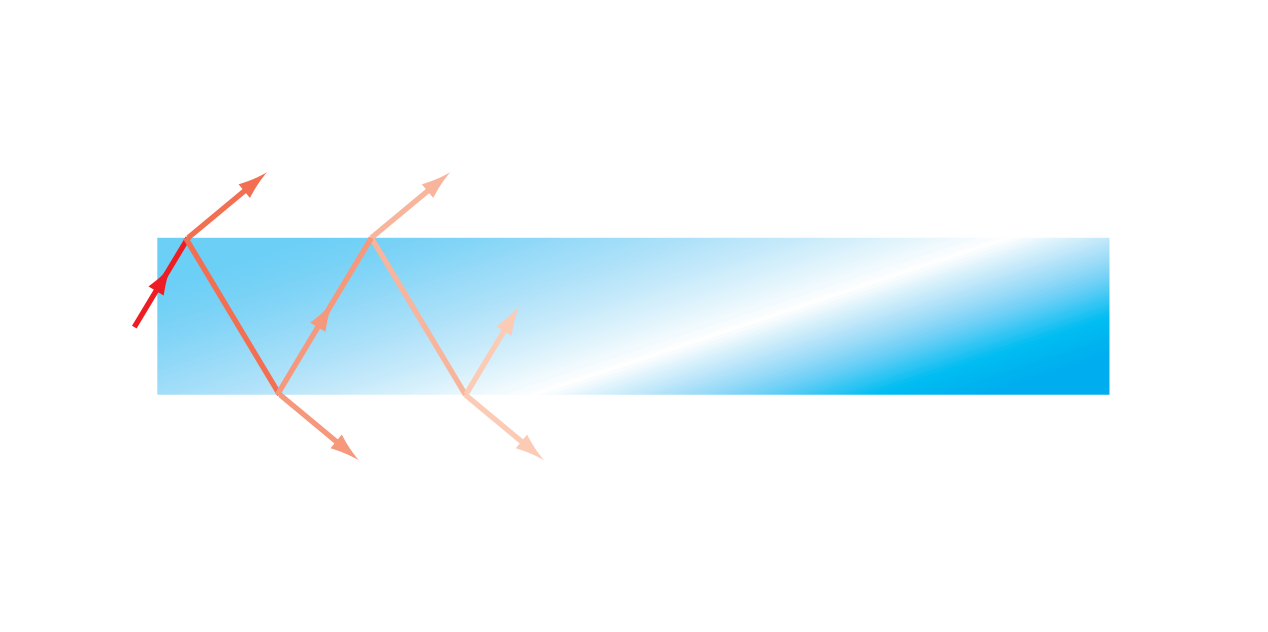


US Patent 247, 229 (1881)

Waveguiding

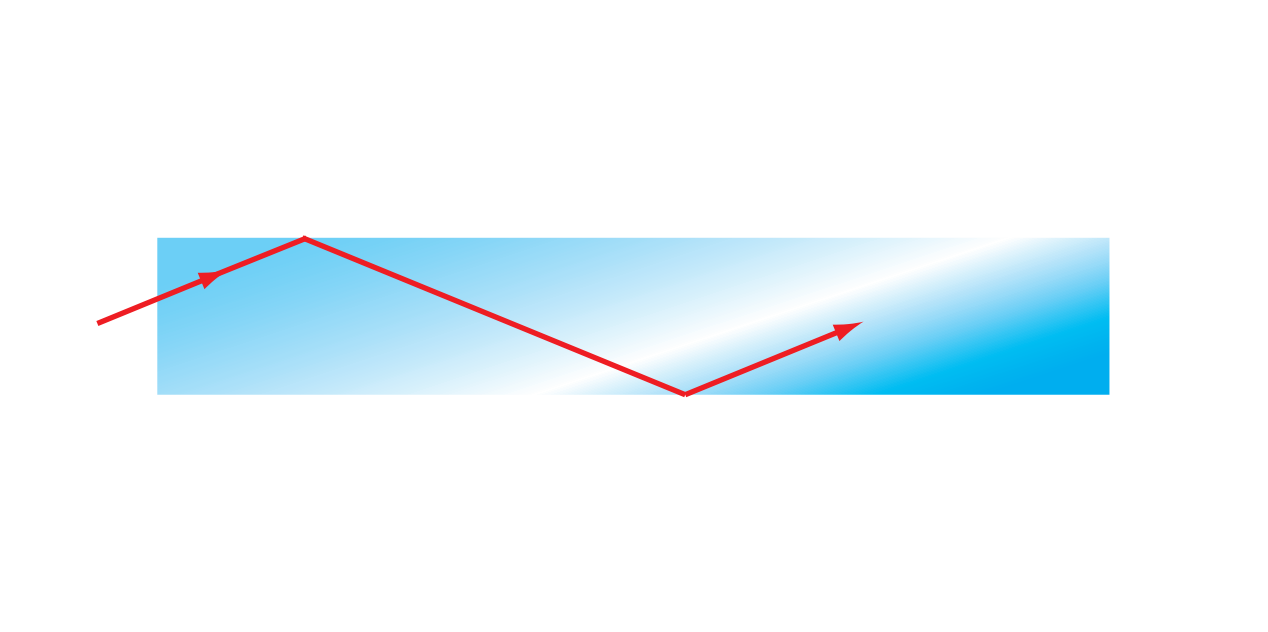
now consider a planar dielectric waveguide

Waveguiding



rays incident at angle $\theta > \pi/2 - \theta_c$ are unguided

Waveguiding



rays incident at angle $\theta < \pi/2 - \theta_c$ are guided

Waveguiding

single mode condition for 600-nm light:

$$M \doteq 2\,\frac{d}{\lambda}(n_1^2 - n_2^2)^{1/2}$$

without cladding: $d < 268\ \mathrm{nm}$

Waveguiding

single mode condition for 600-nm light:

$$M \doteq 2\,\frac{d}{\lambda}(n_1^2 - n_2^2)^{1/2}$$

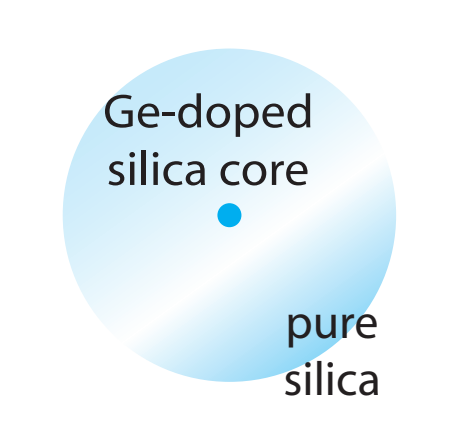
without cladding: $d < 268\ \mathrm{nm}$

Add cladding with 0.4% index difference:

$$d < 5\ \mu\mathrm{m}$$

Waveguiding

commercial single-mode fiber (Corning Titan®)



	core	cladding
index	$n_1 = 1.468$	$n_2 = 1.462$
diameter:	$8.3\ \mu\text{m}$	$125.0 \pm 1.0\ \mu\text{m}$

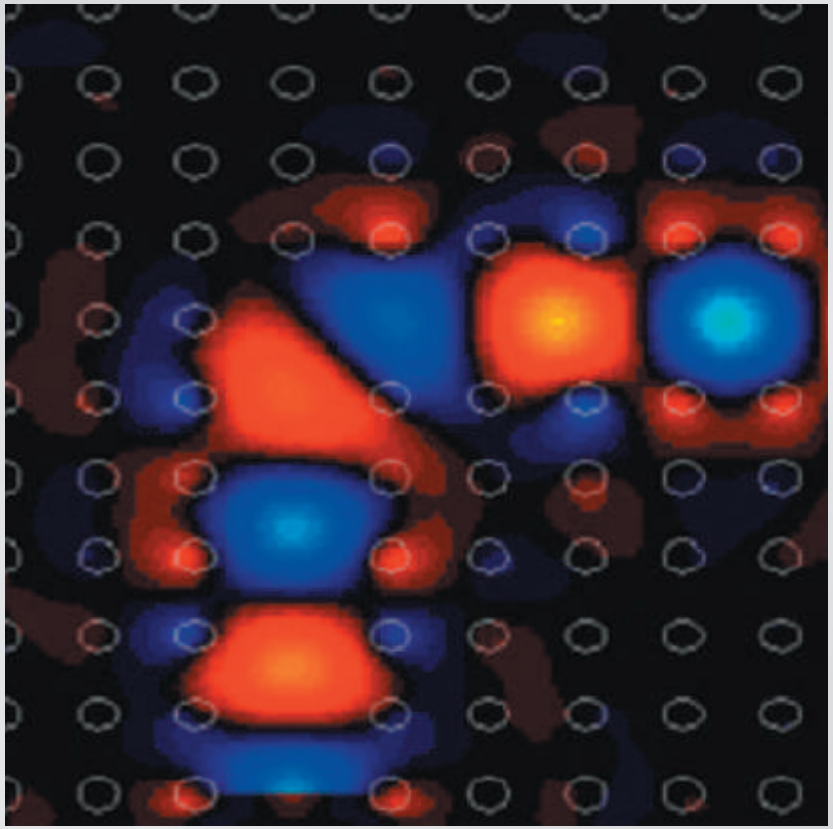
operating wavelength: $\lambda = 1310\ \text{nm}/1550\ \text{nm}$

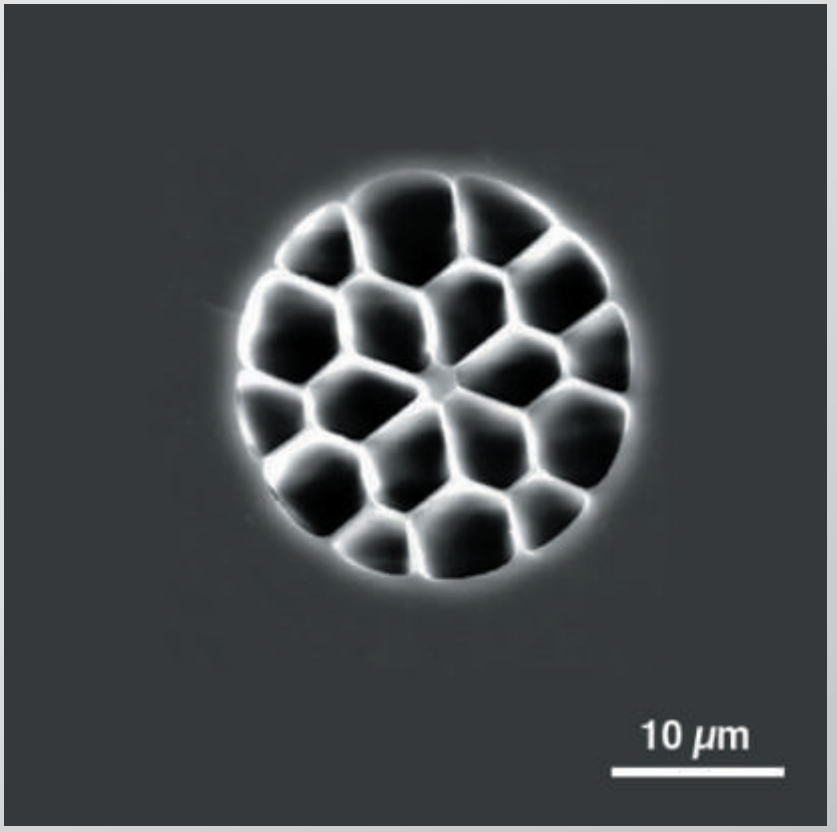
Waveguiding

drawbacks of clad fibers:

- weak confinement
- no tight bending
- coupling requires splicing

Waveguiding



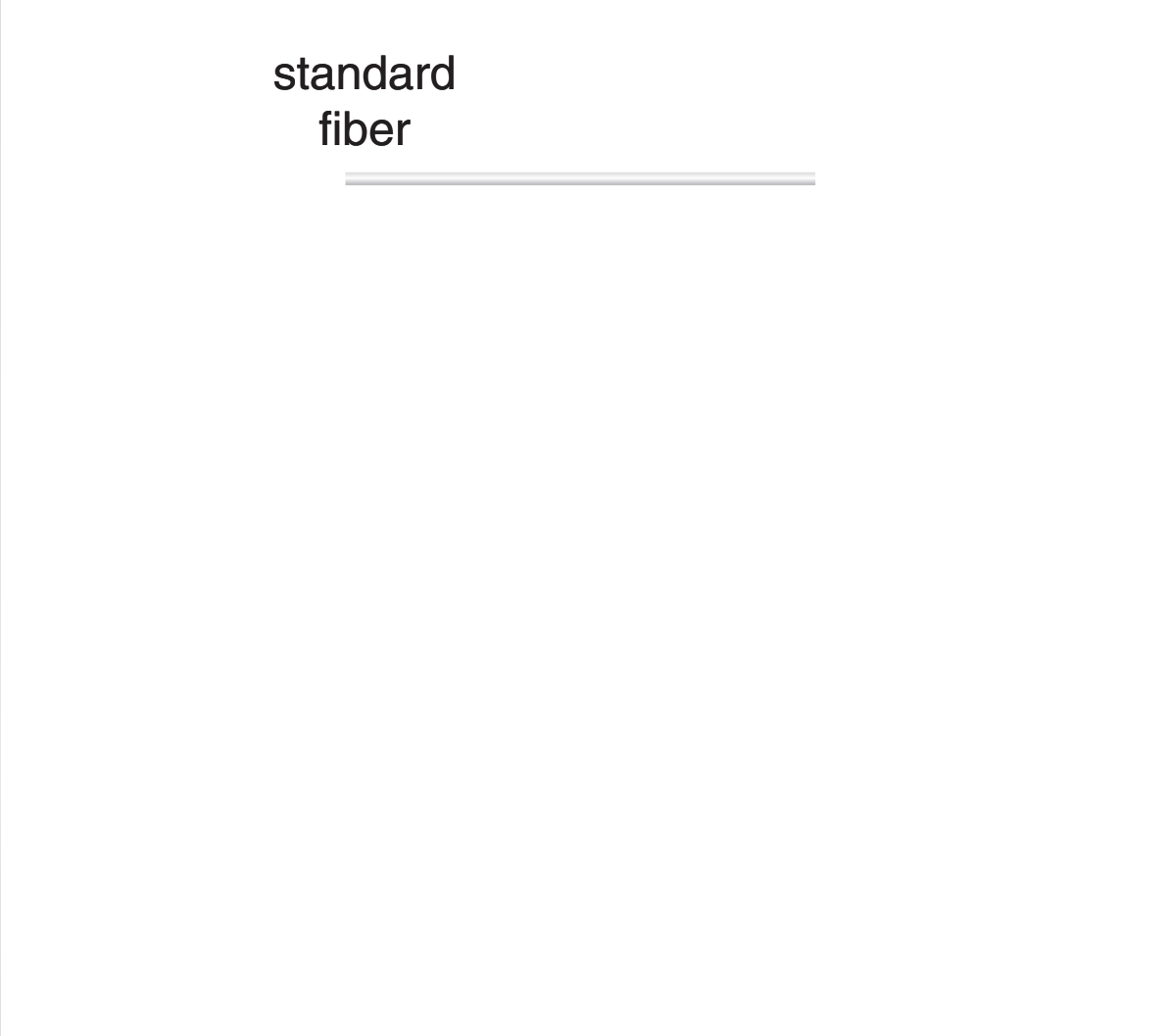


Outline

- waveguiding
- nanowire fabrication
- optical properties

Nanowire fabrication

two-step drawing process



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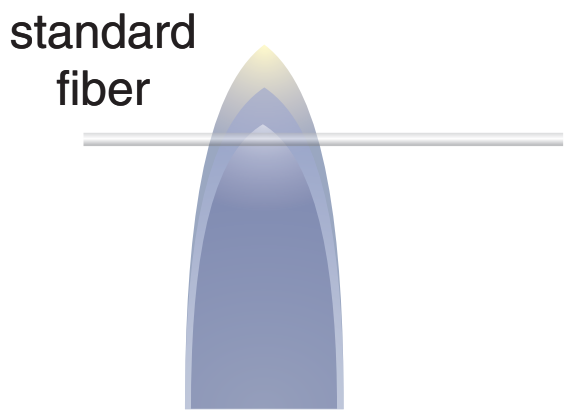

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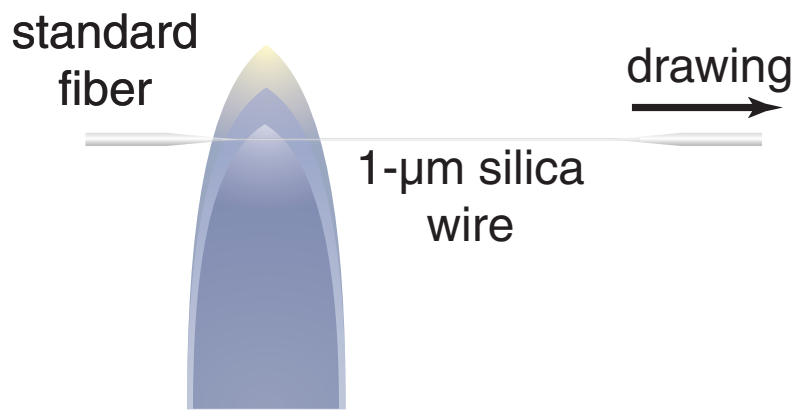

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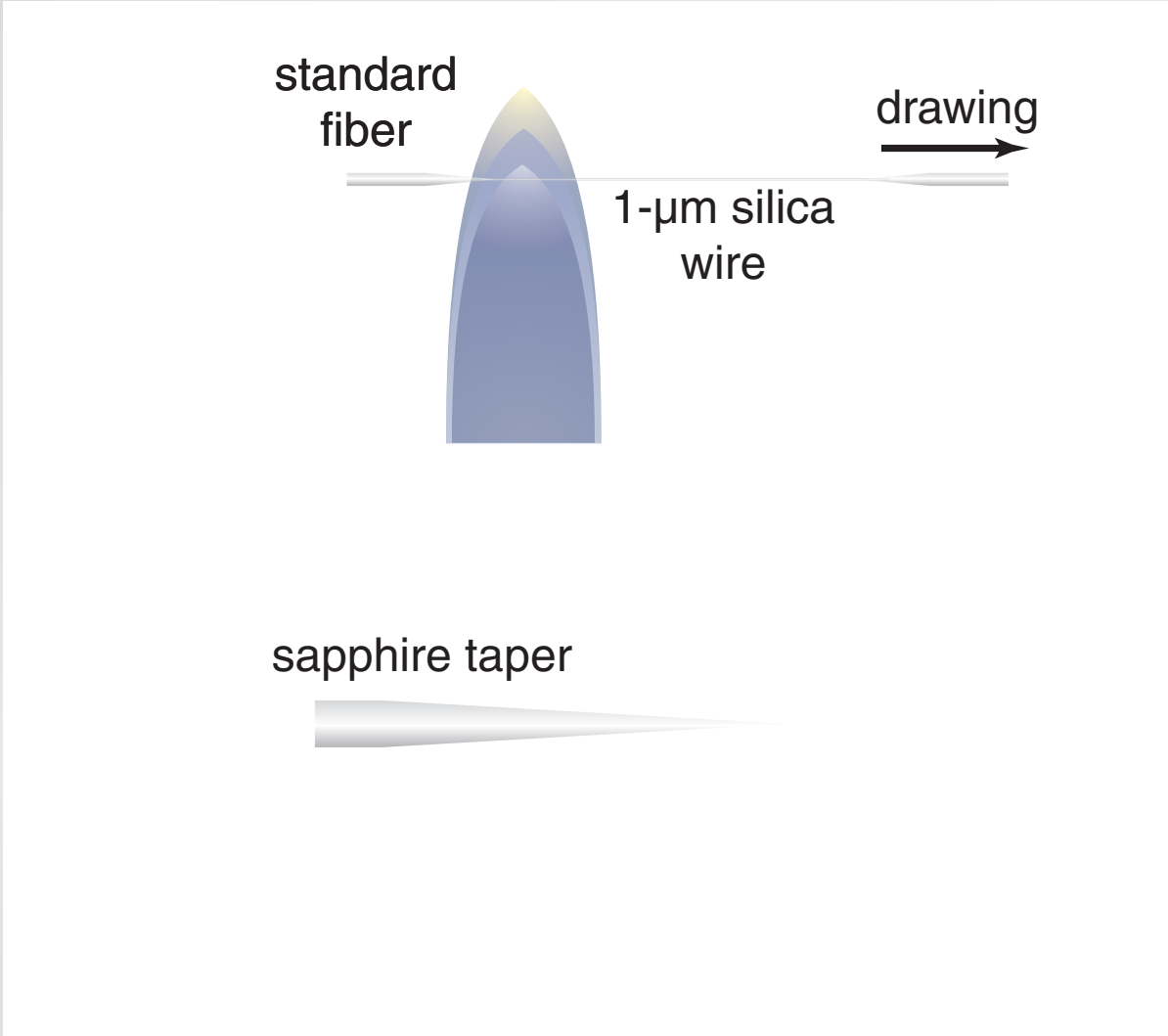

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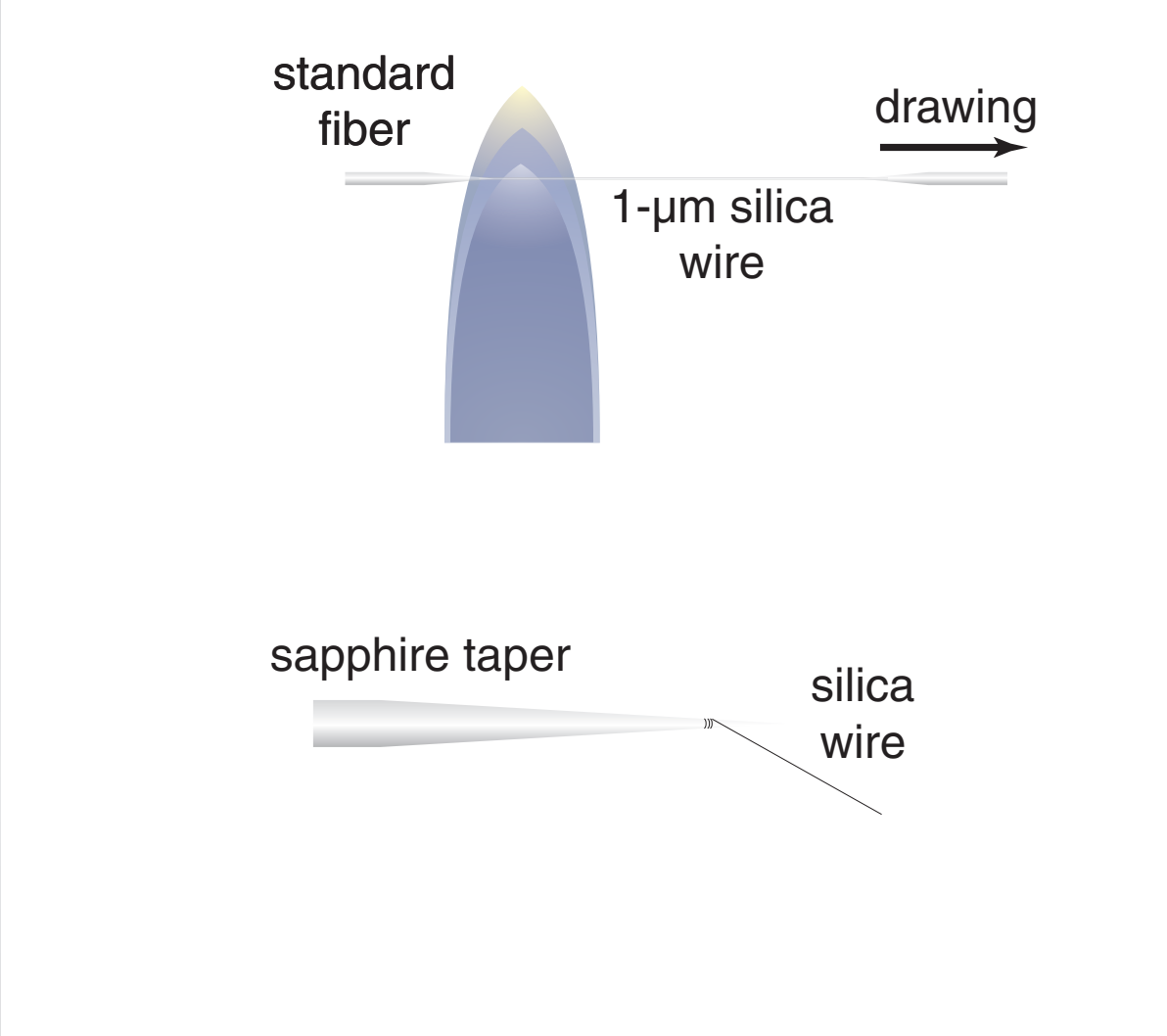

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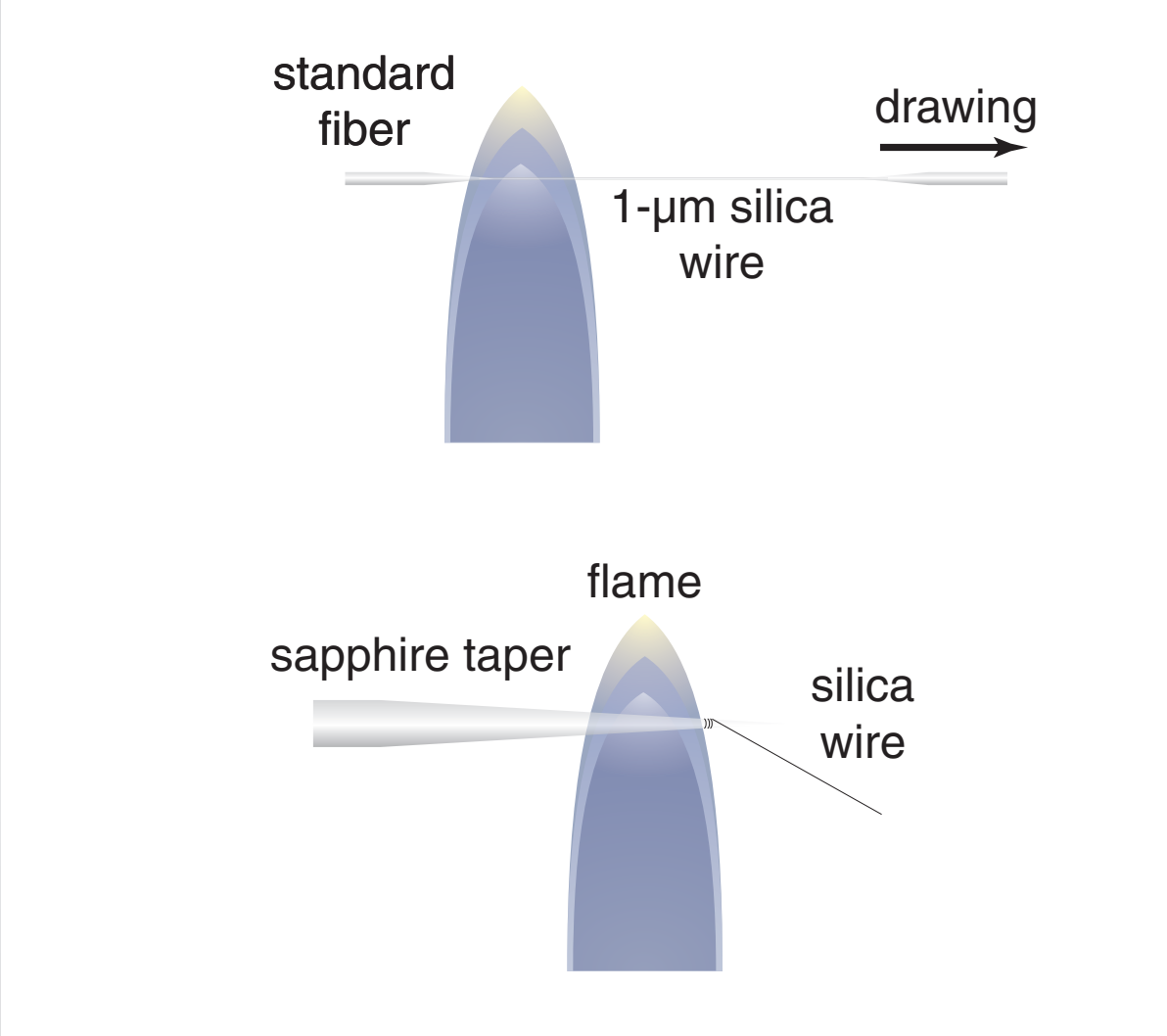

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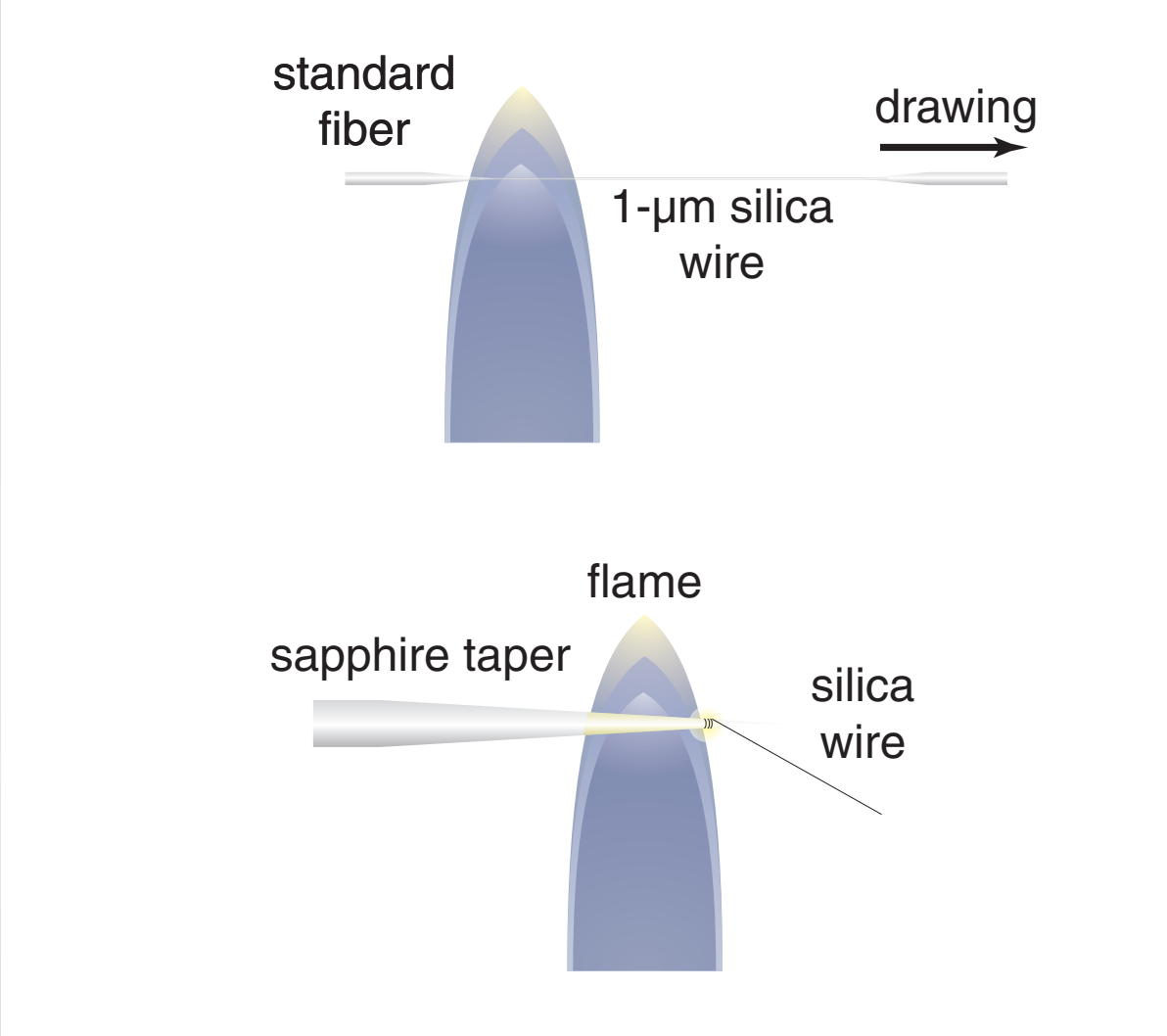

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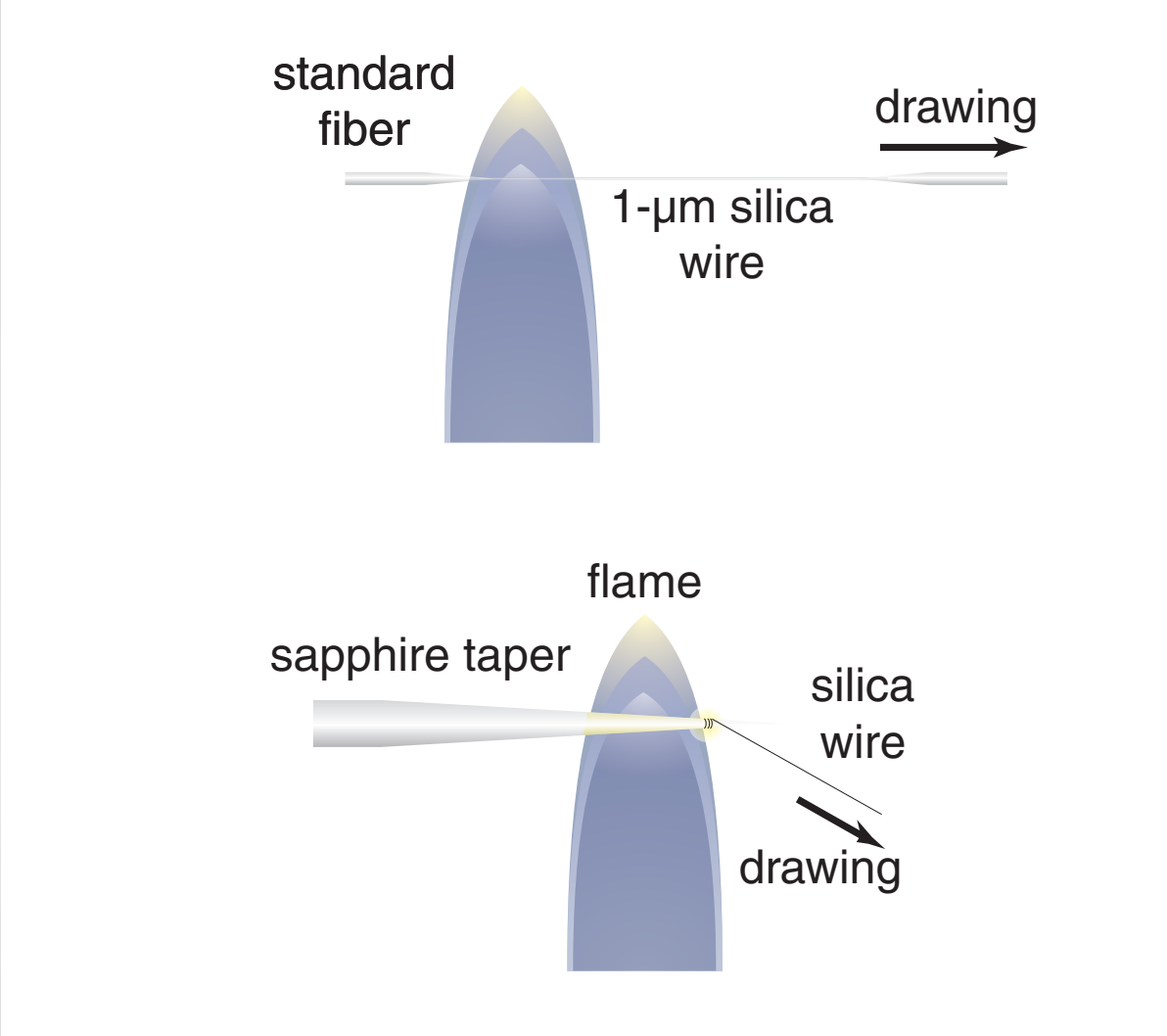

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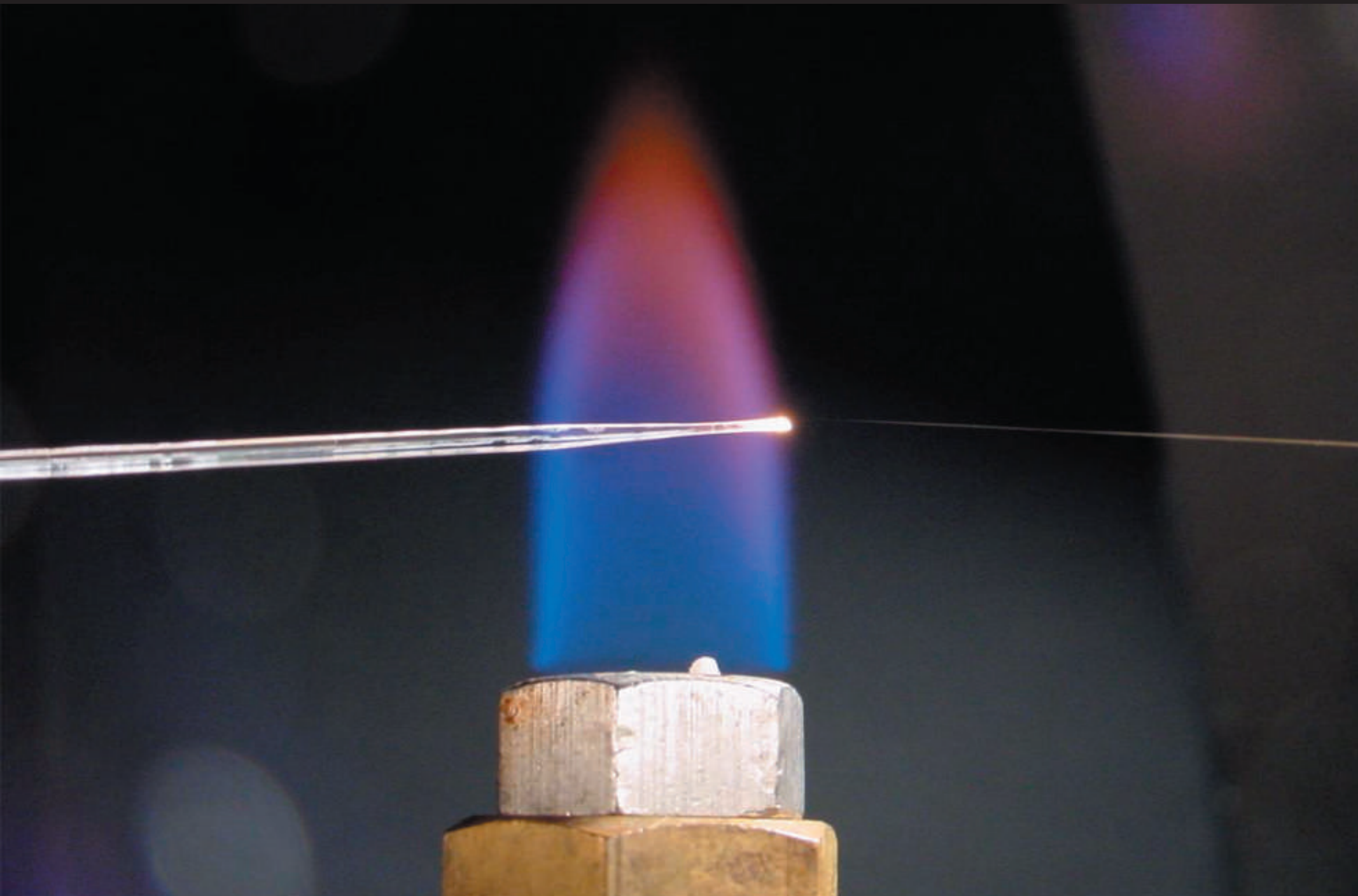

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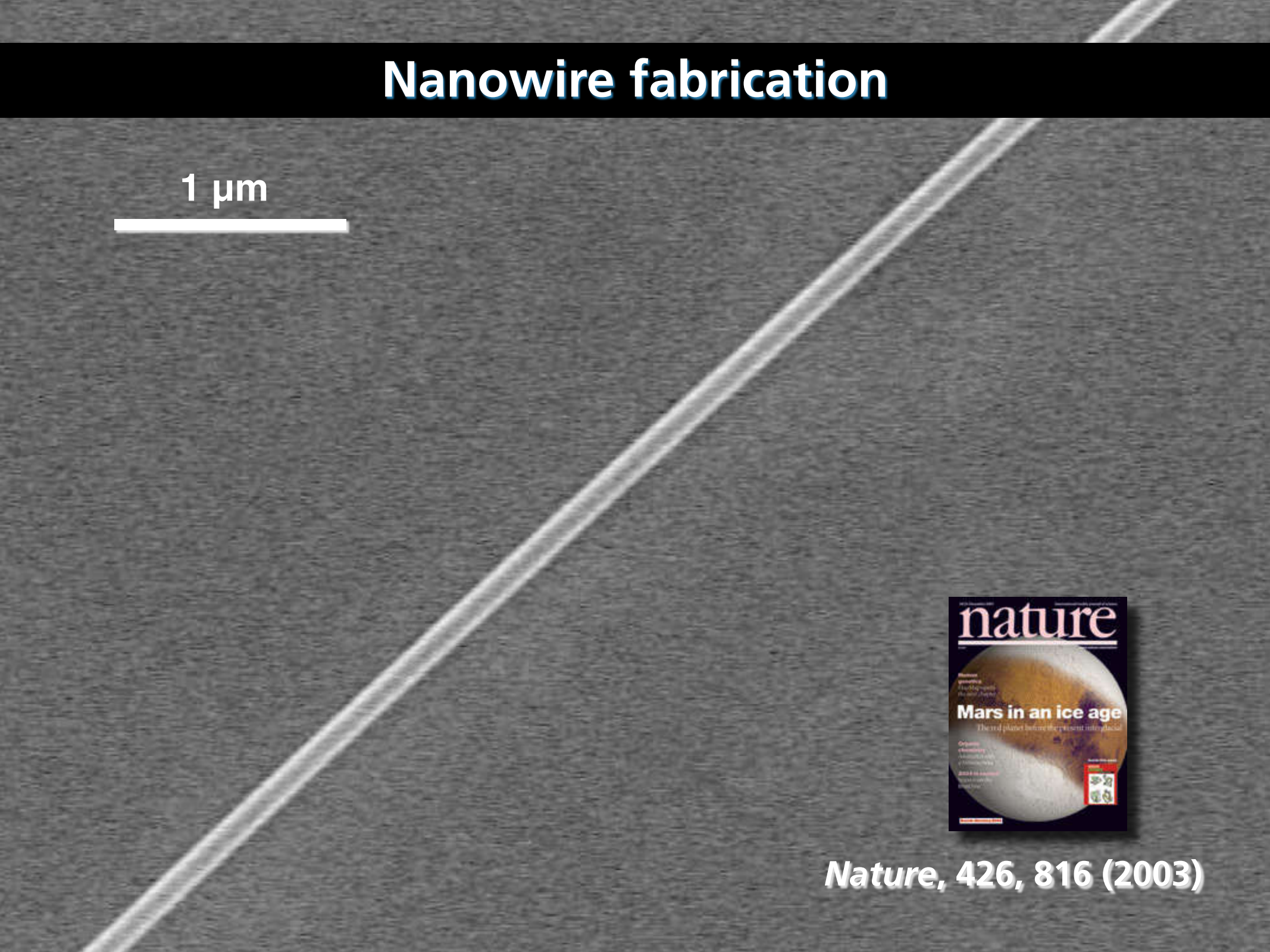
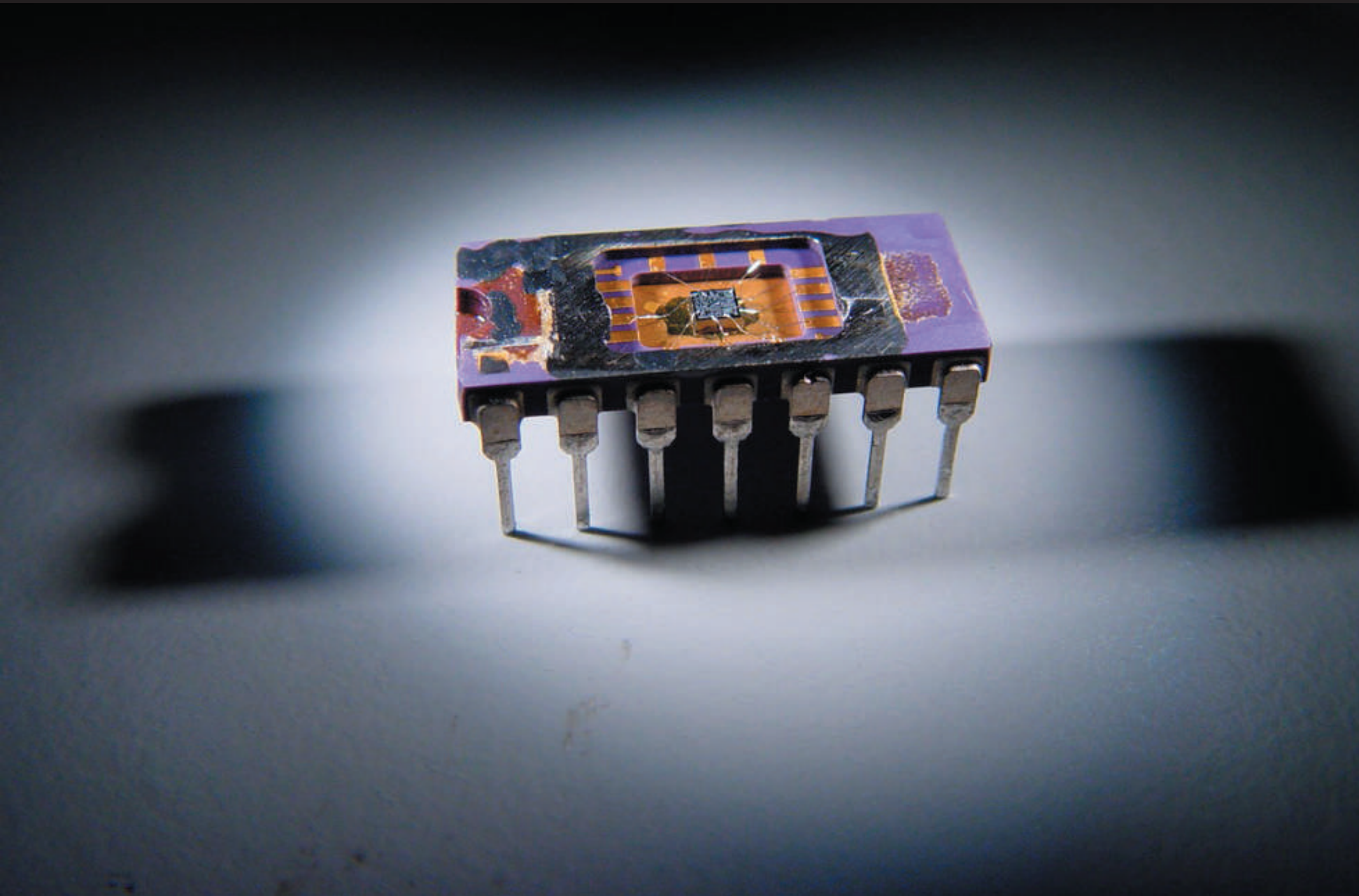


Nature, 426, 816 (2003)

Nanowire fabrication



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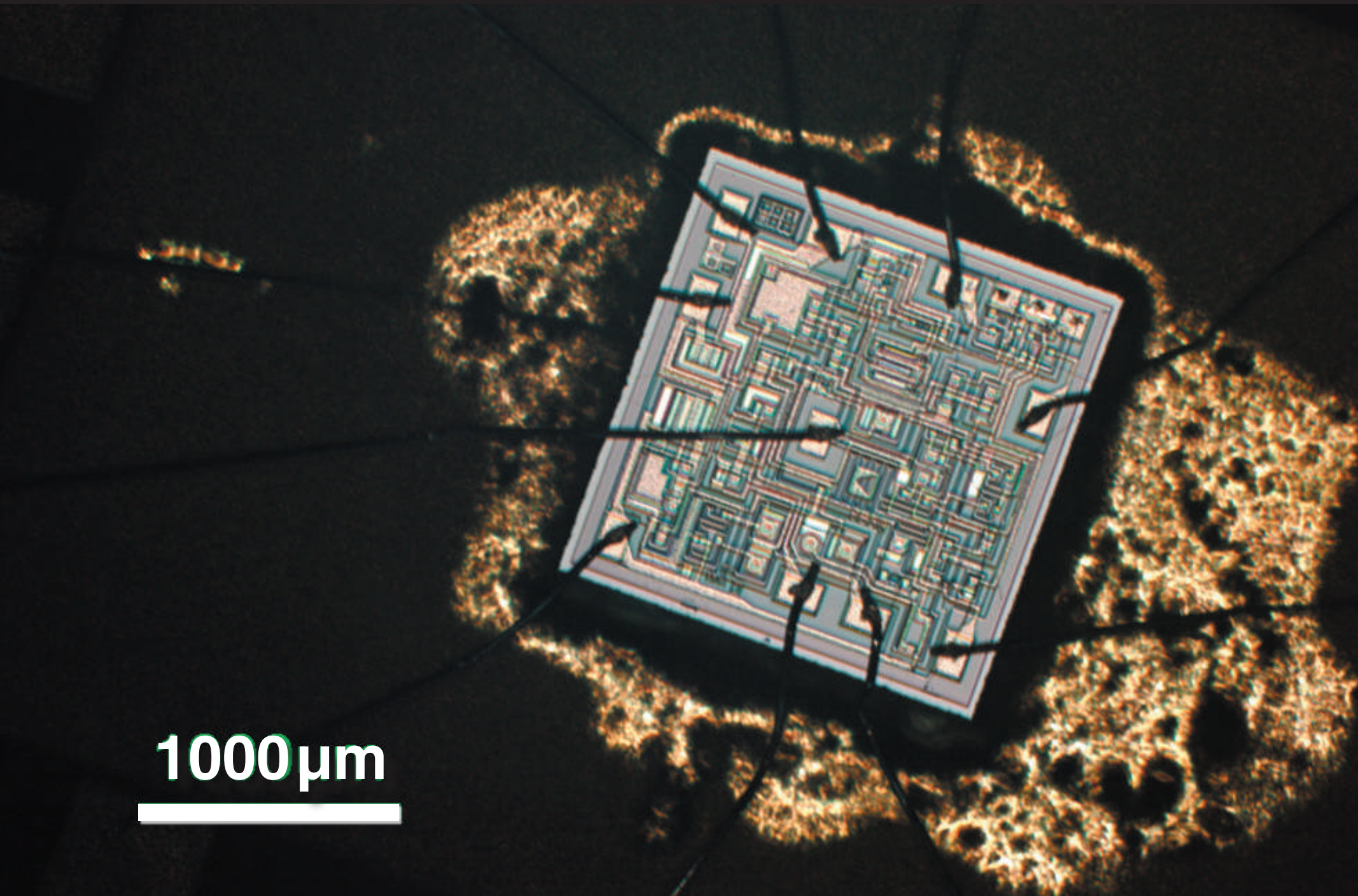

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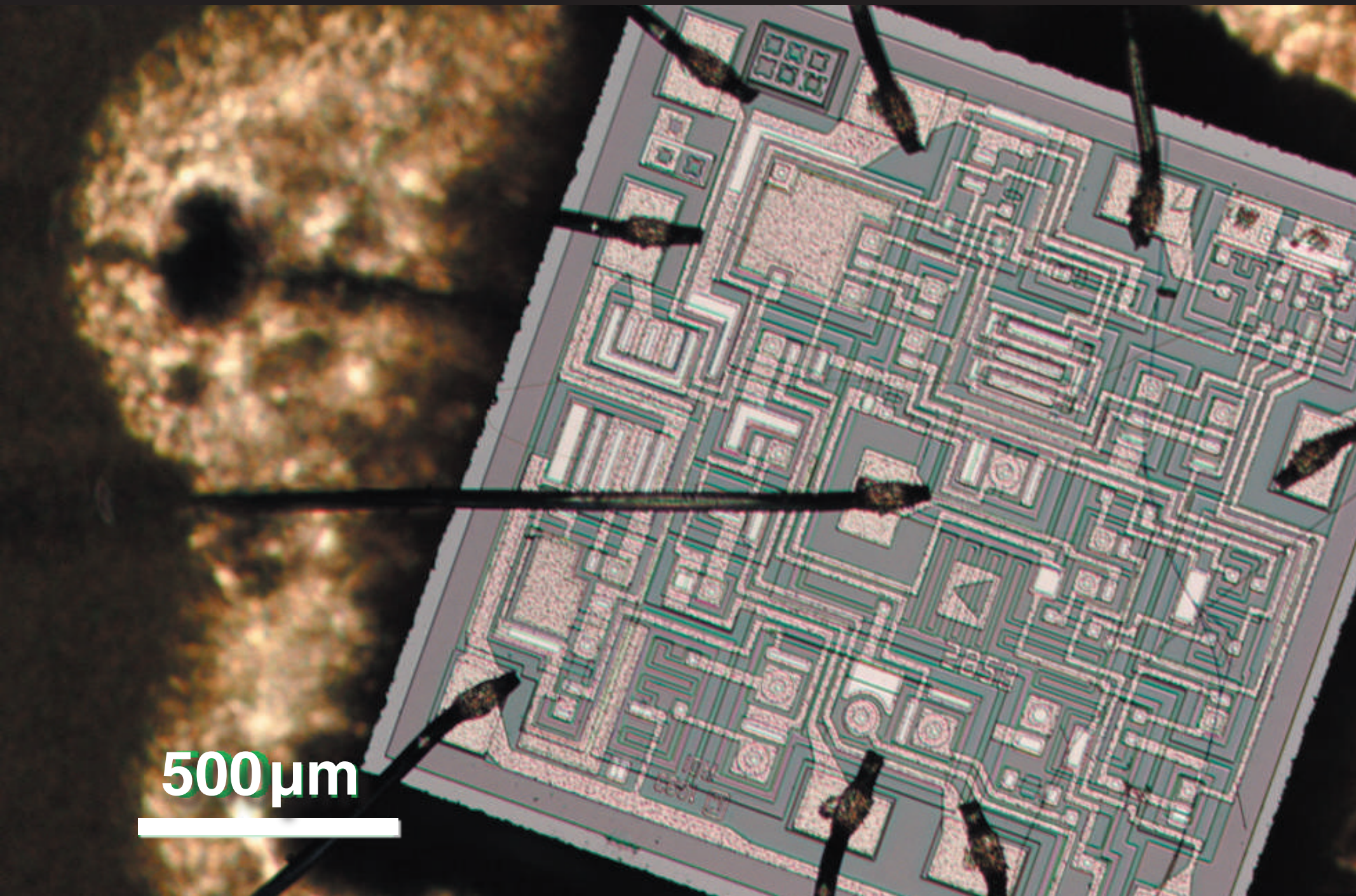

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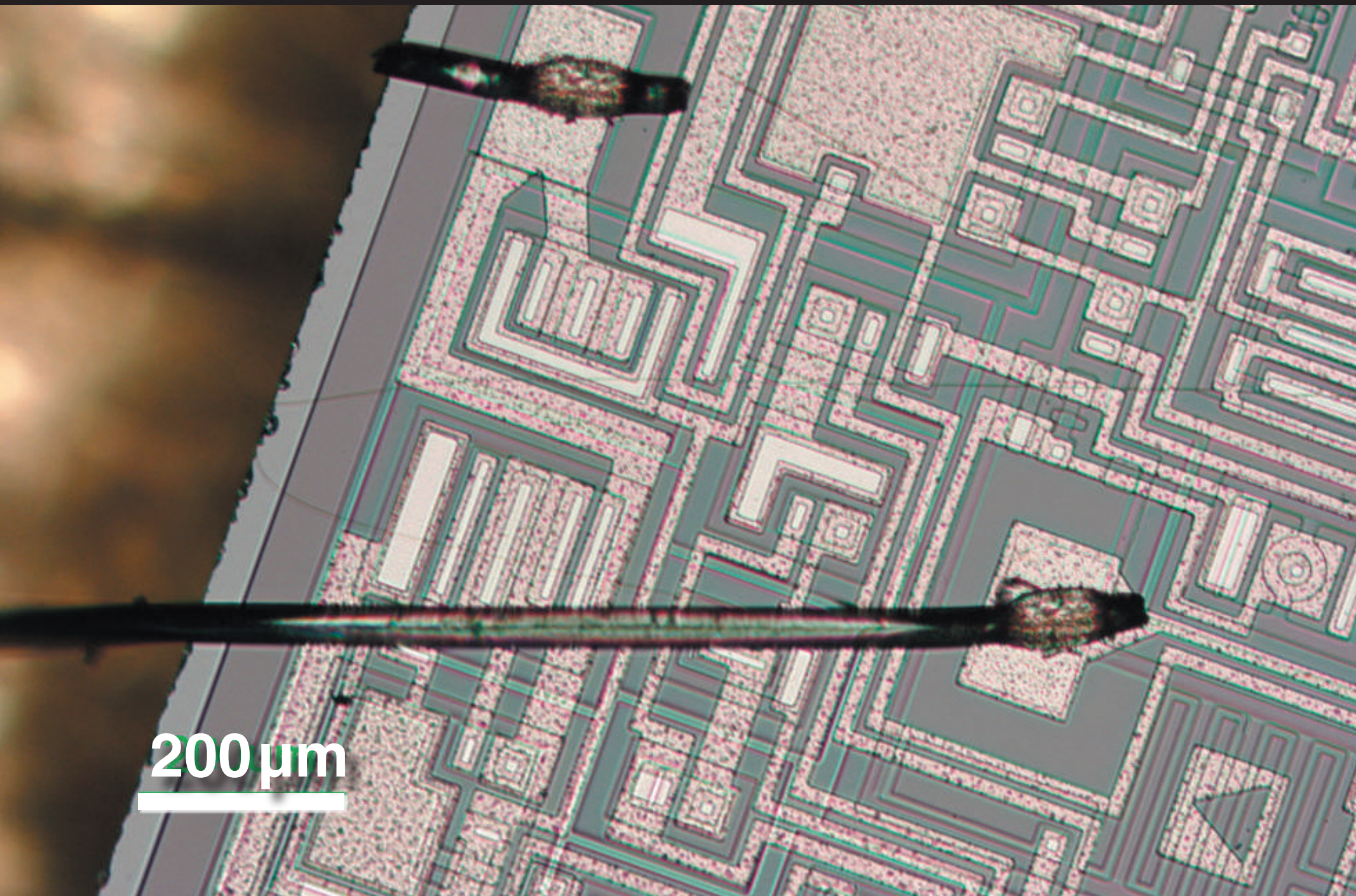

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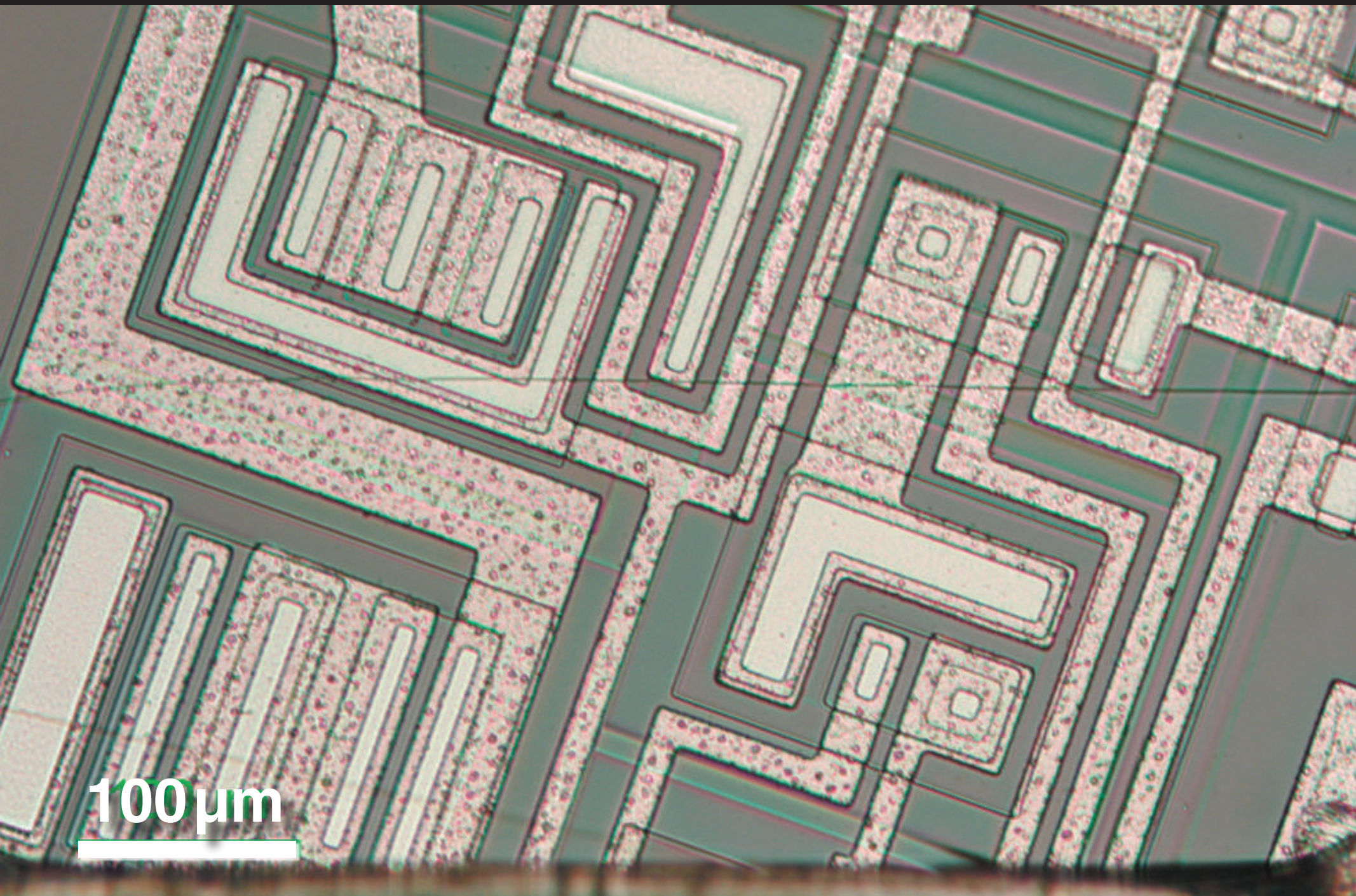

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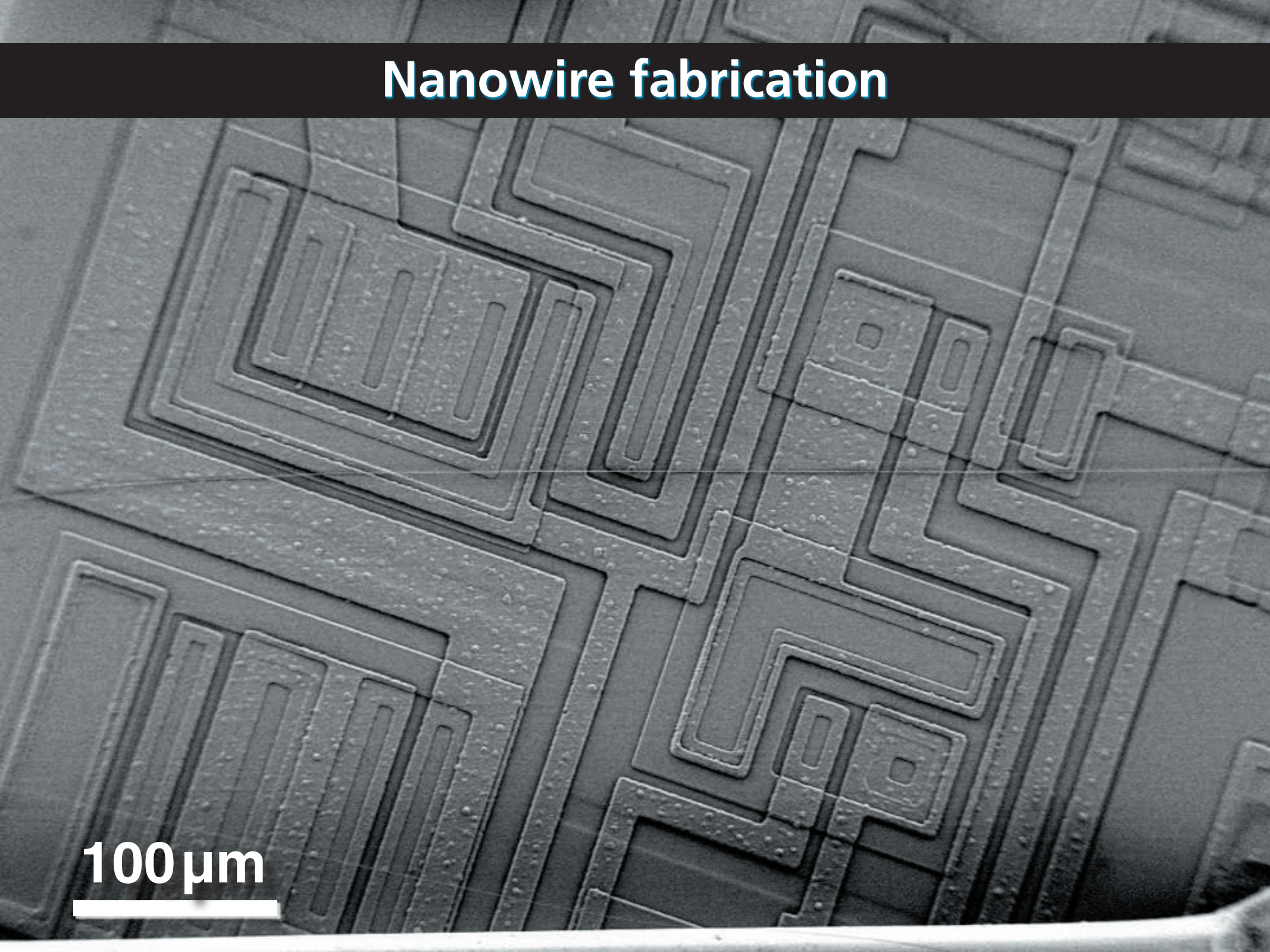

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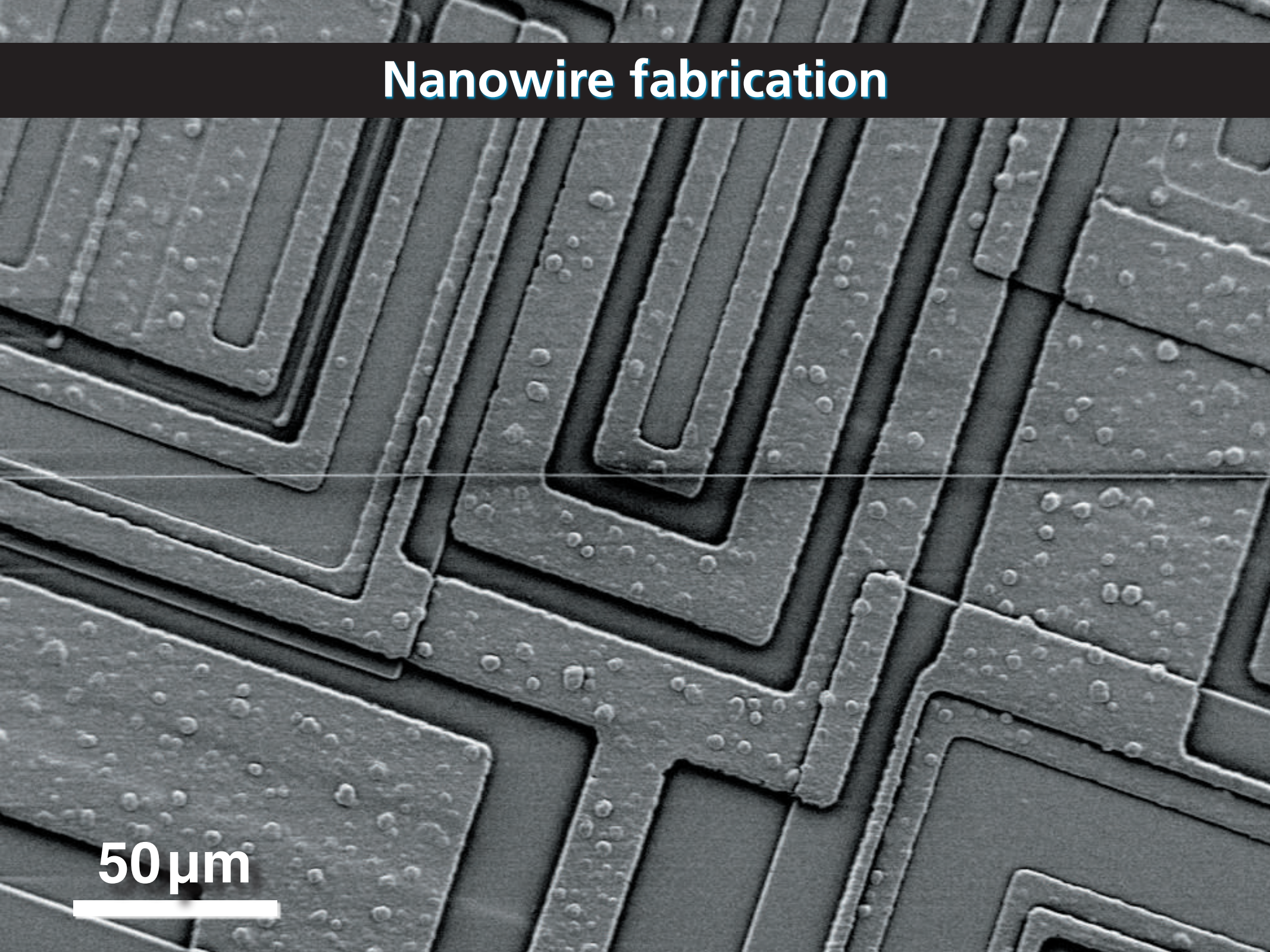

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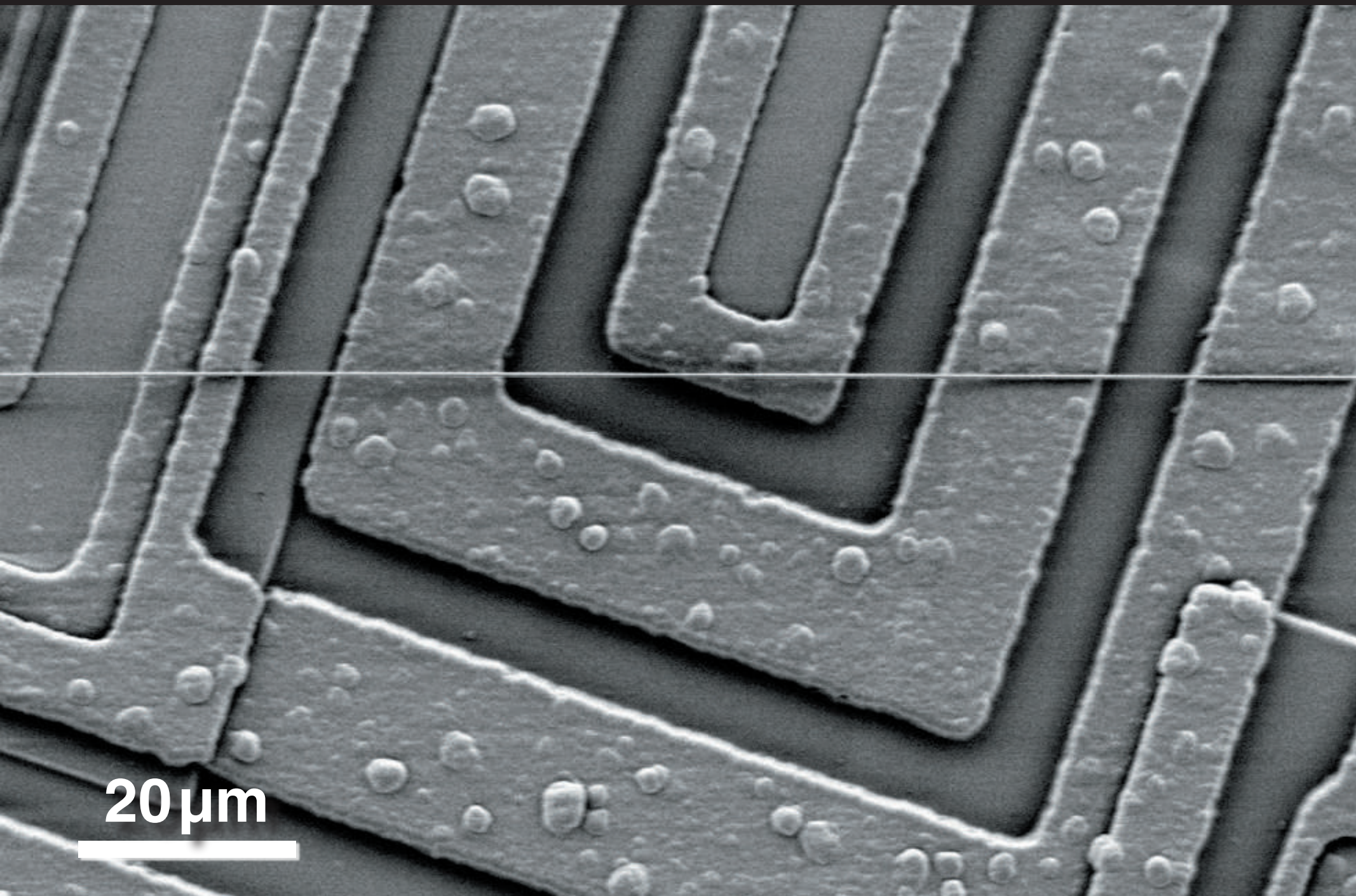

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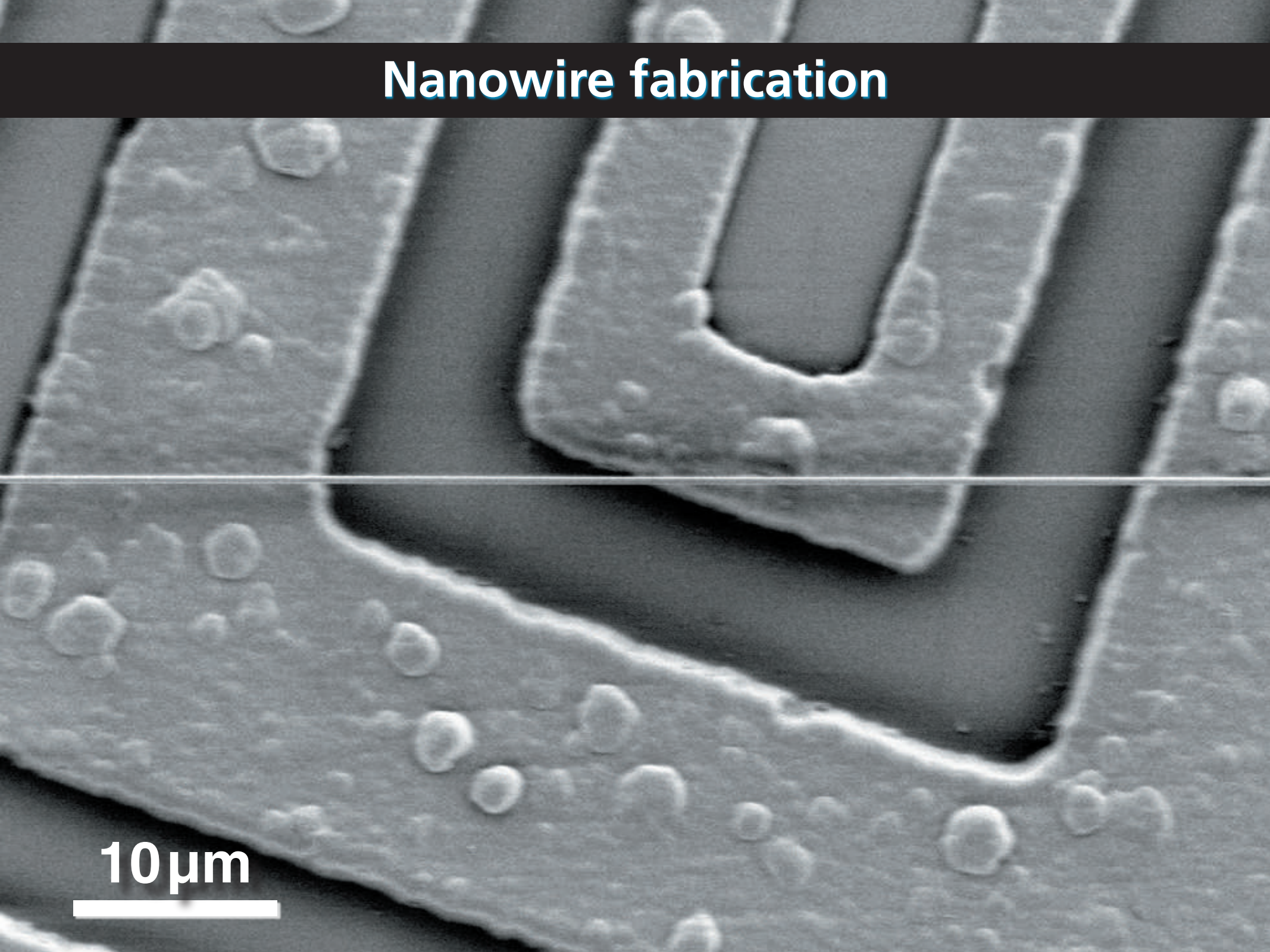

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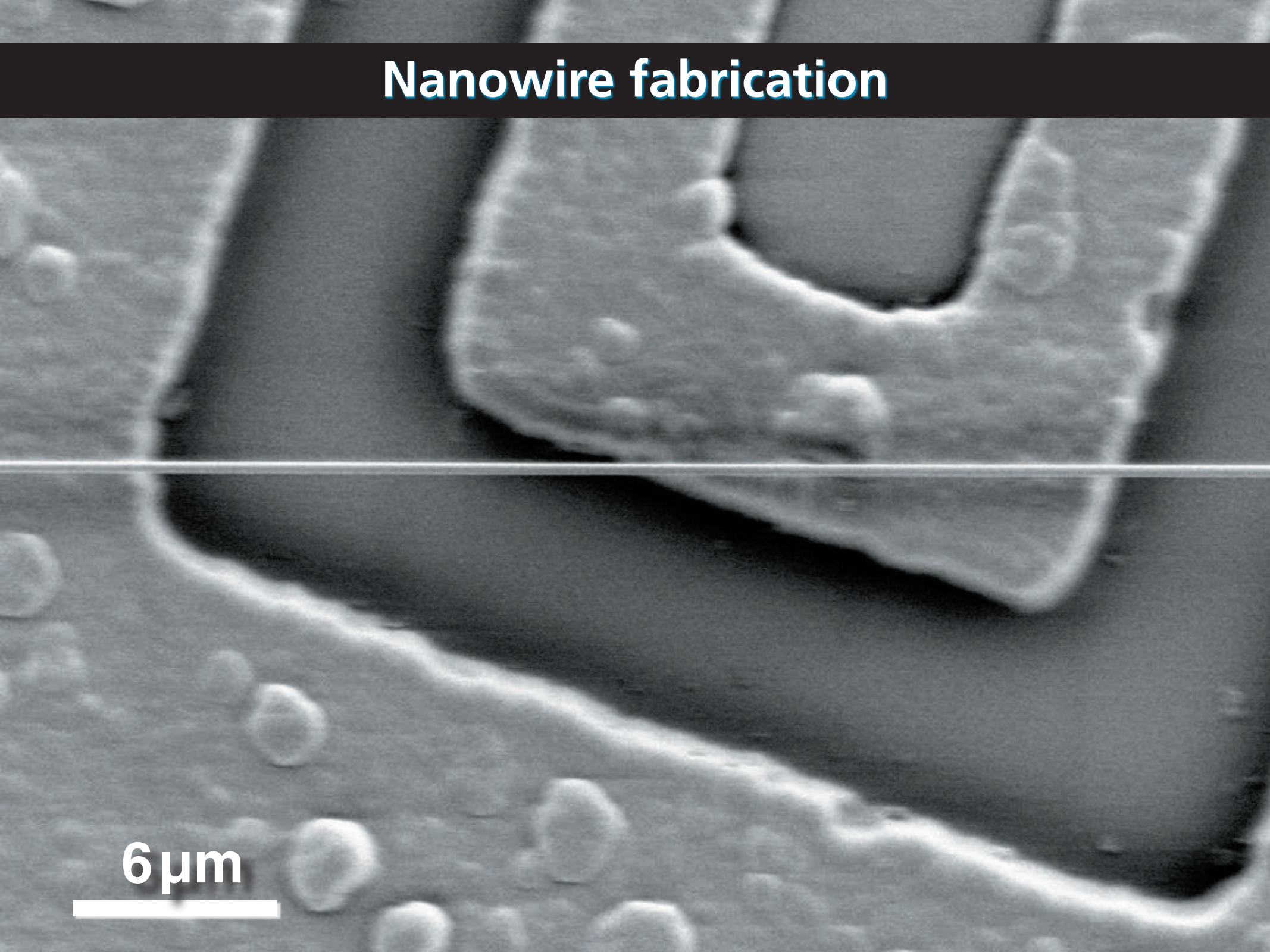

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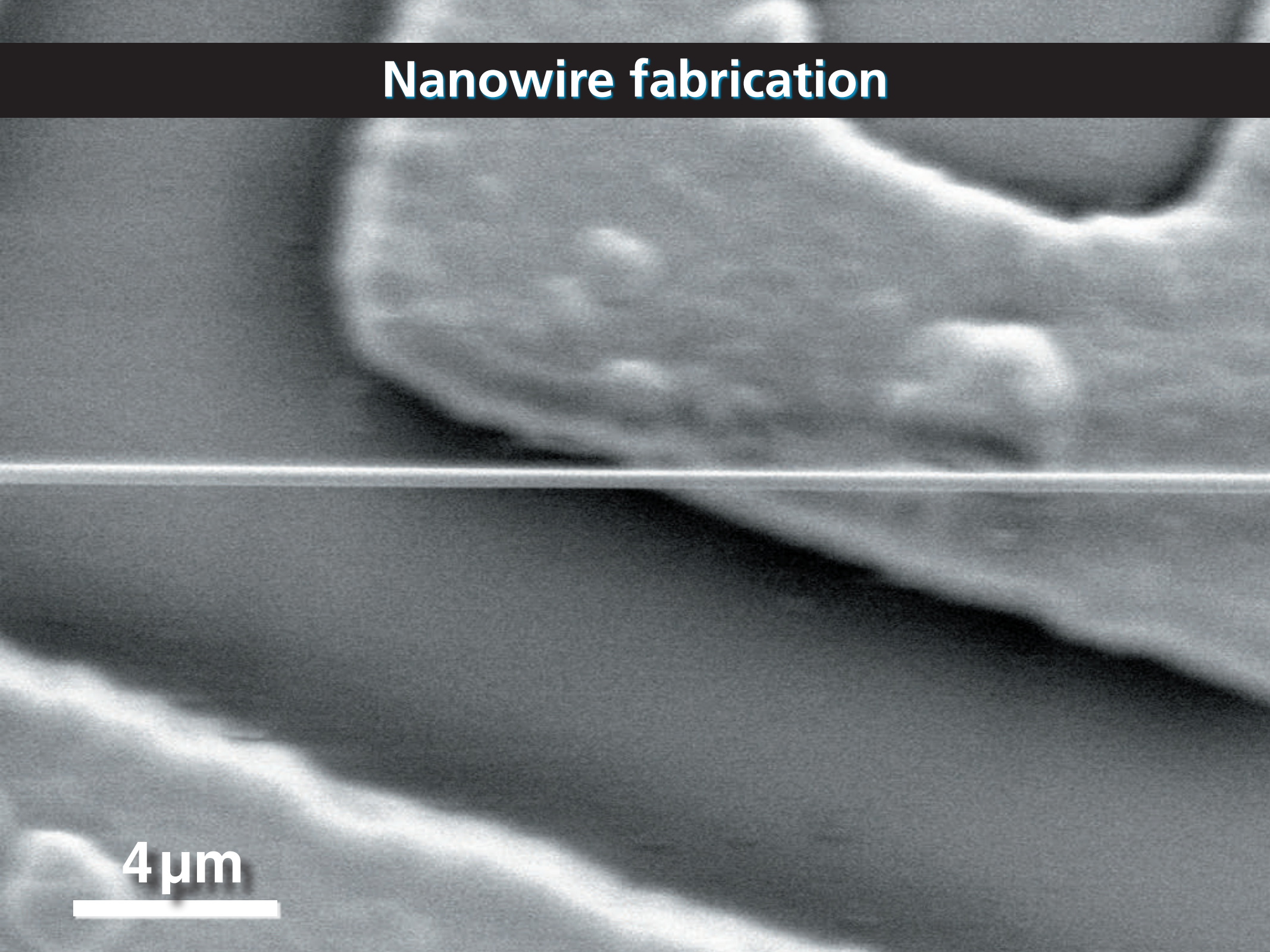

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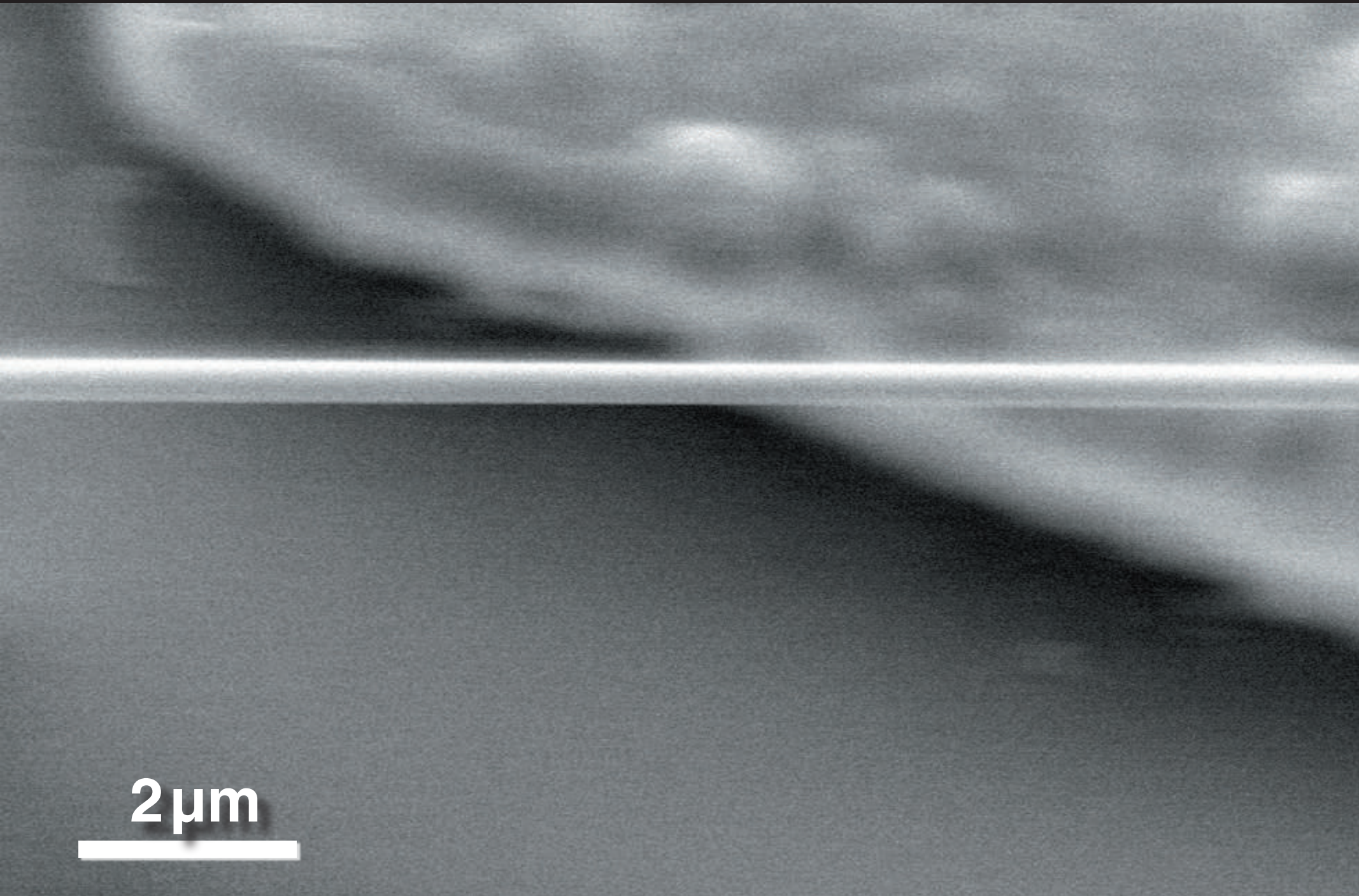

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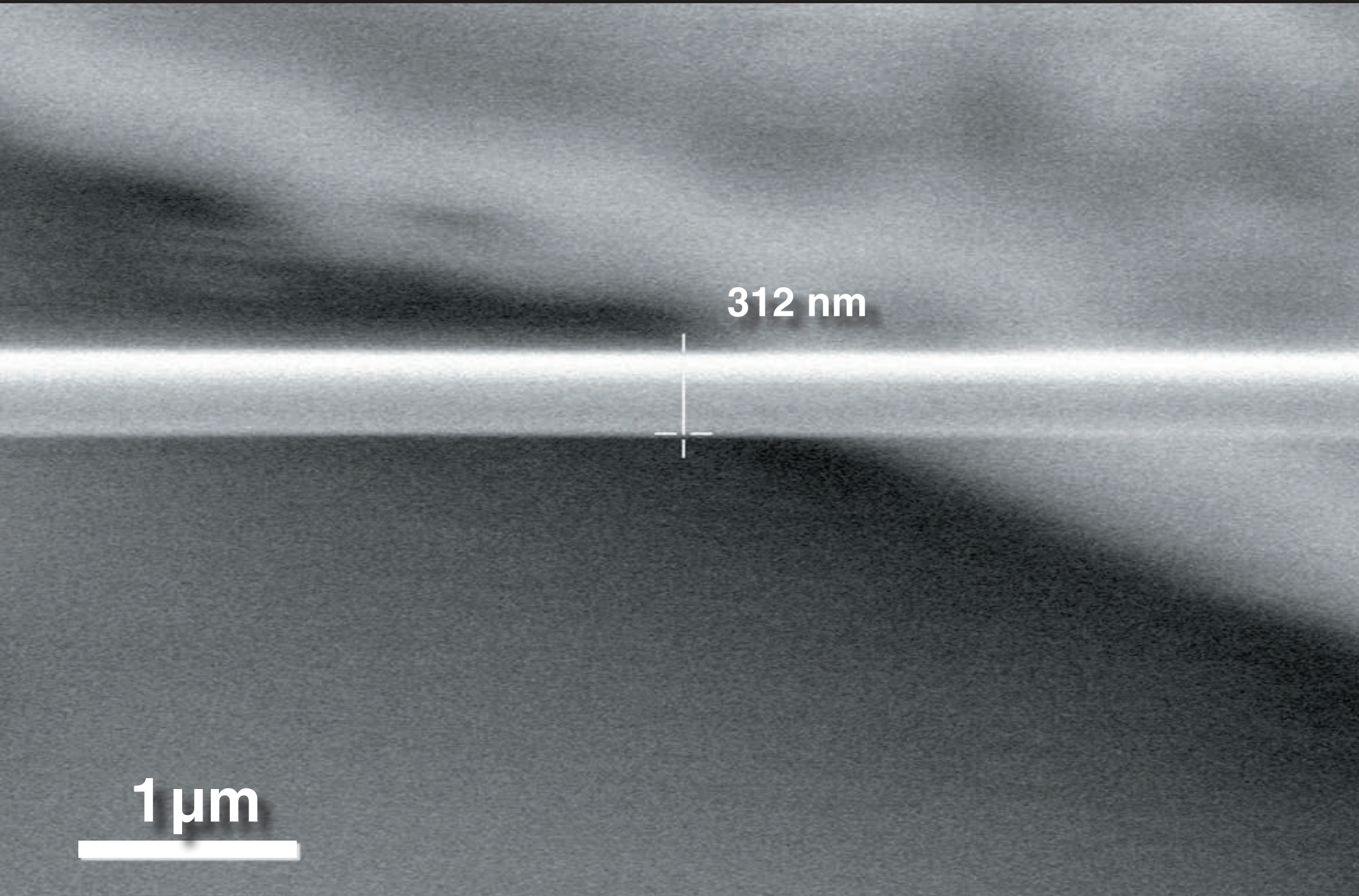
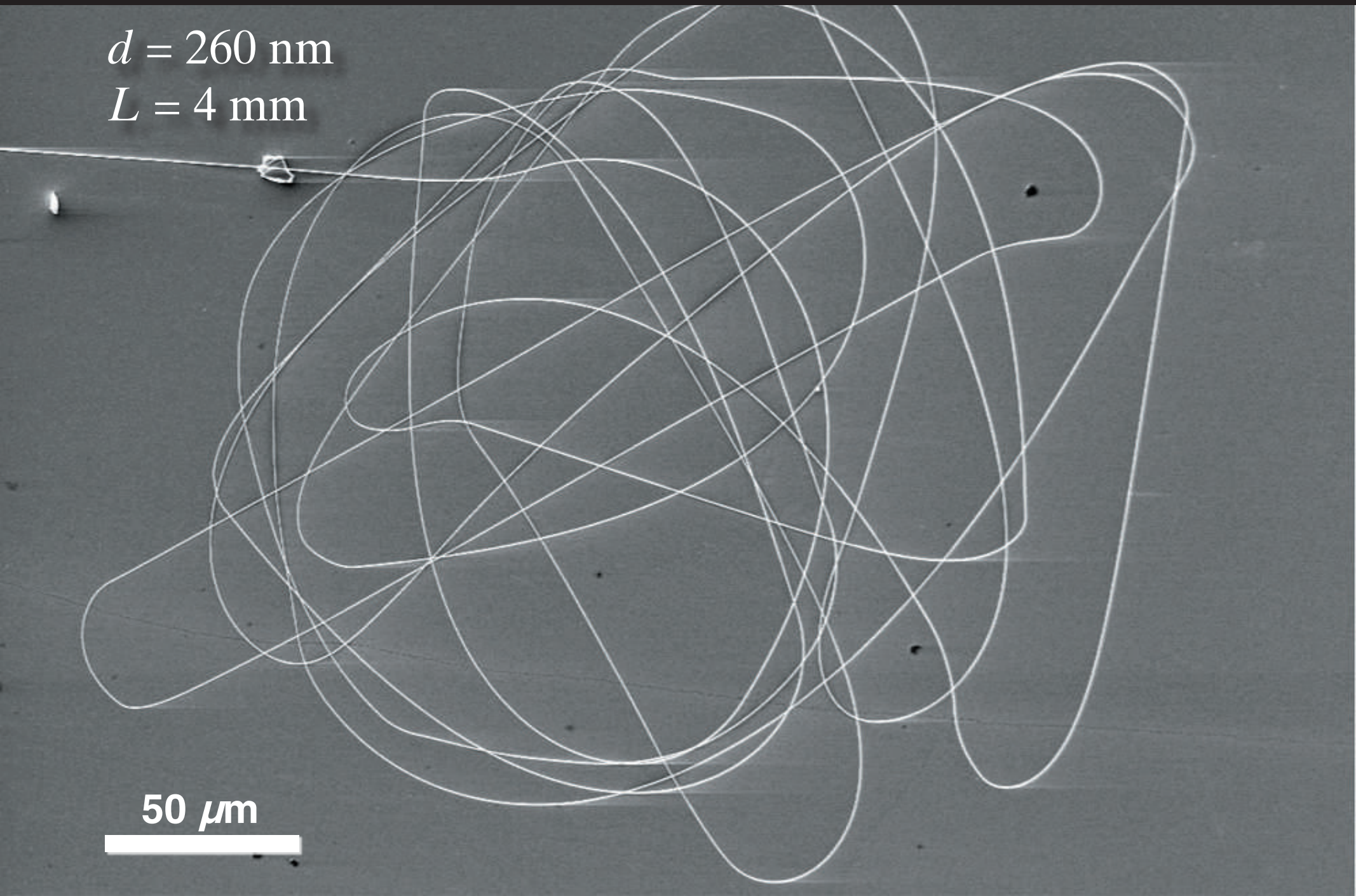


Waveguiding

Specifications

diameter D:	down to 20 nm
length L:	up to 90 mm
aspect ratio D/L:	up to 10^6
diameter uniformity $\Delta D/L$:	2×10^{-6}

Nanowire fabrication



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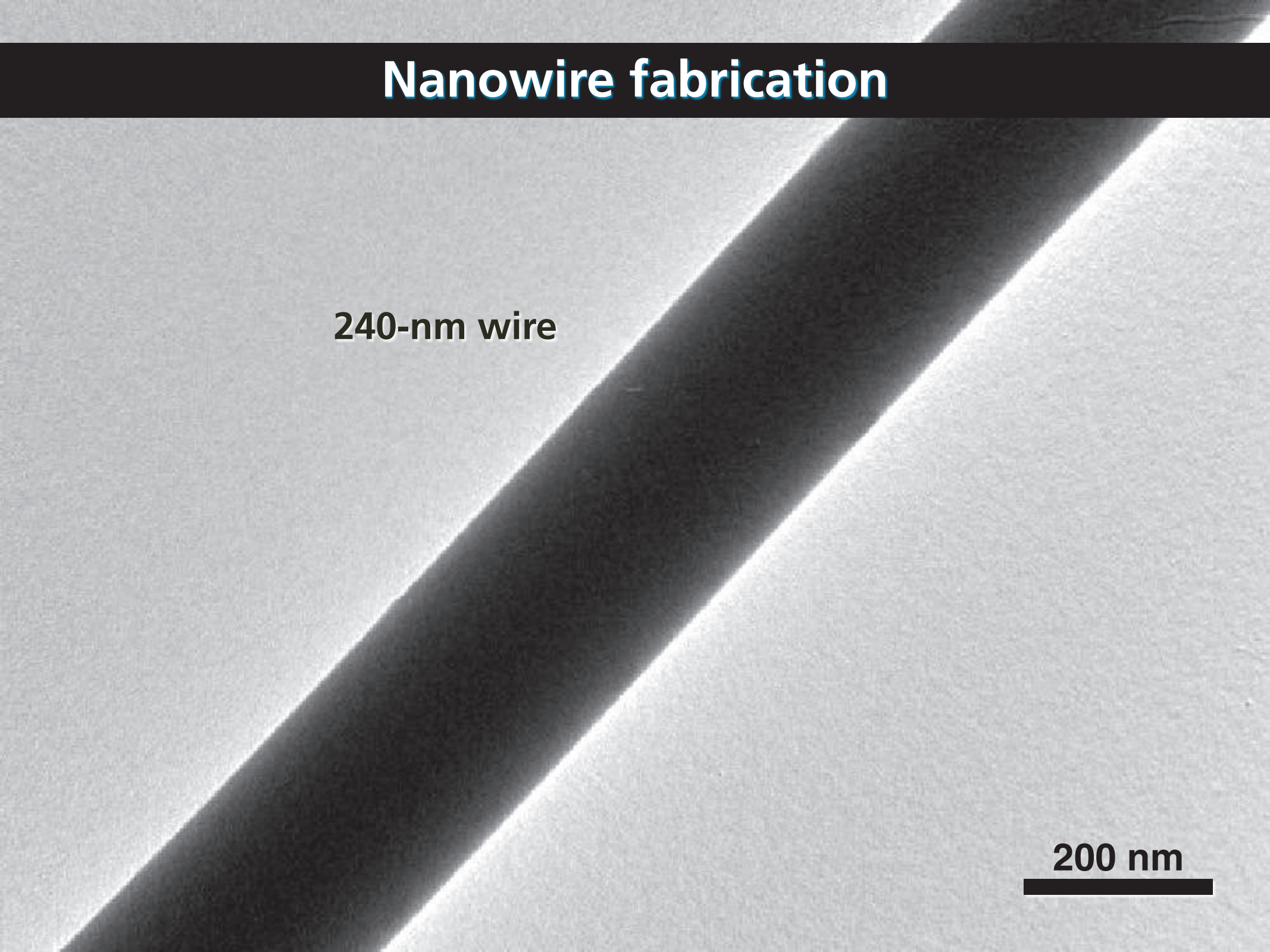

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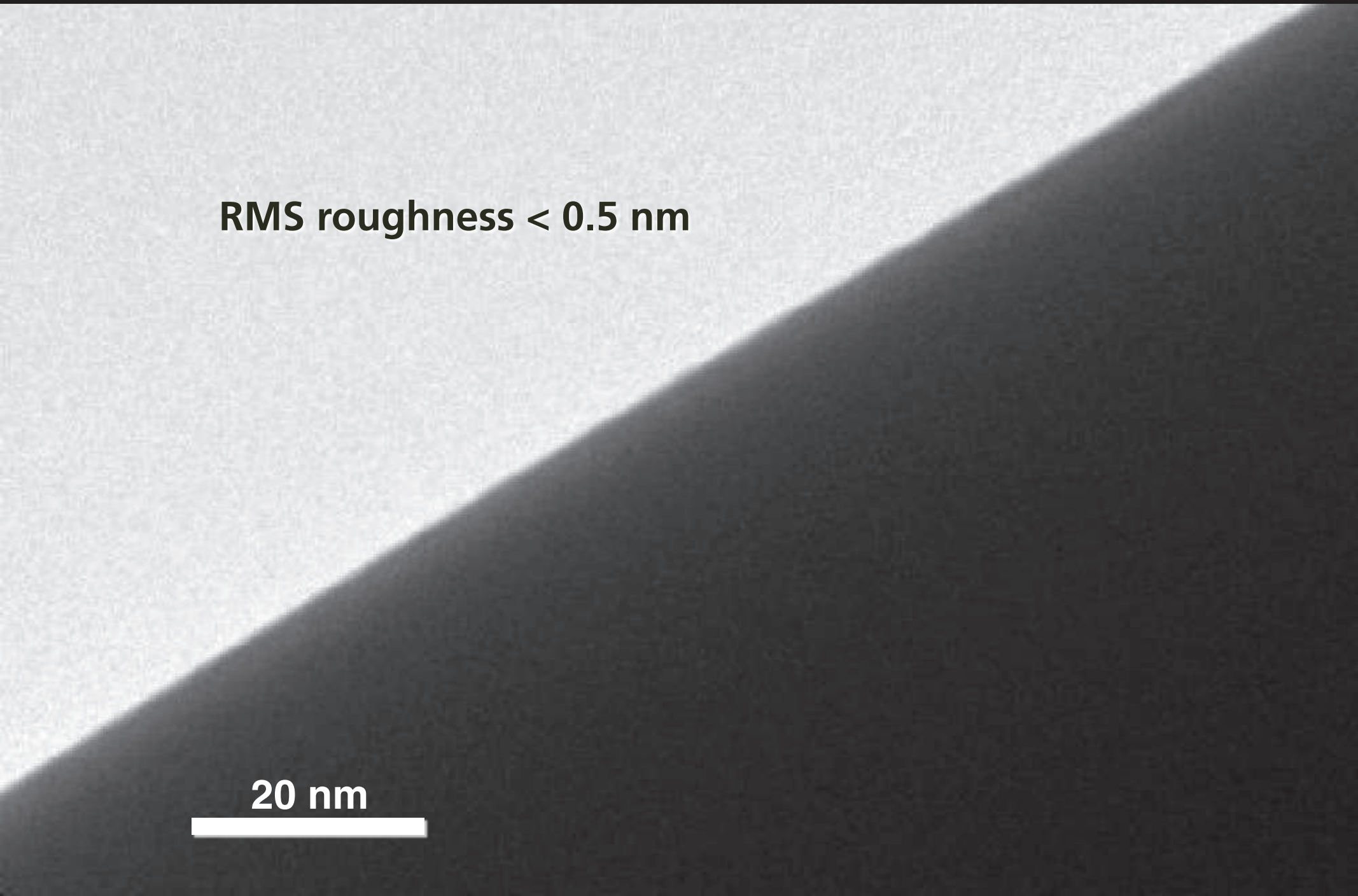

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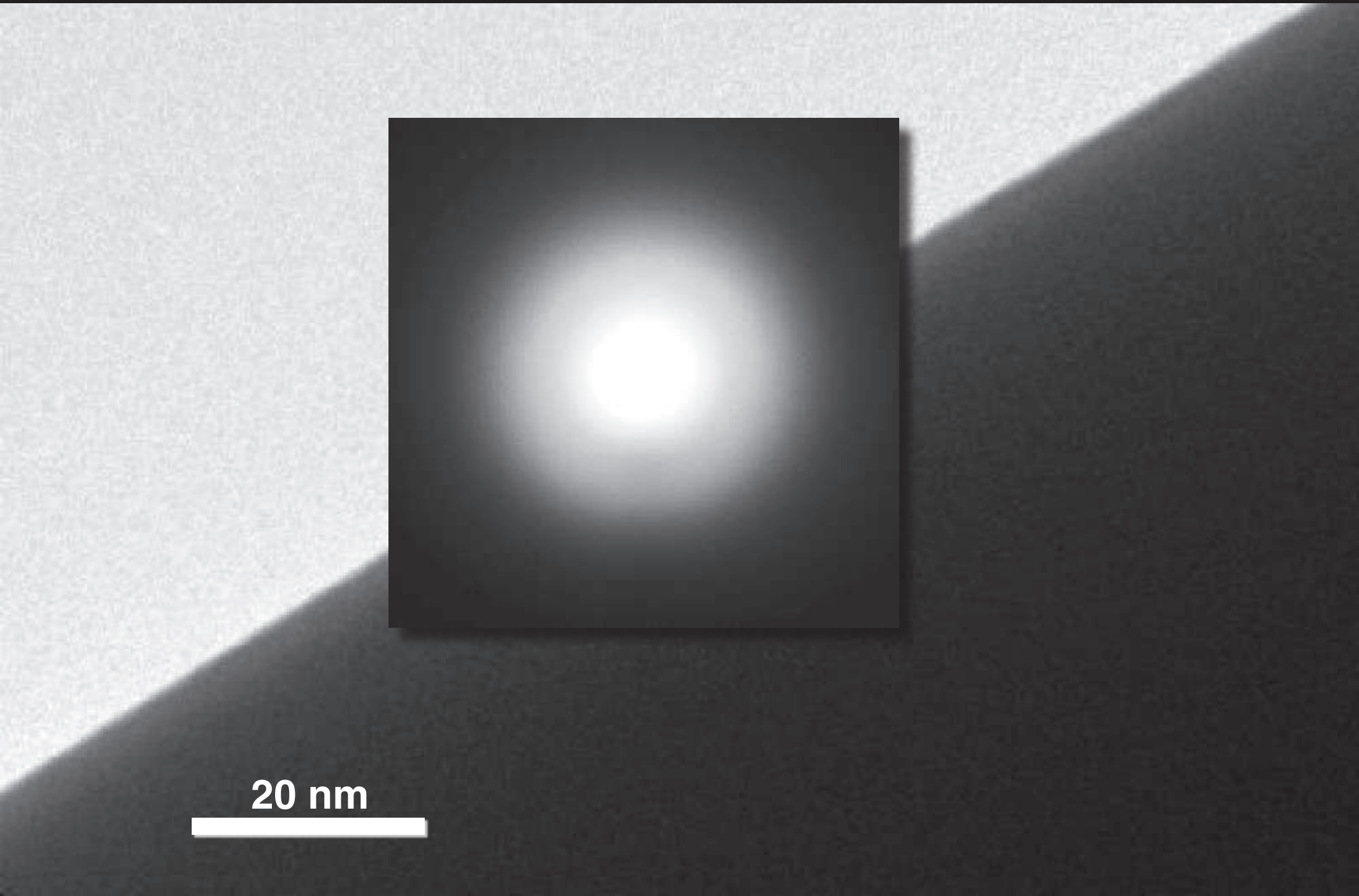

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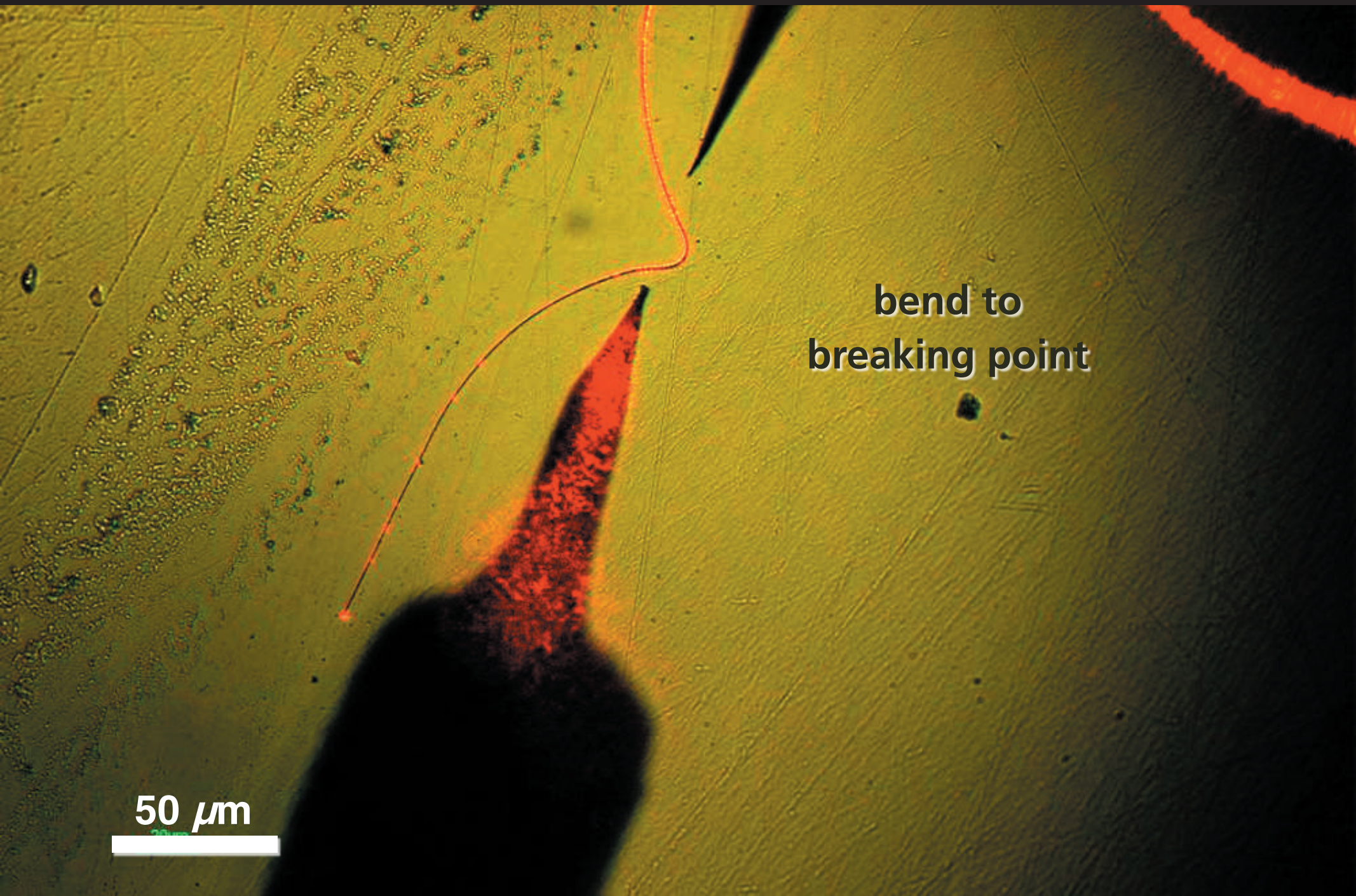

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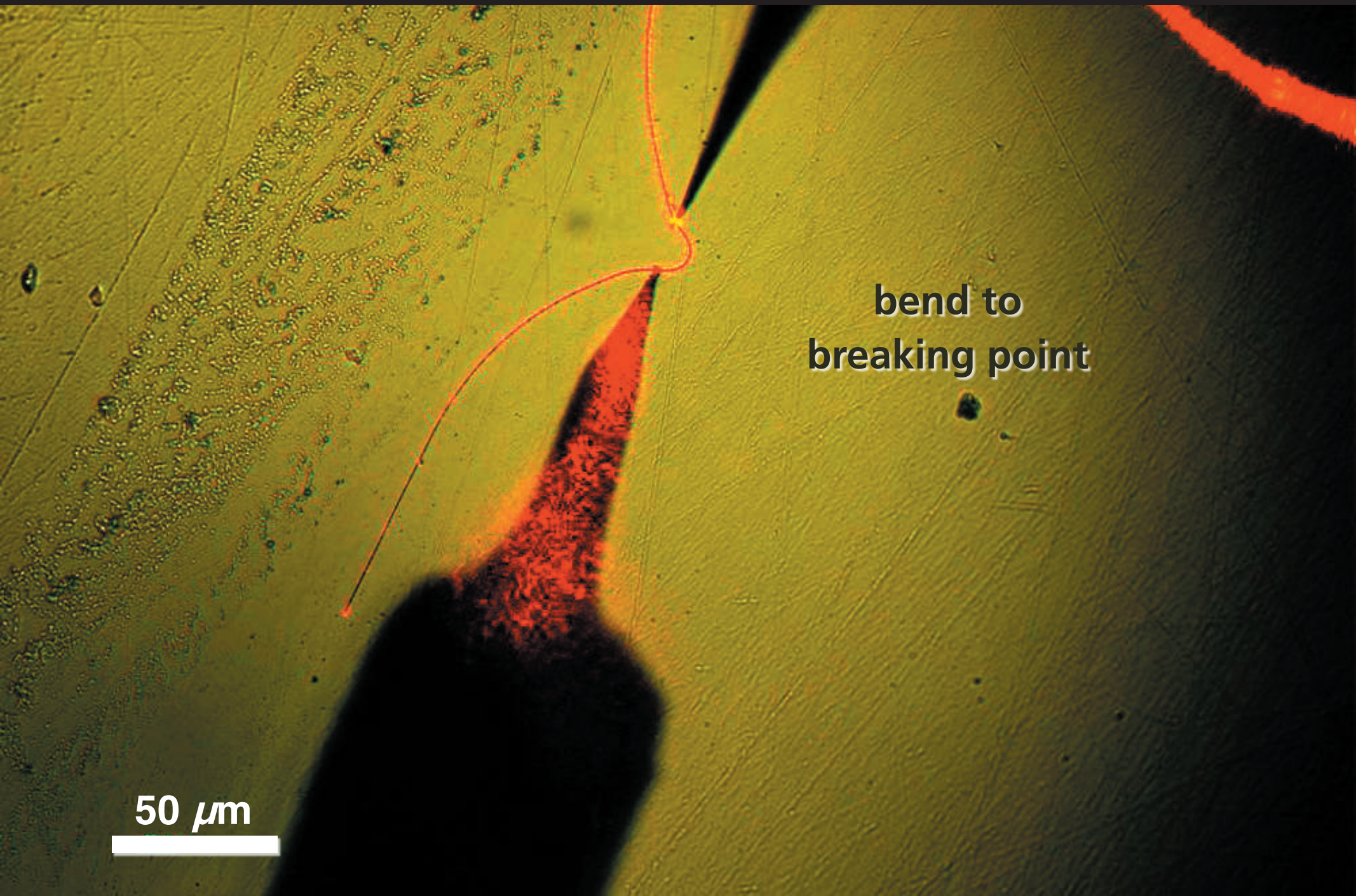

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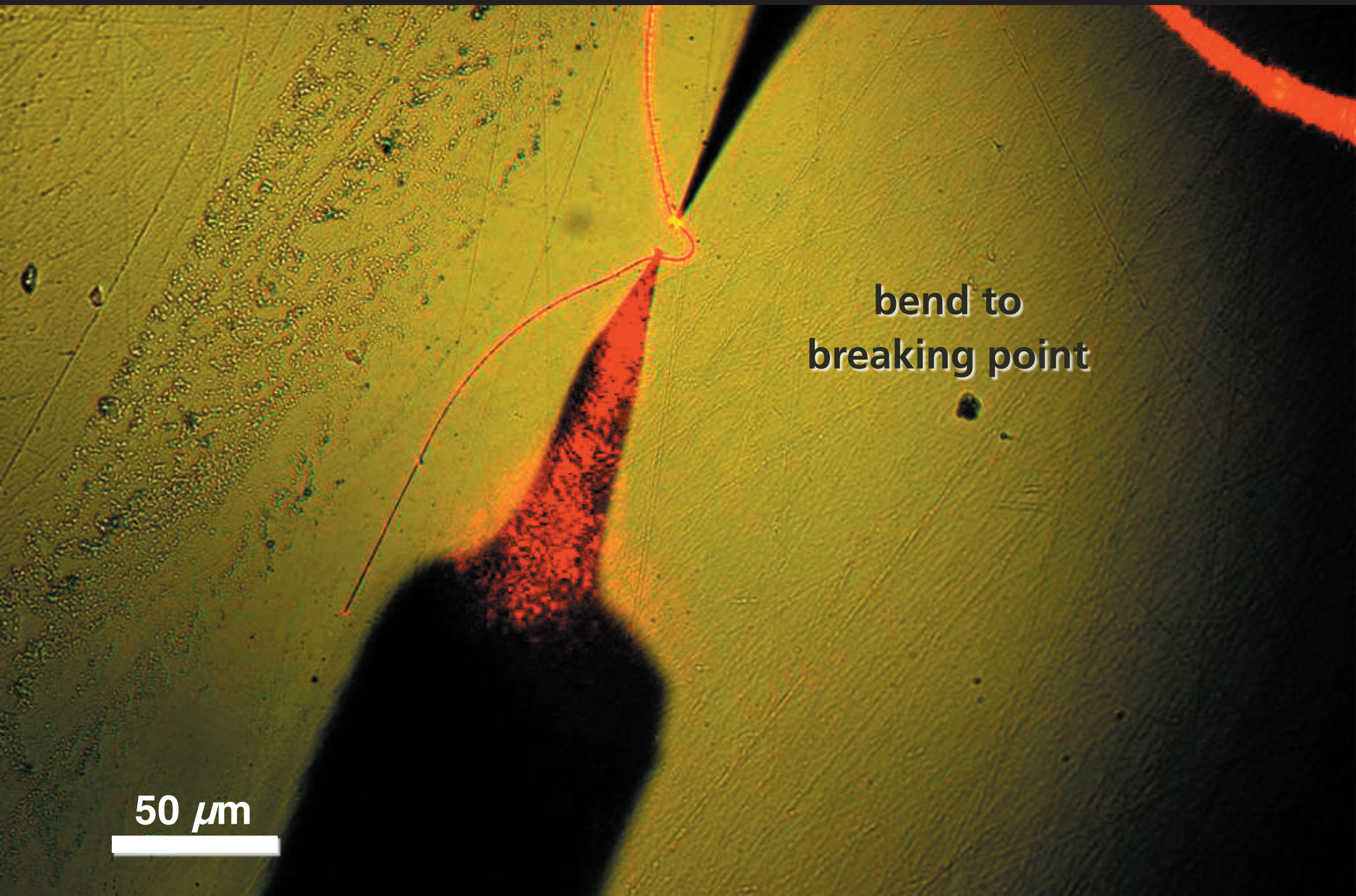

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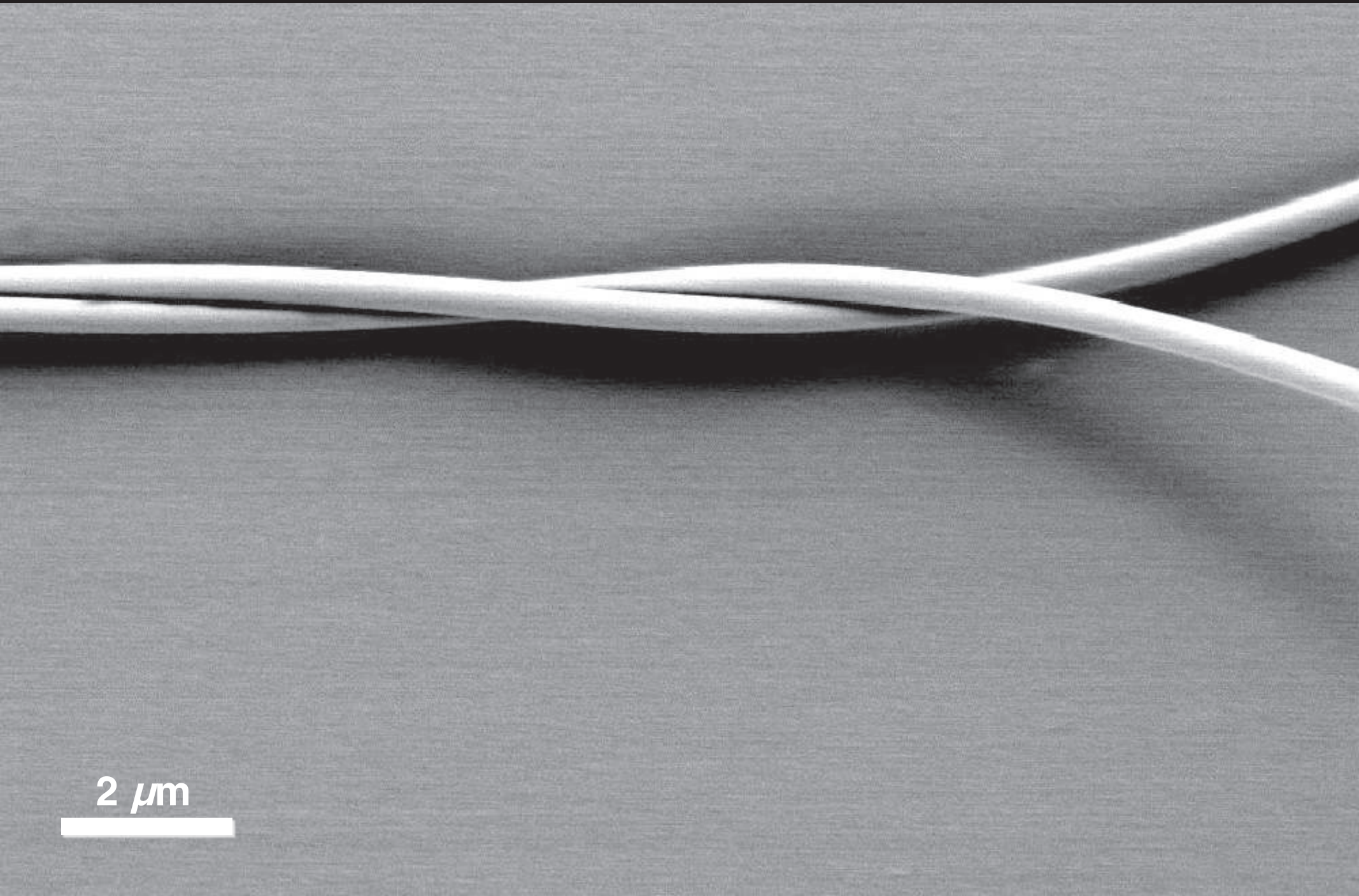

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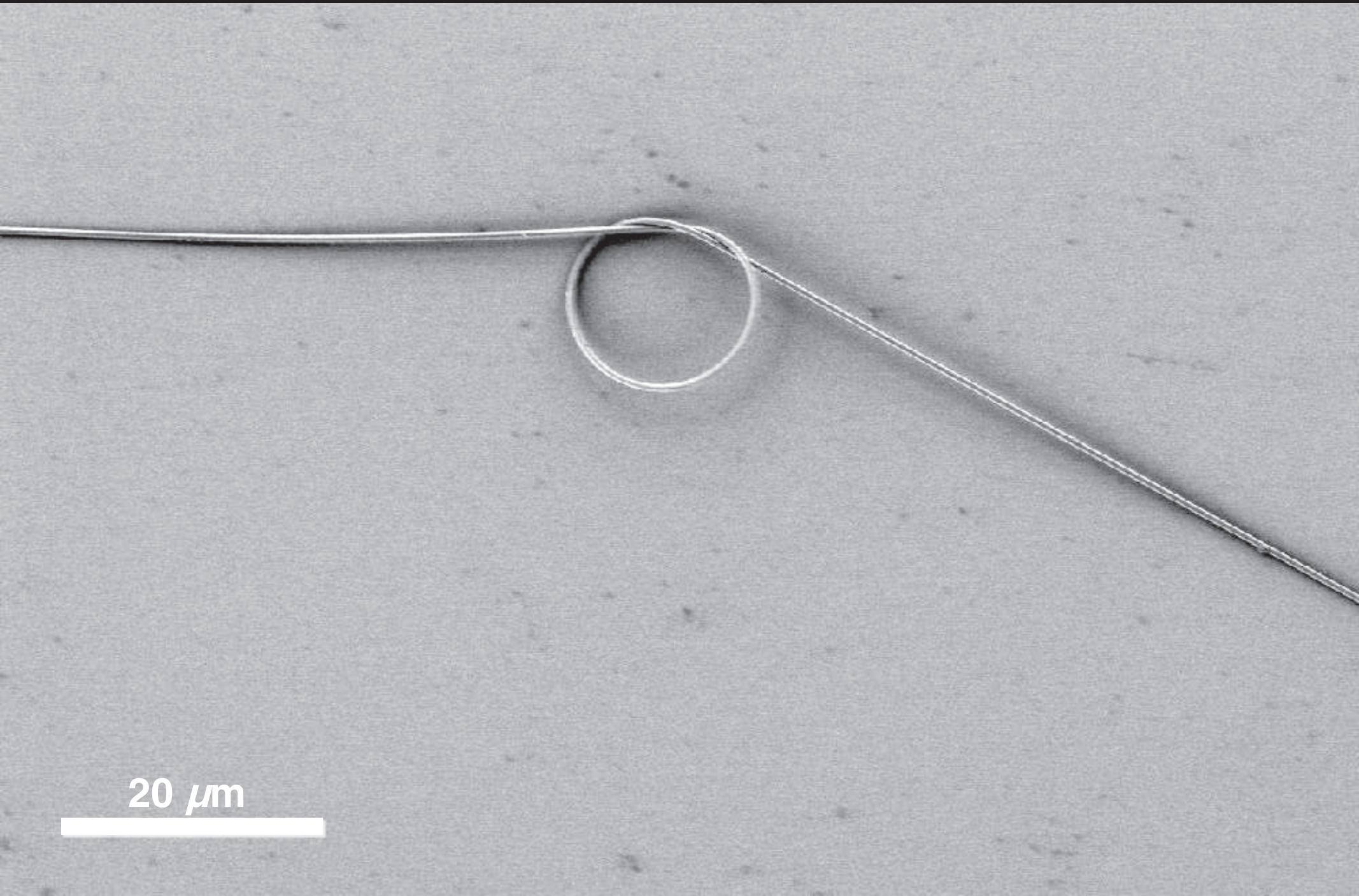

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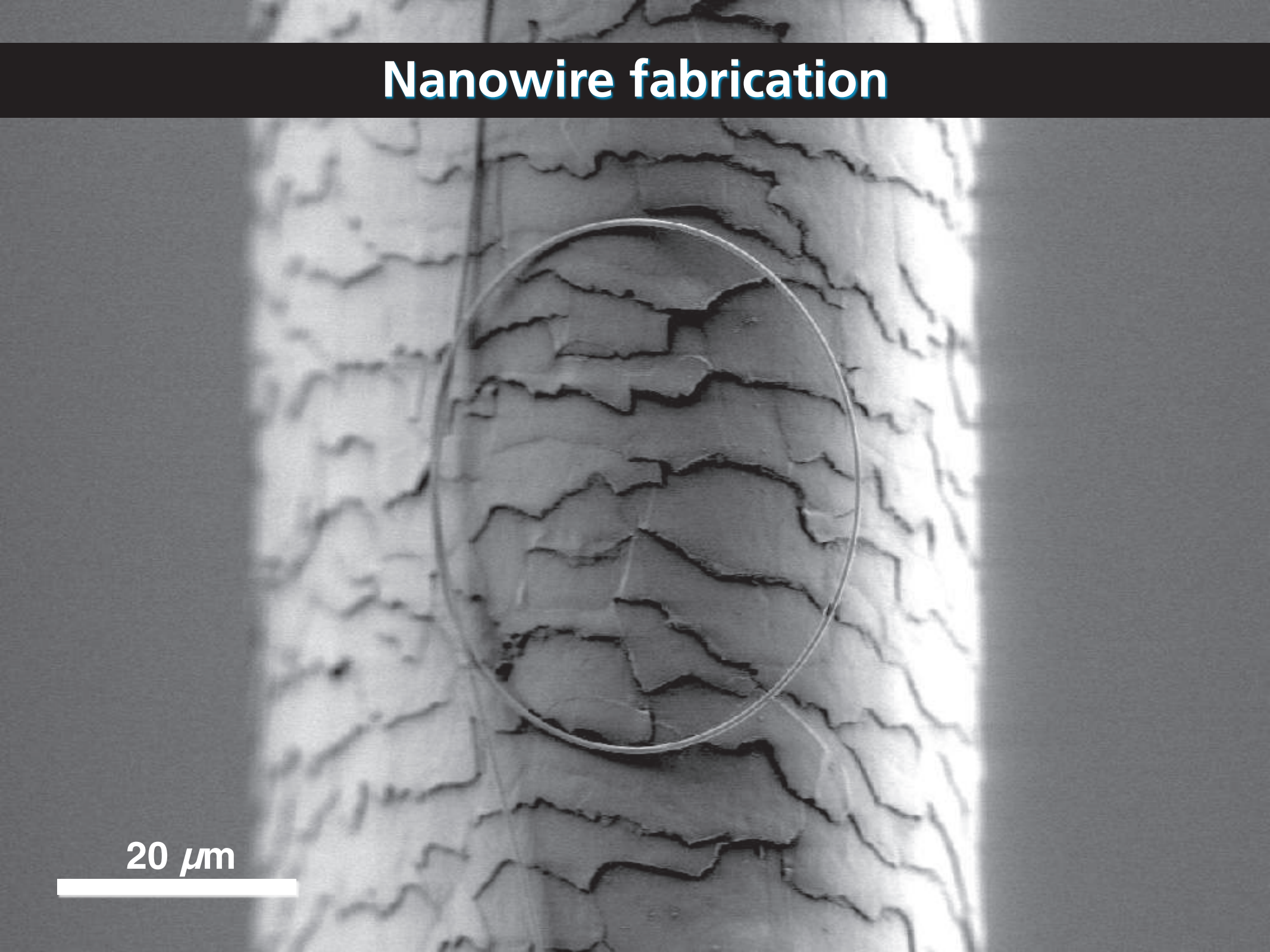


Outline

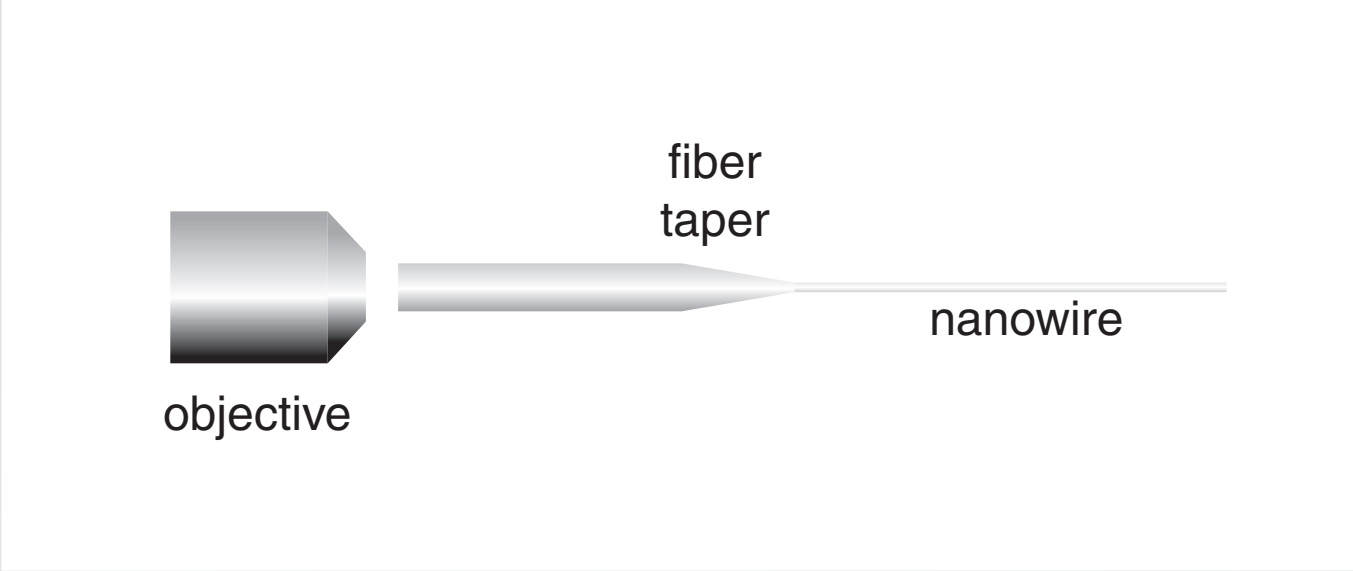
- waveguiding
- nanowire fabrication
- optical properties

Optical properties

coupling light into nanowires

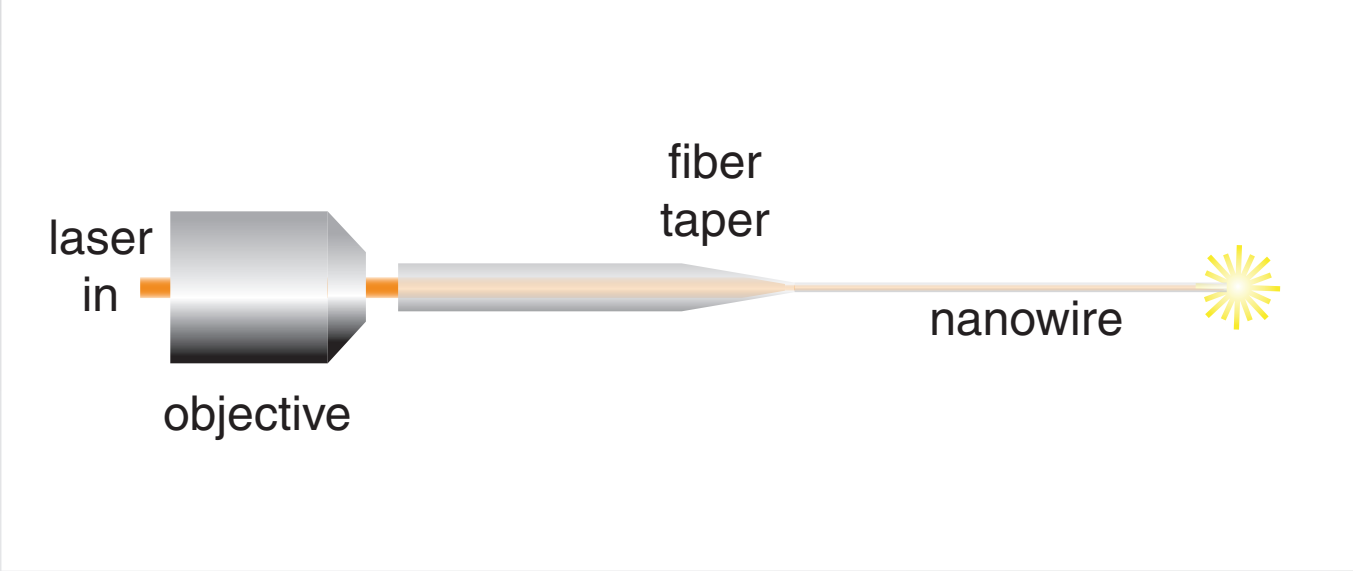
Optical properties

coupling light into nanowires



Optical properties

coupling light into nanowires



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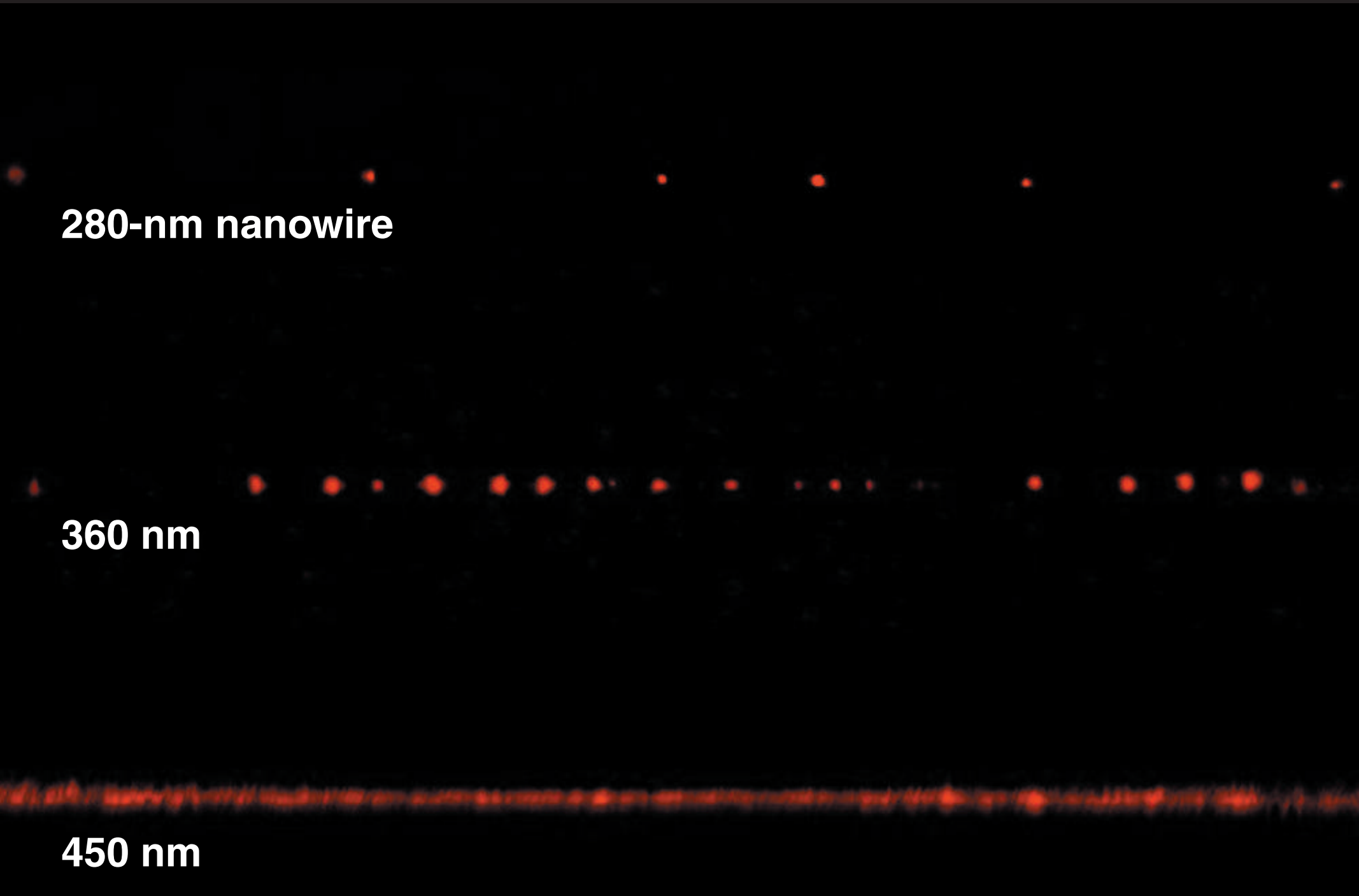

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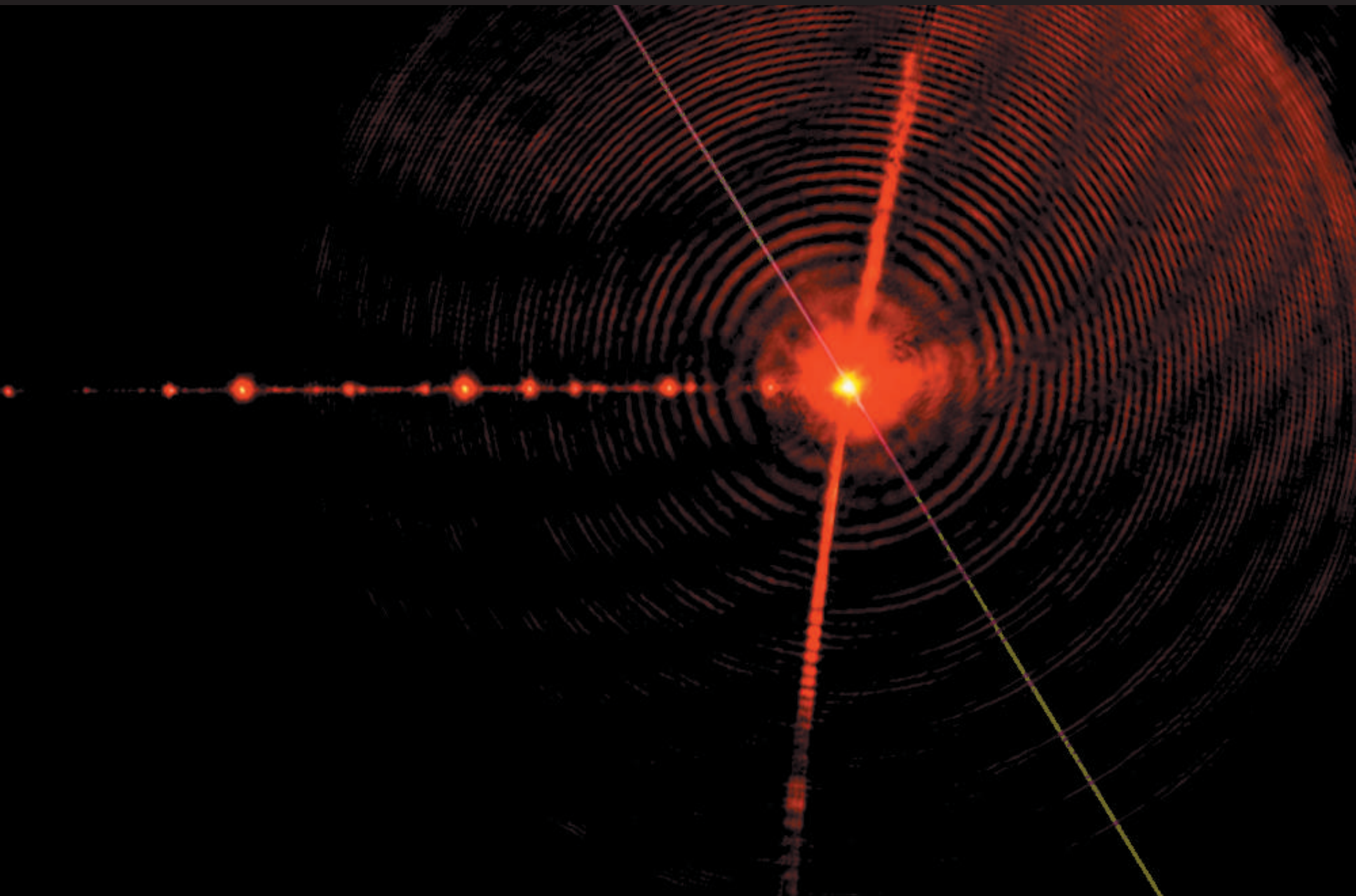
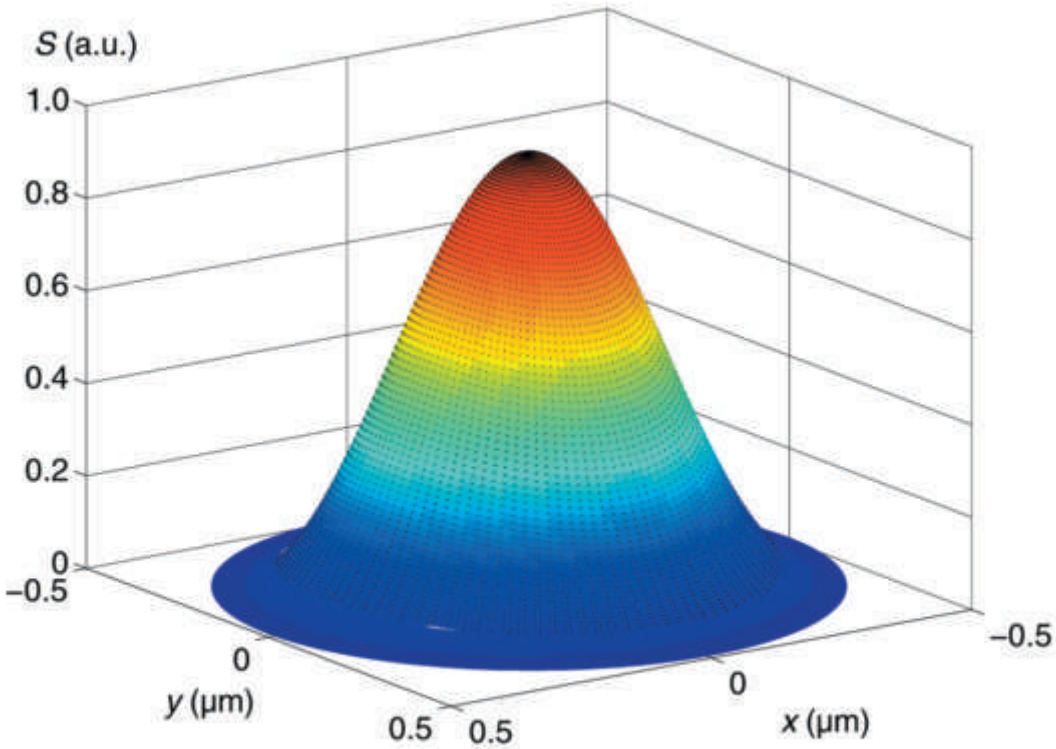


Optical properties

Optical properties

Poynting vector profile for 800-nm nanowire



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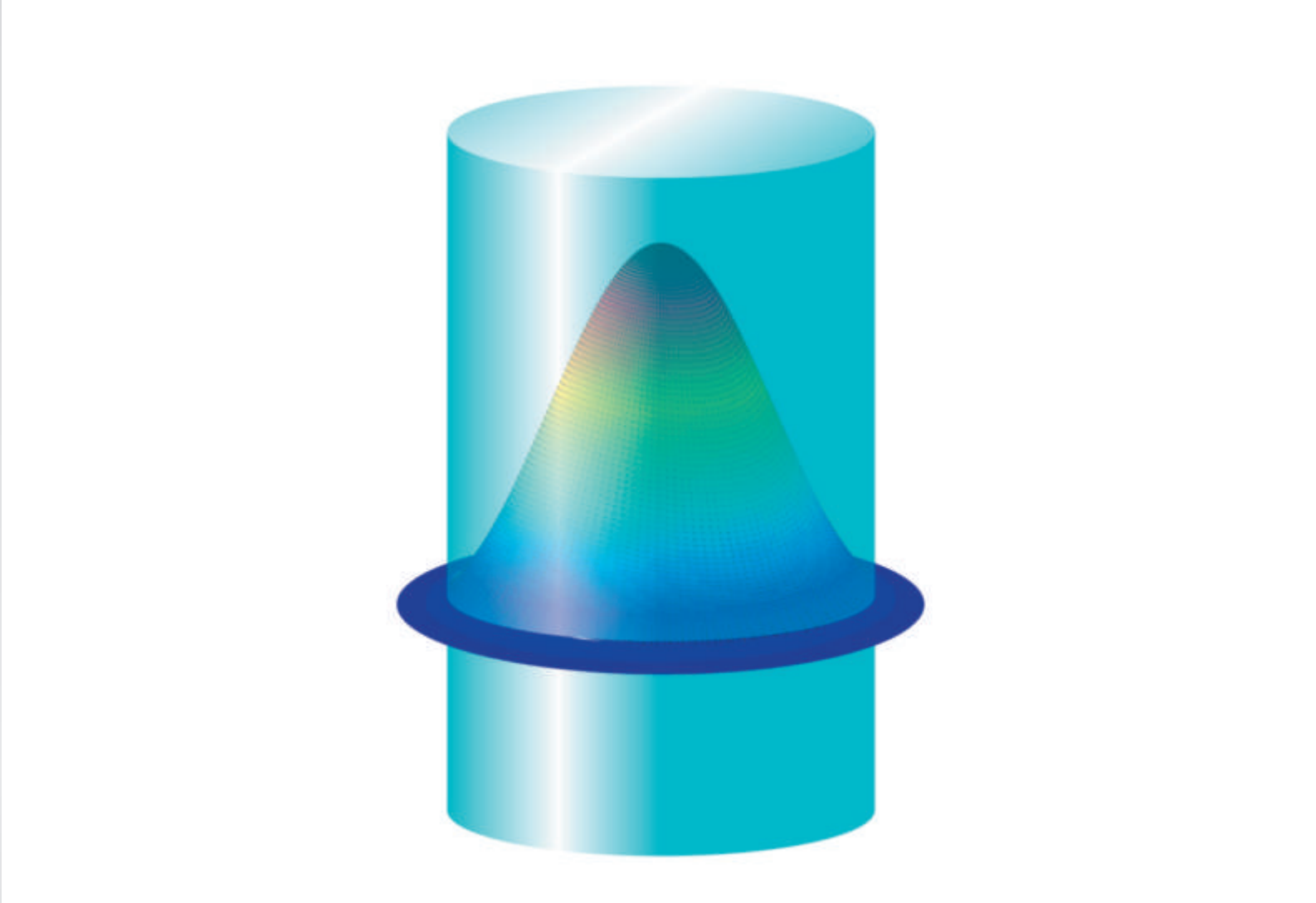

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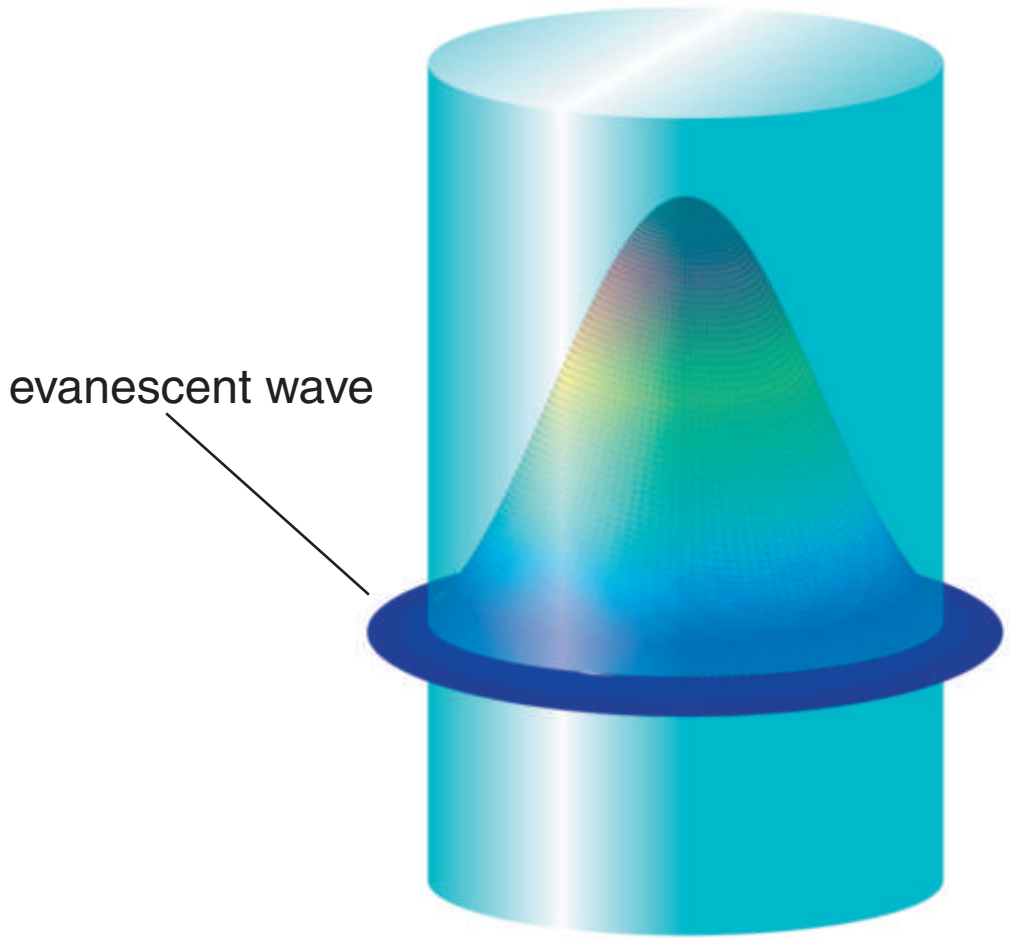
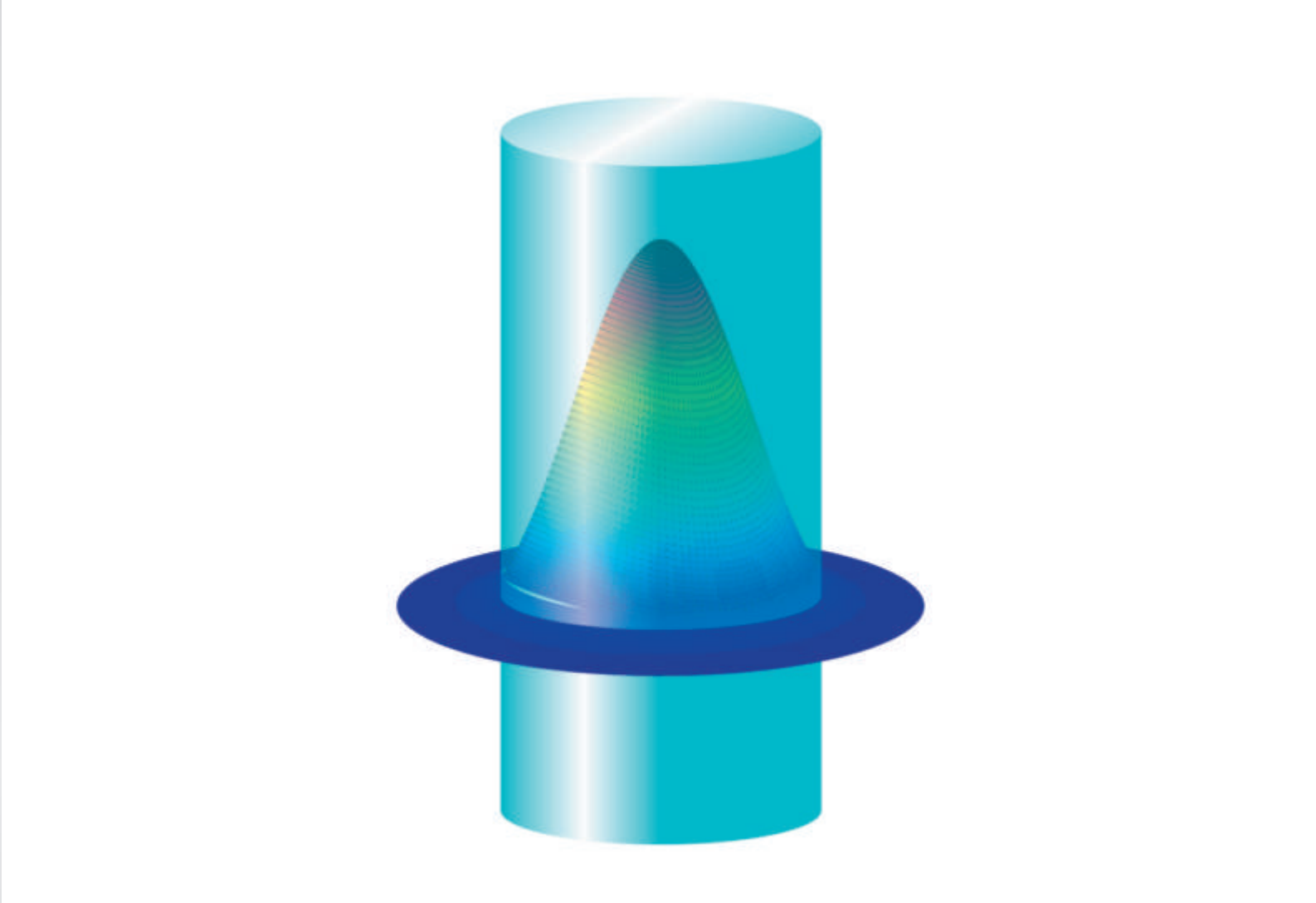
Poynting vector profile for 800-nm nanowire



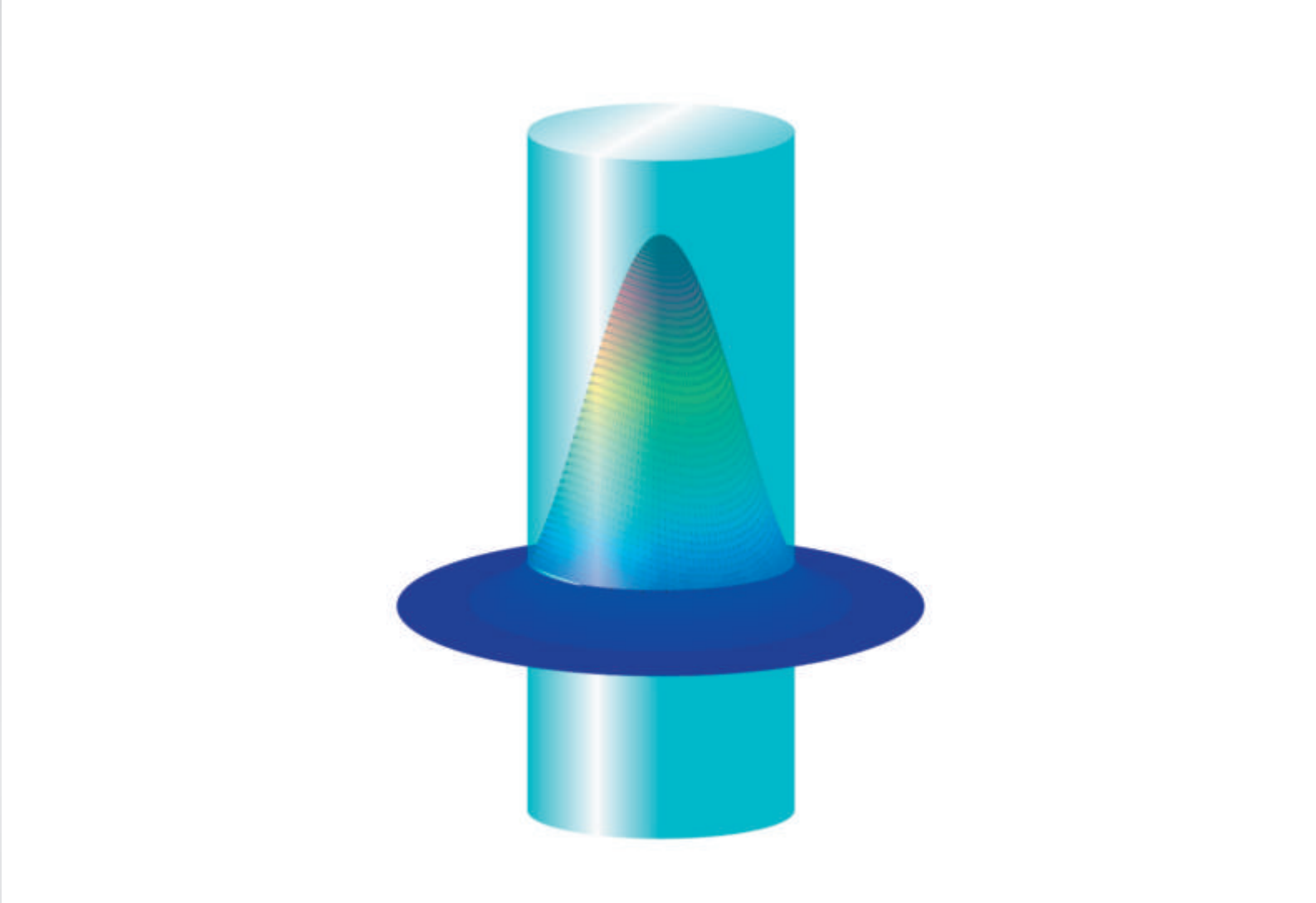
Optical properties

Poynting vector profile for 600-nm nanowire



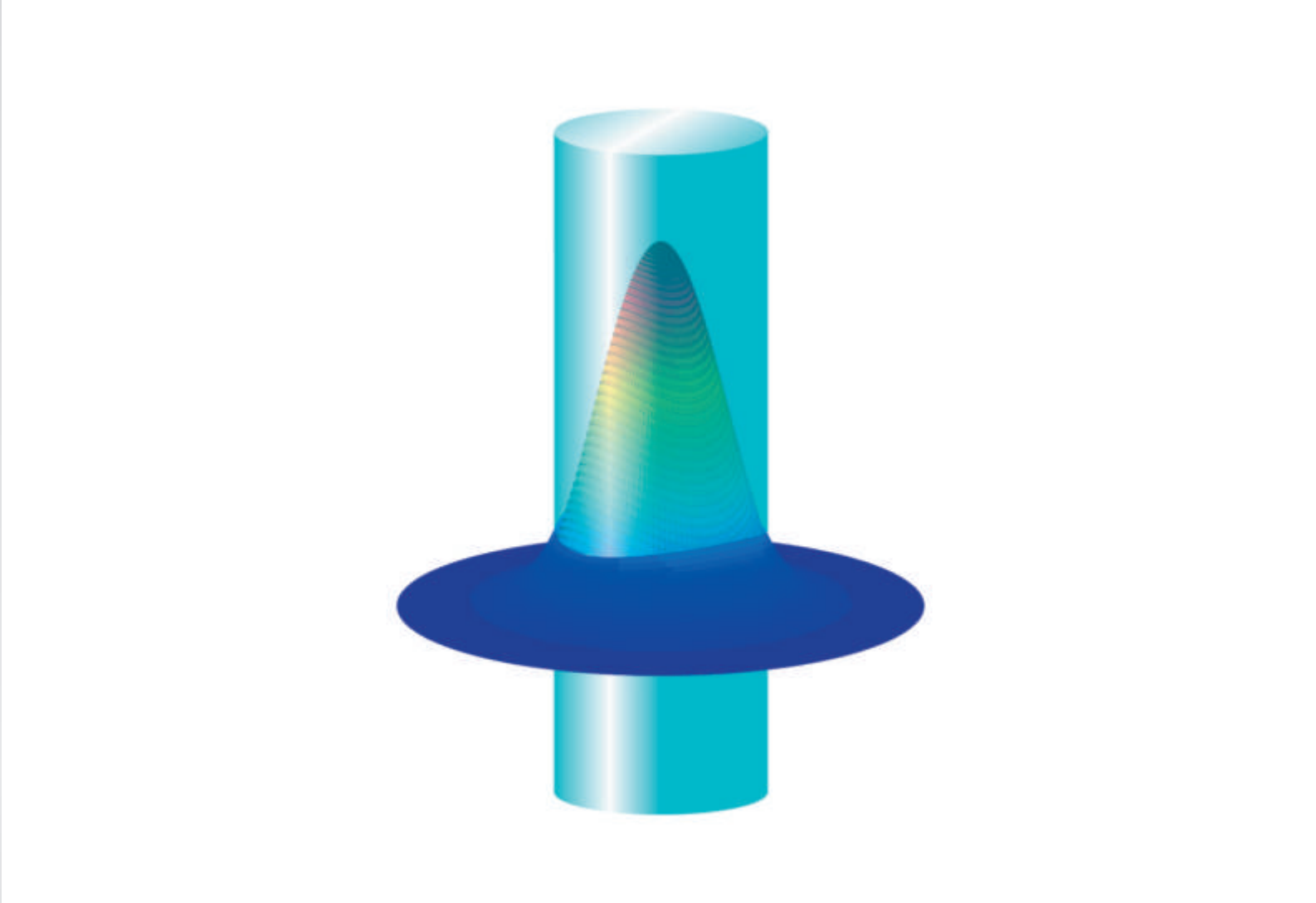
Optical properties

Poynting vector profile for 500-nm nanowire



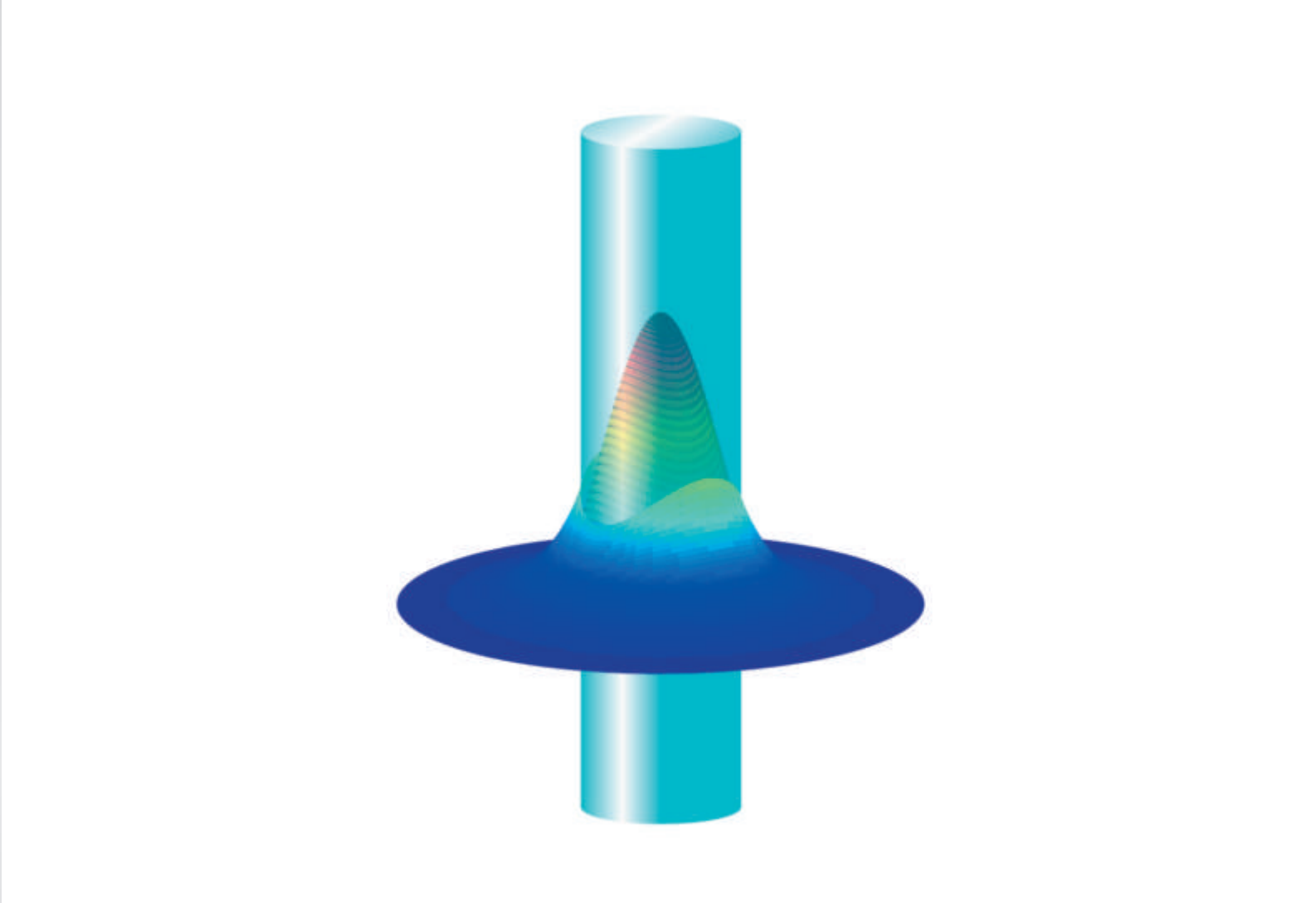
Optical properties

Poynting vector profile for 400-nm nanowire



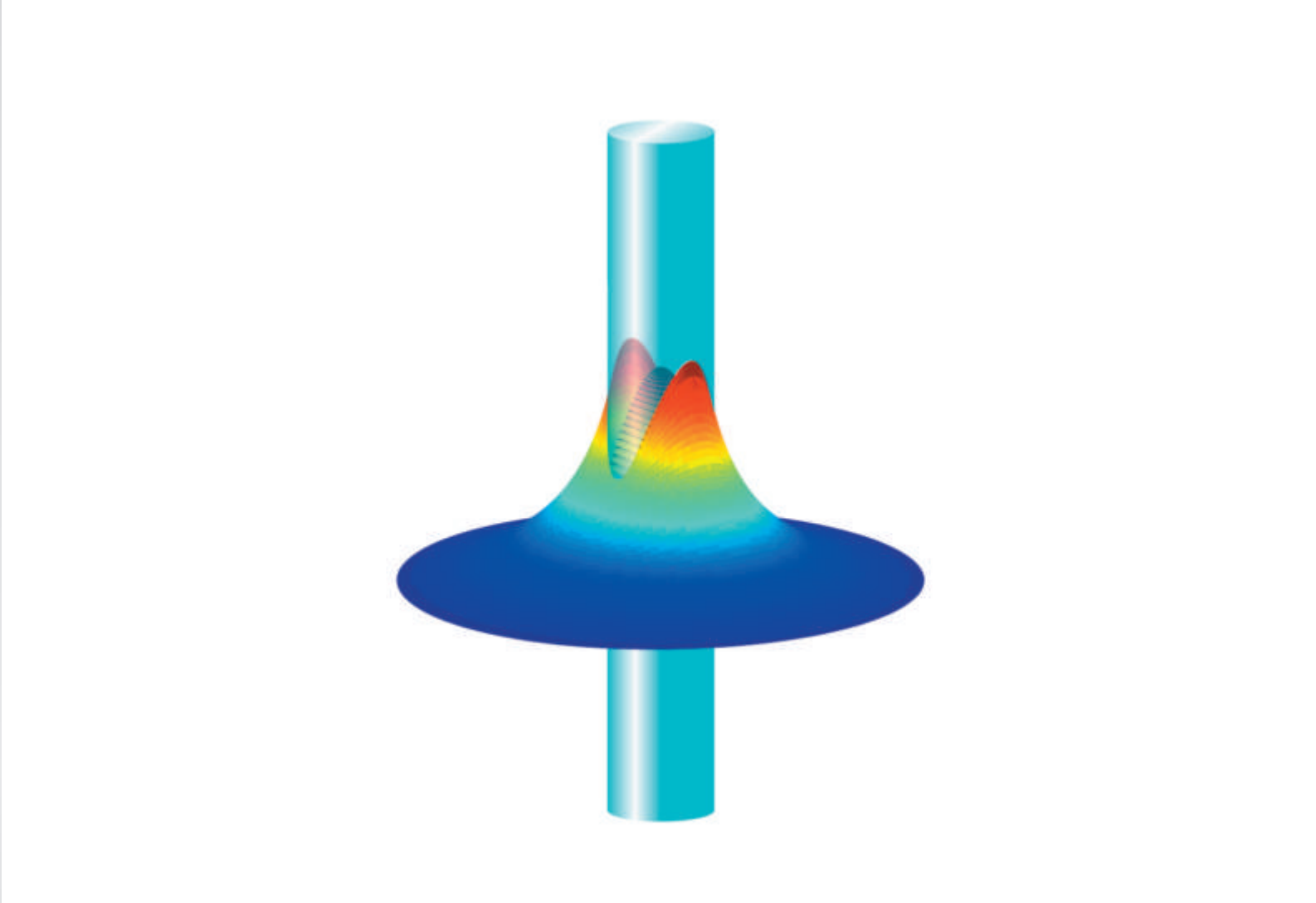
Optical properties

Poynting vector profile for 300-nm nanowire



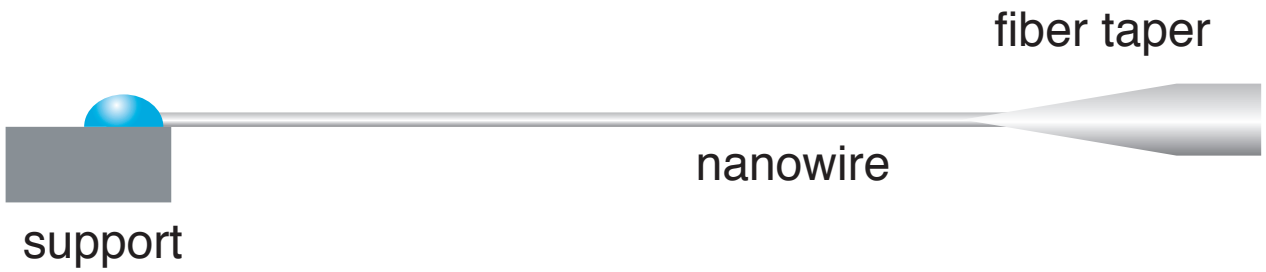
Optical properties

Poynting vector profile for 200-nm nanowire



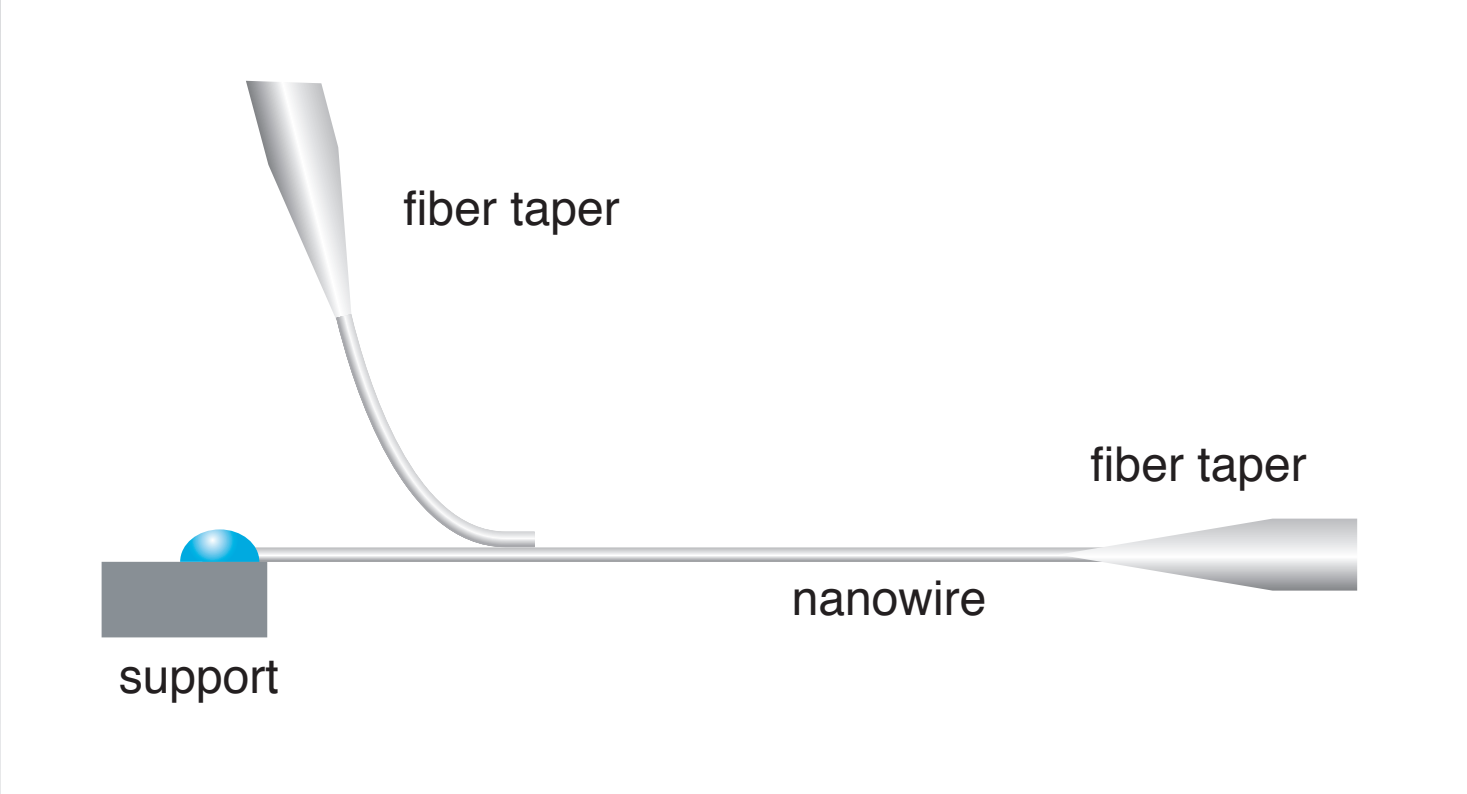
Optical properties

coupling light between nanowires



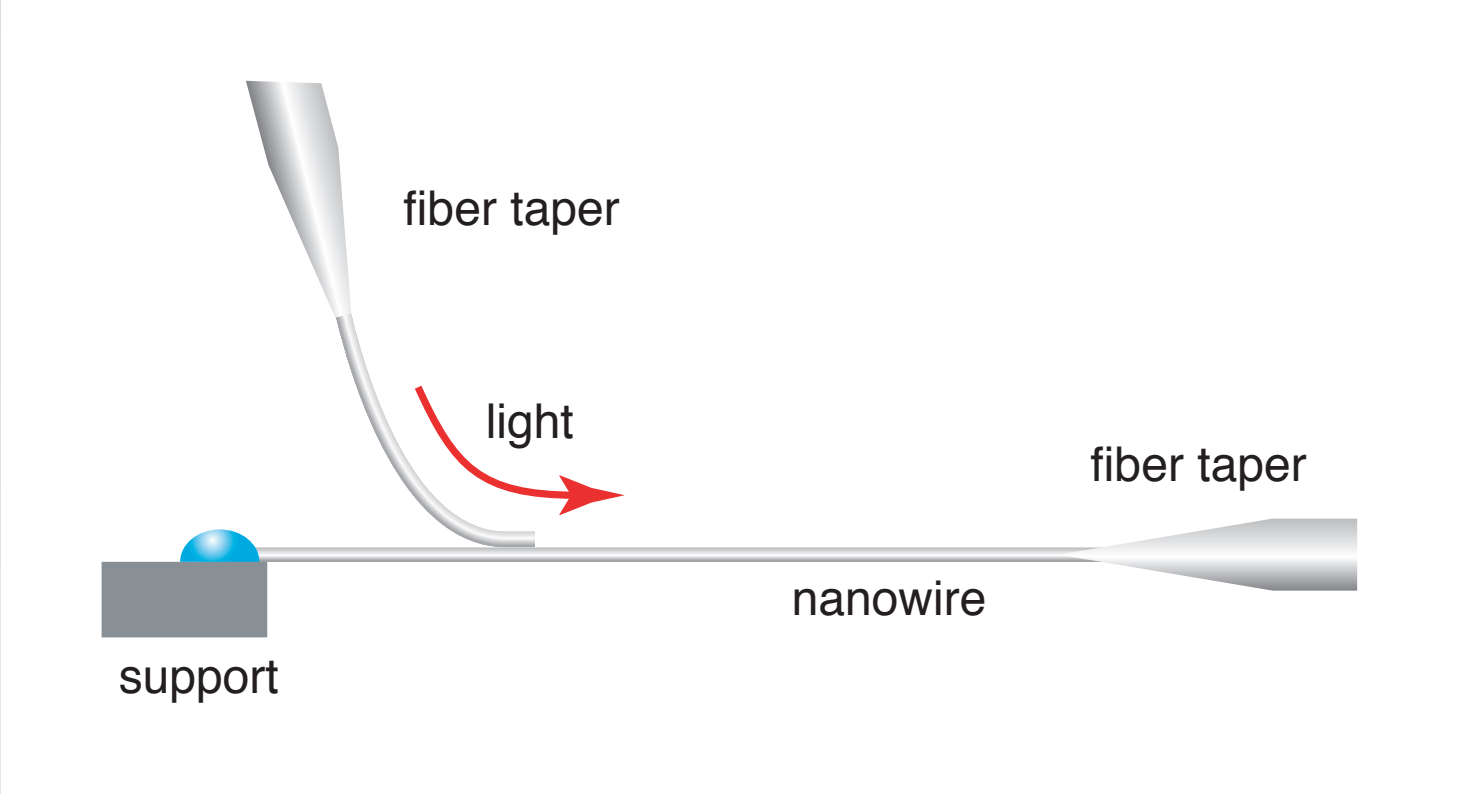
Optical properties

coupling light between nanowires

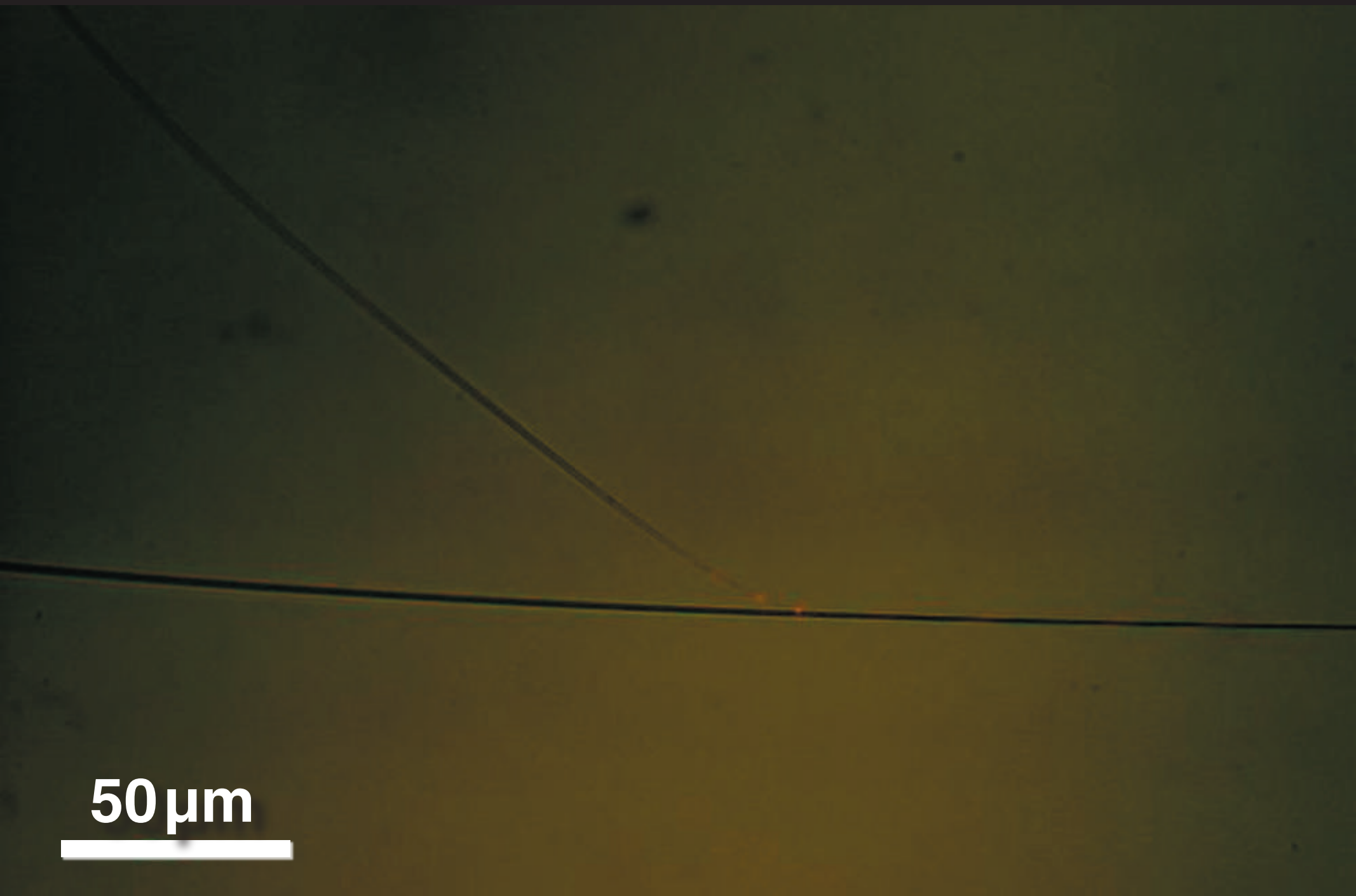


Optical properties

coupling light between nanowires



Optical properties



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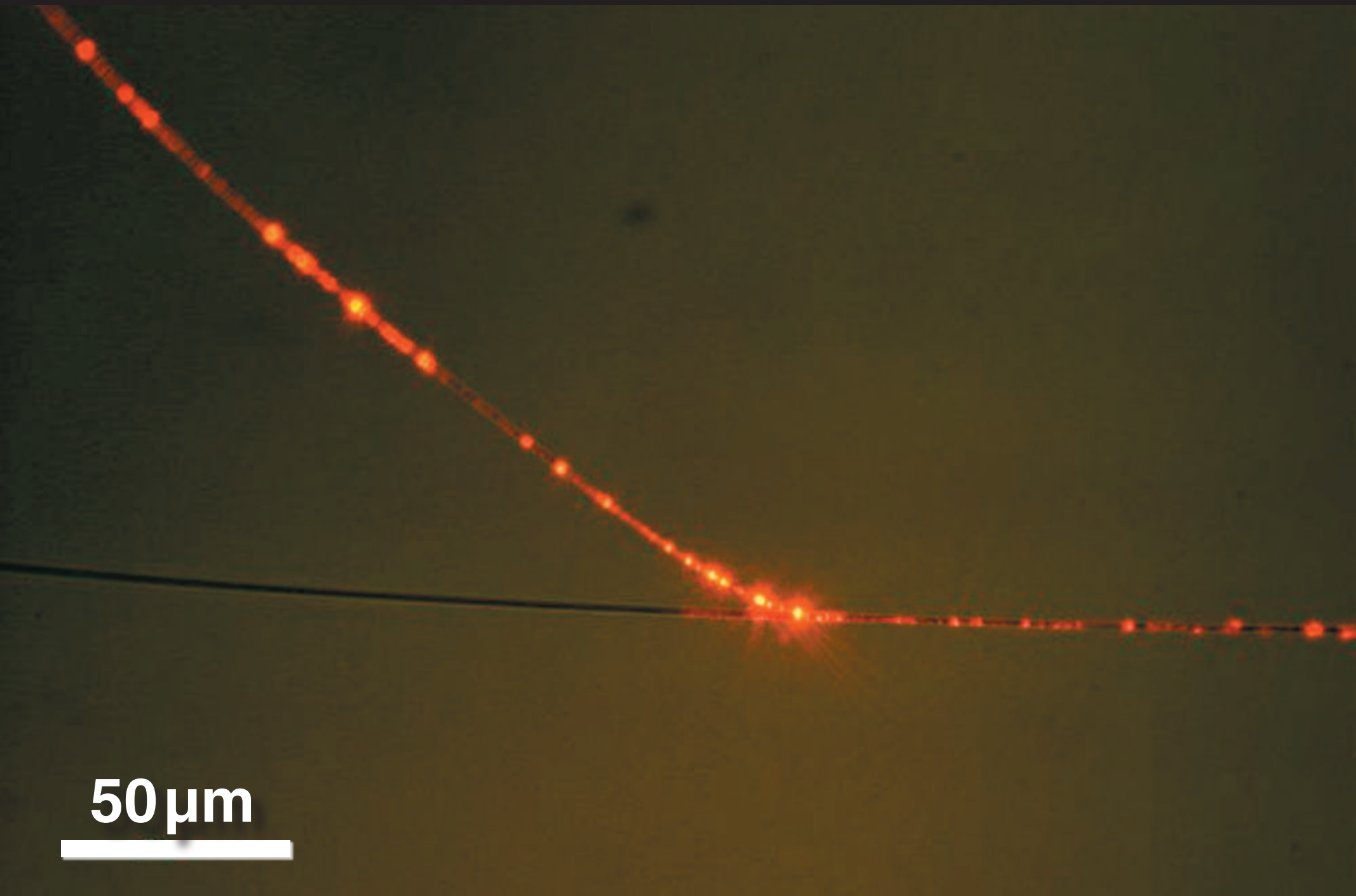

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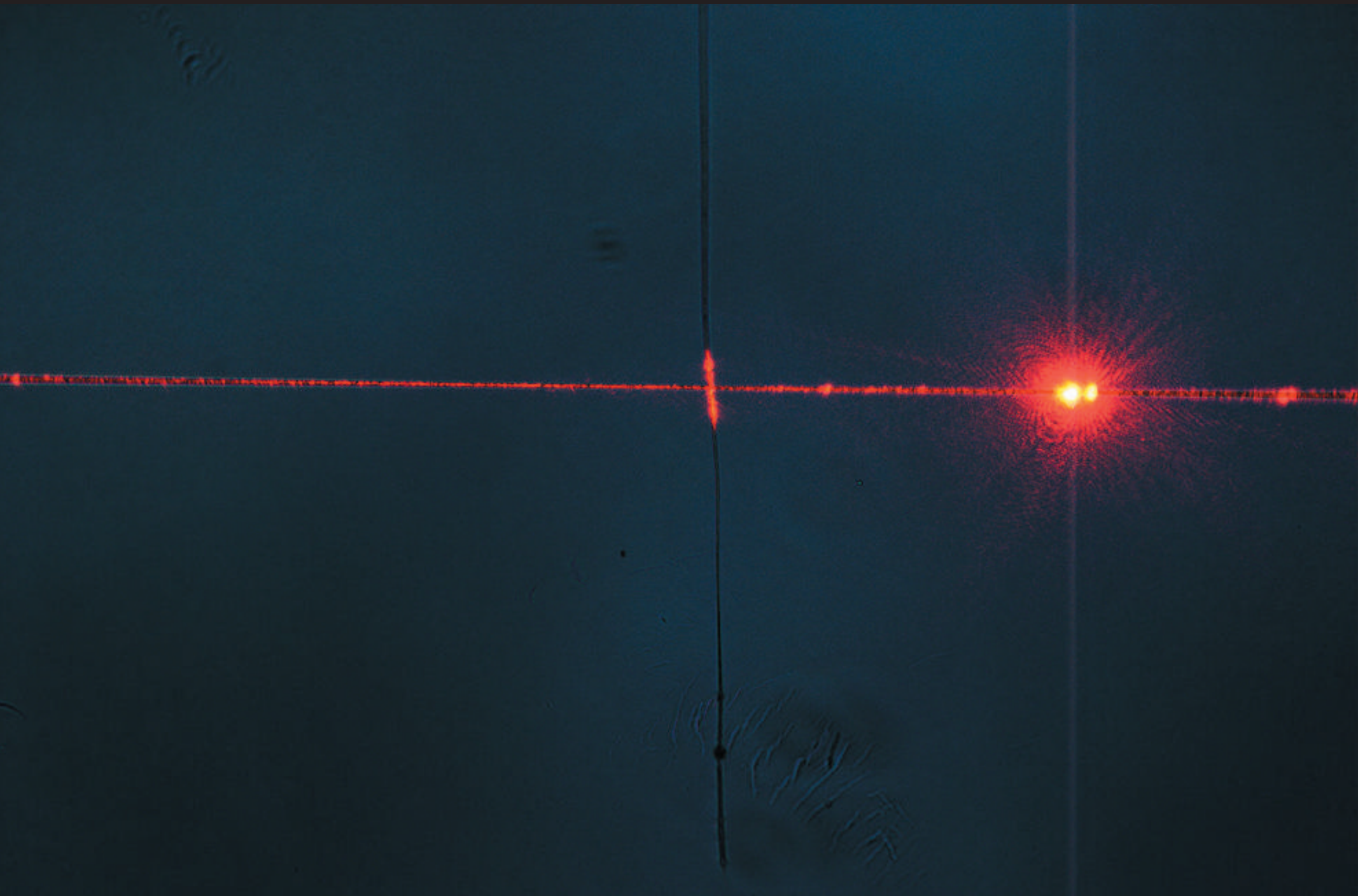

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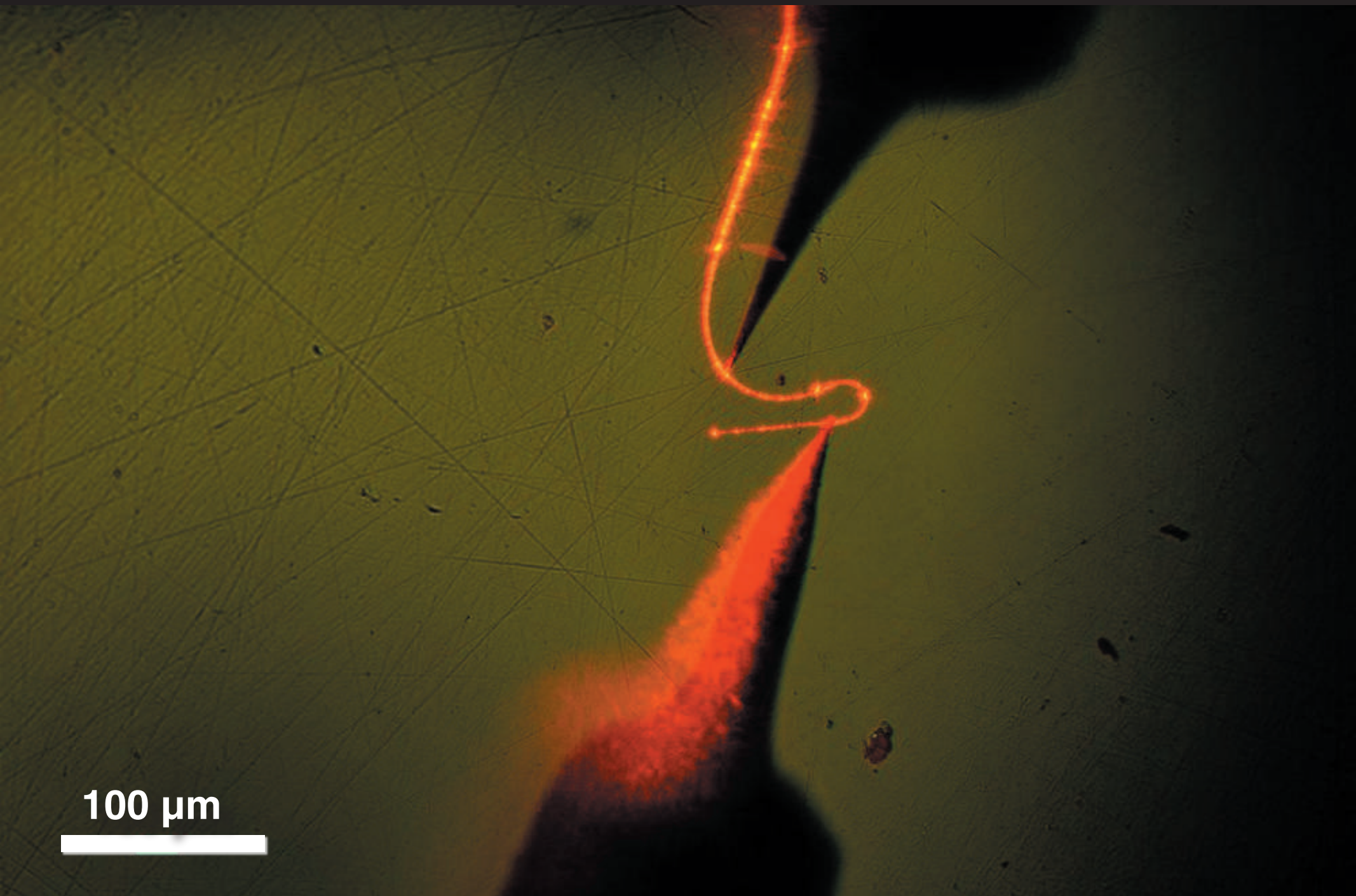

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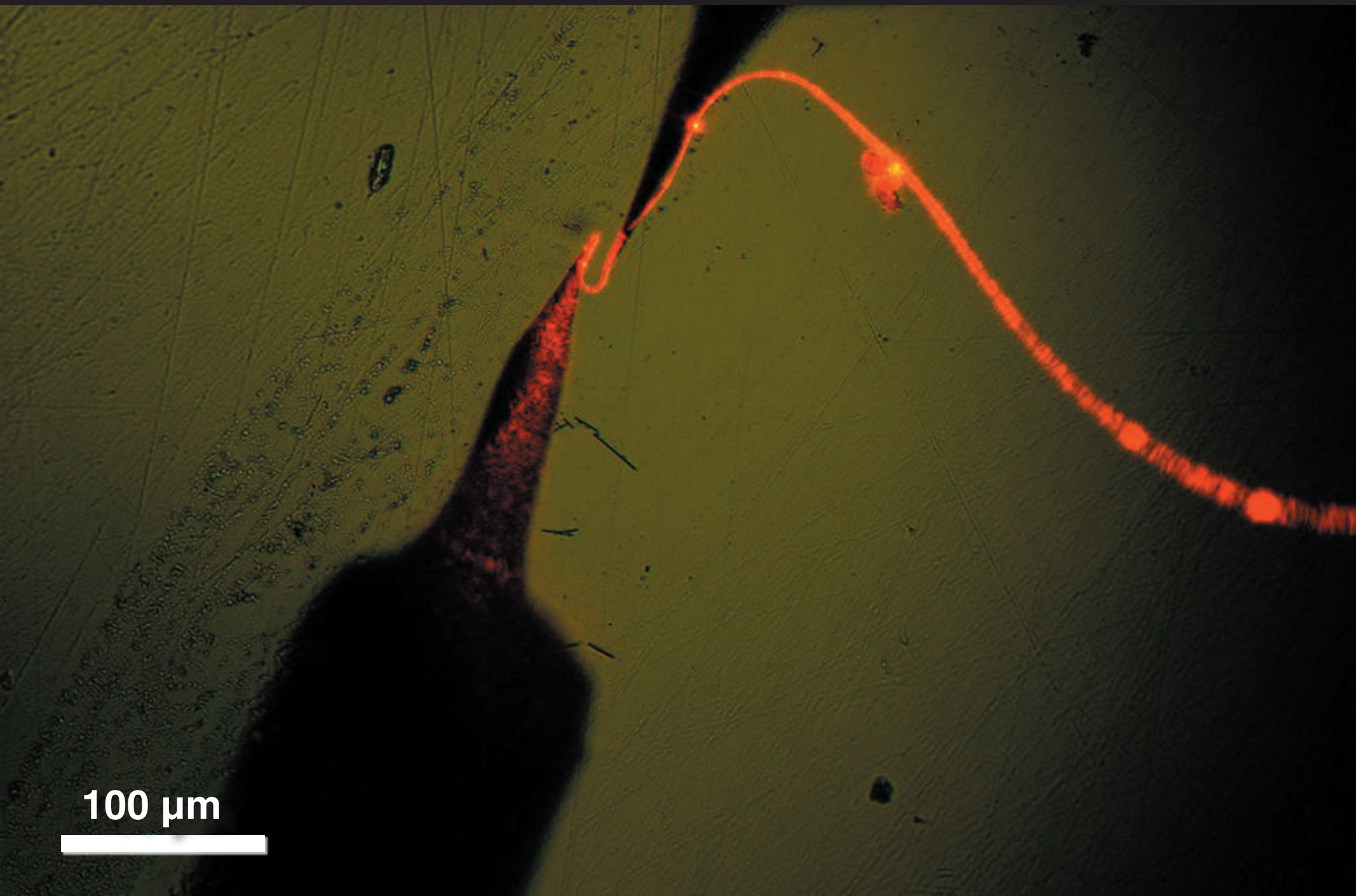

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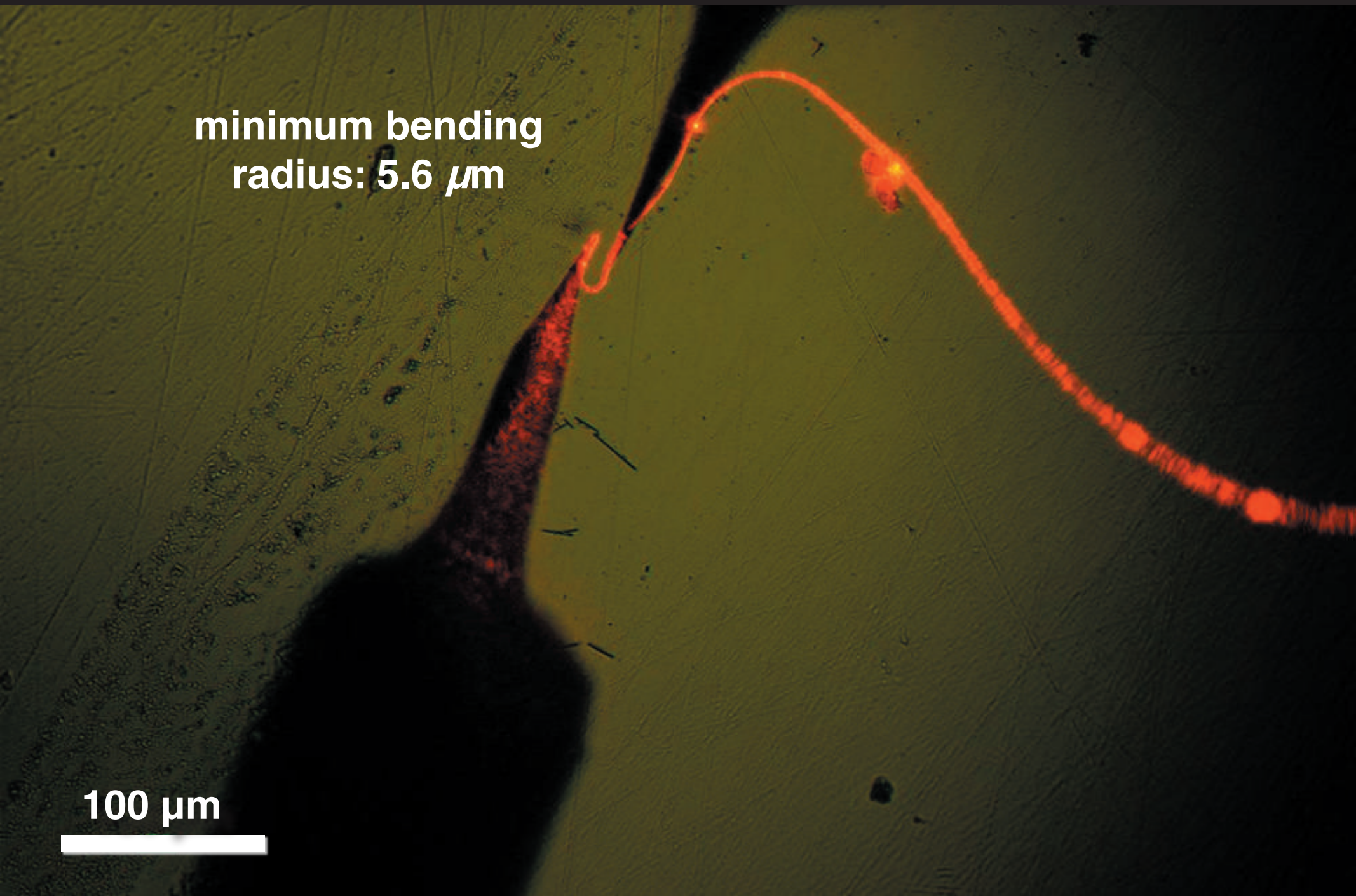
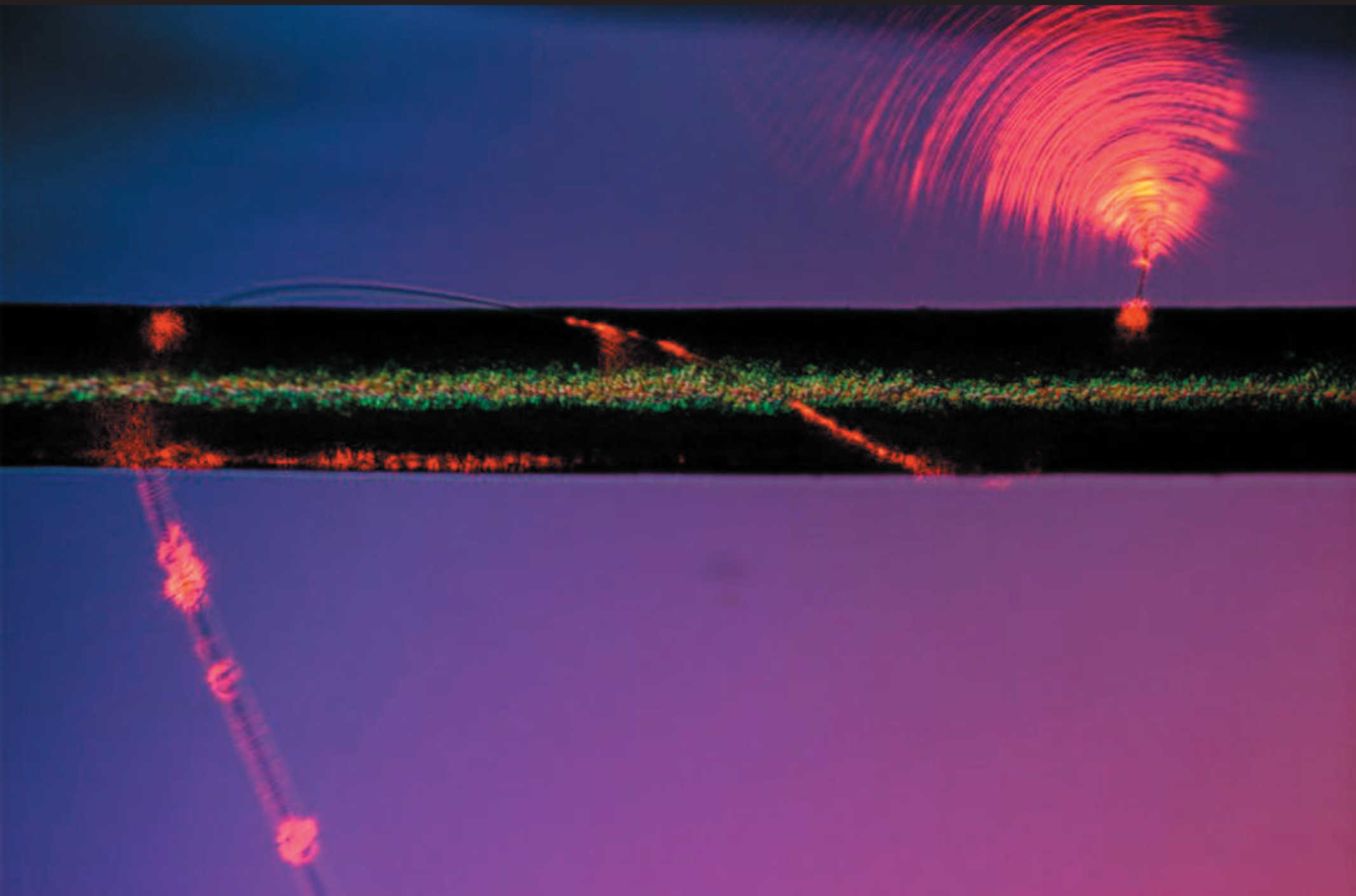


Summary



Summary

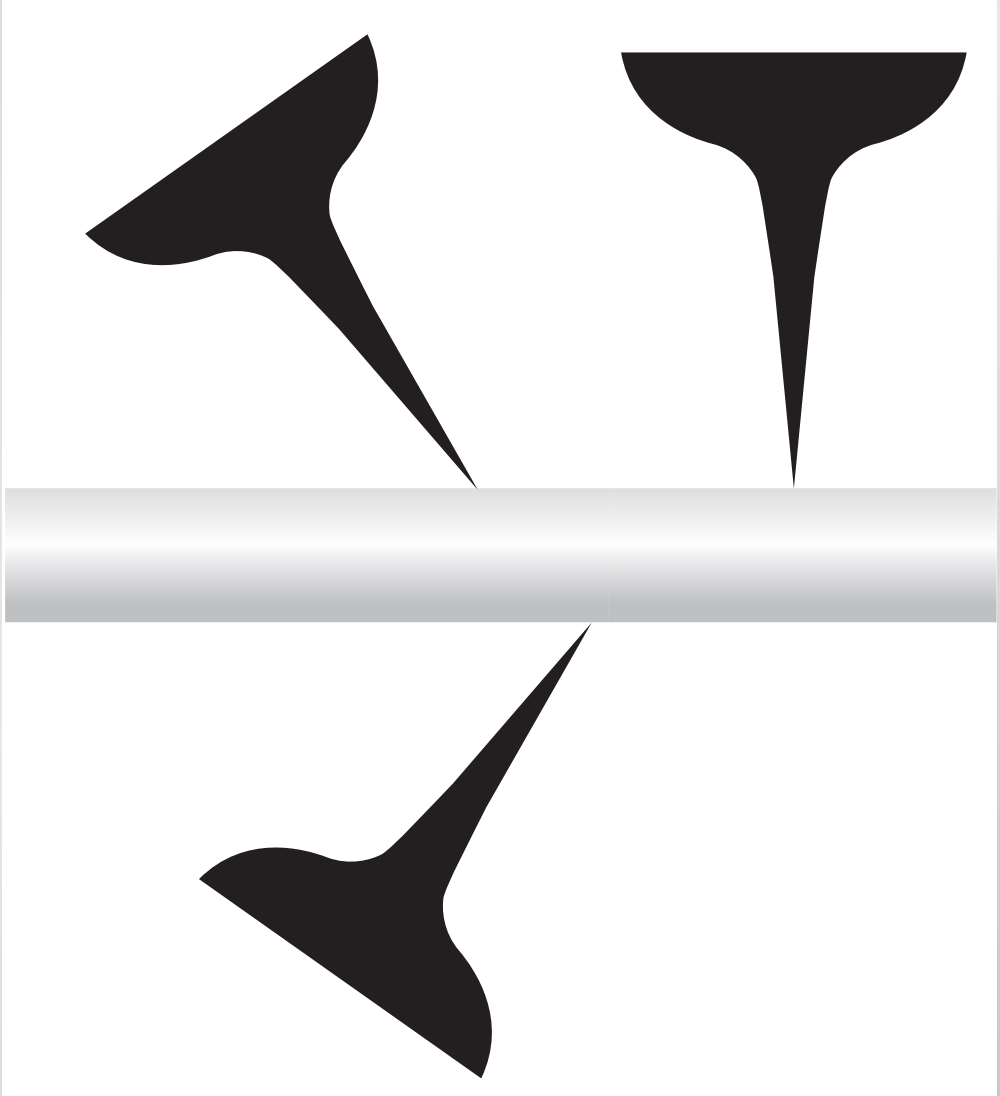
- strong confinement
- very tight bending
- large evanescent wave

Outlook

microphotonic components

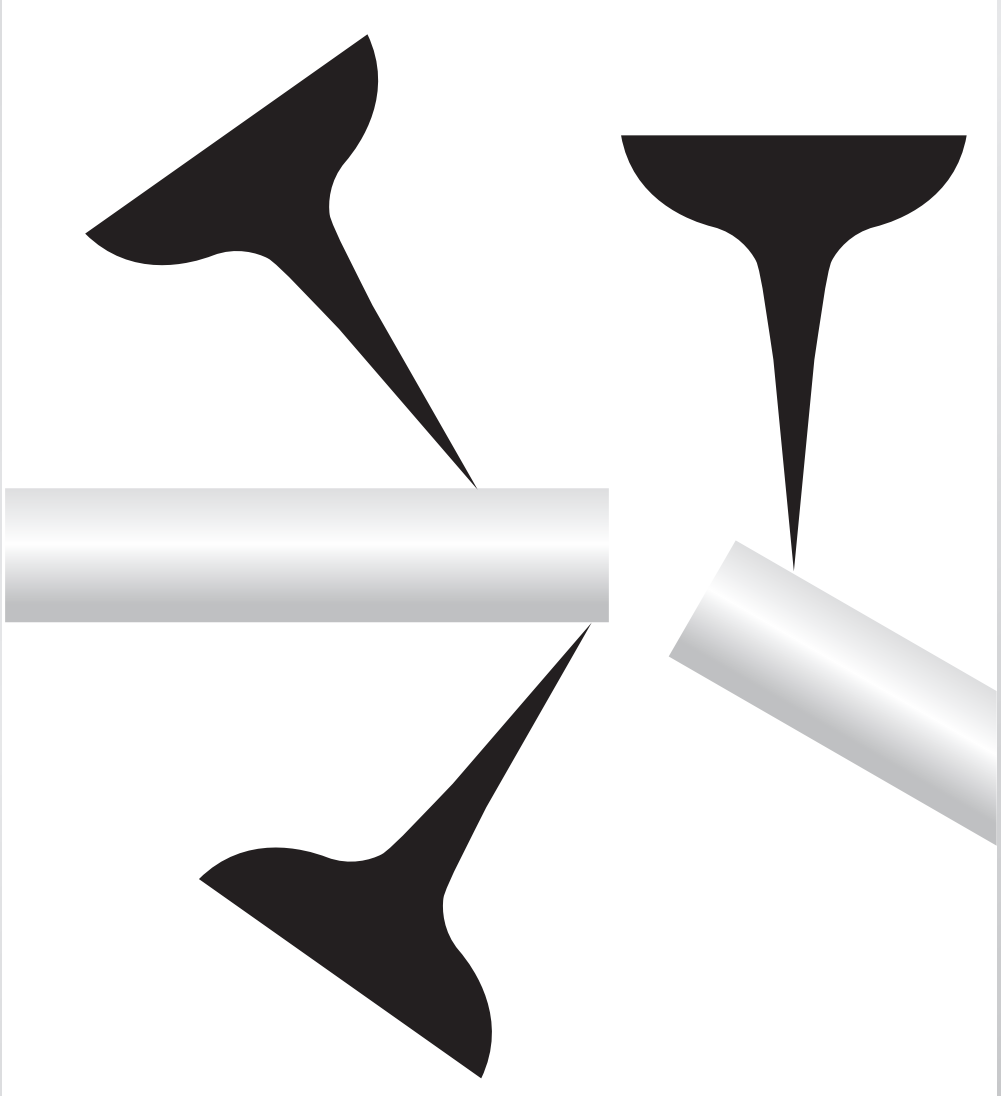
Outlook

microphotonic components



Outlook

microphotonic components



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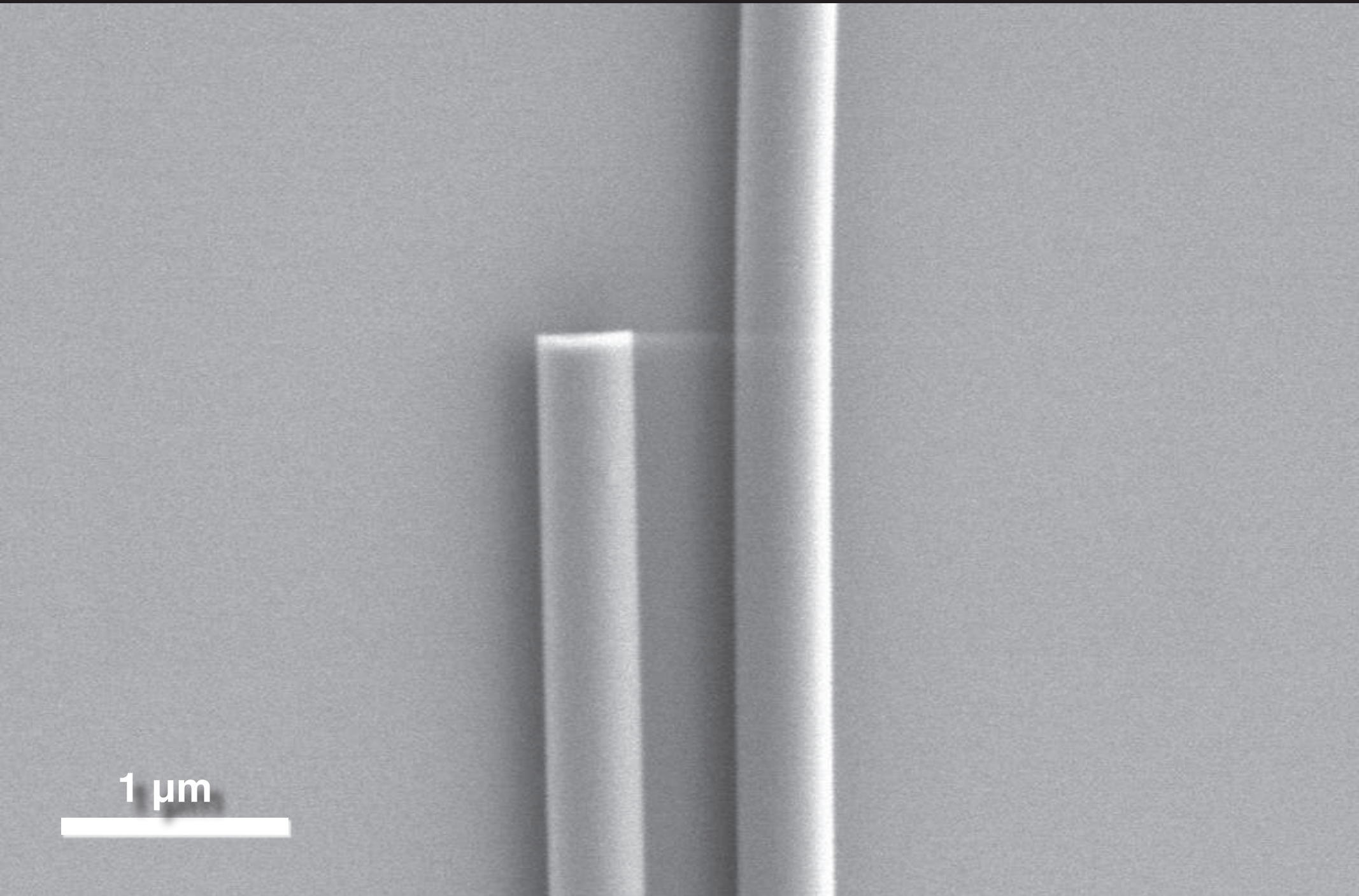

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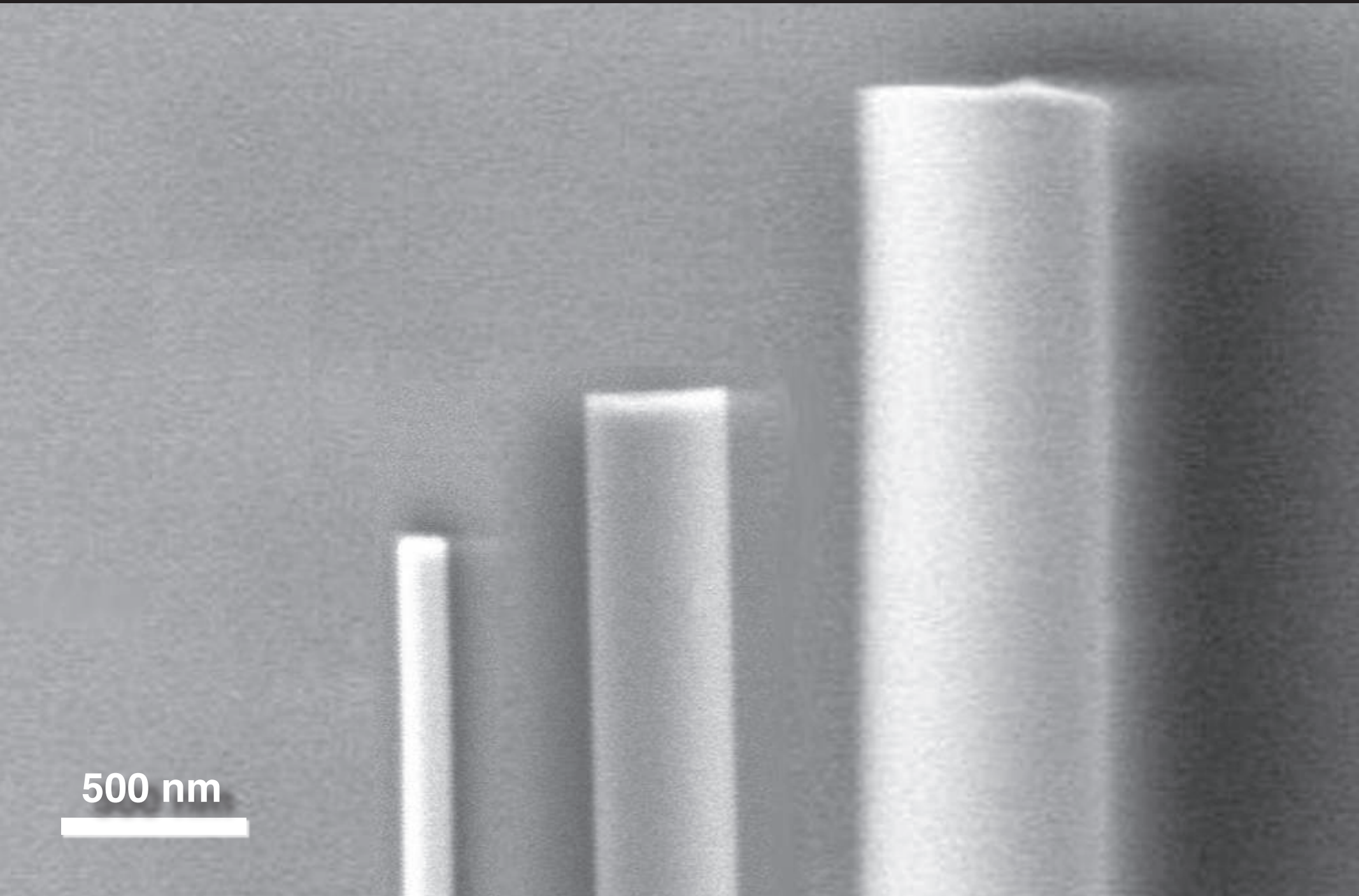

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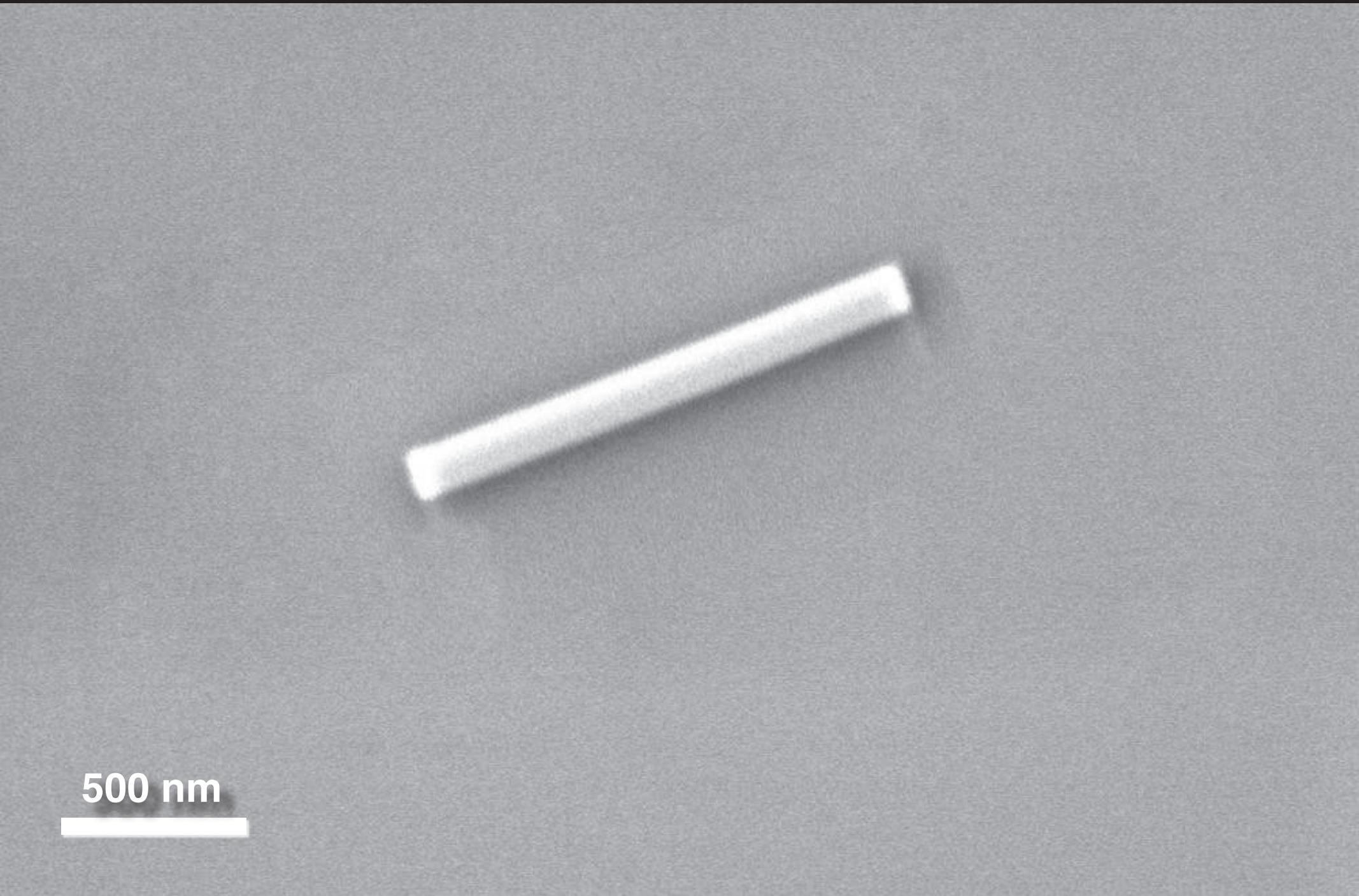
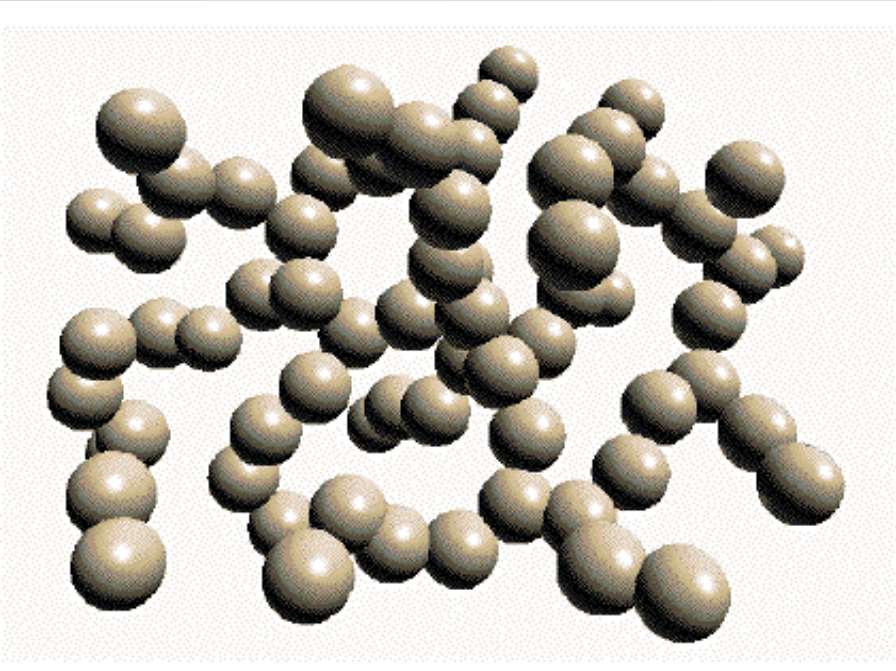
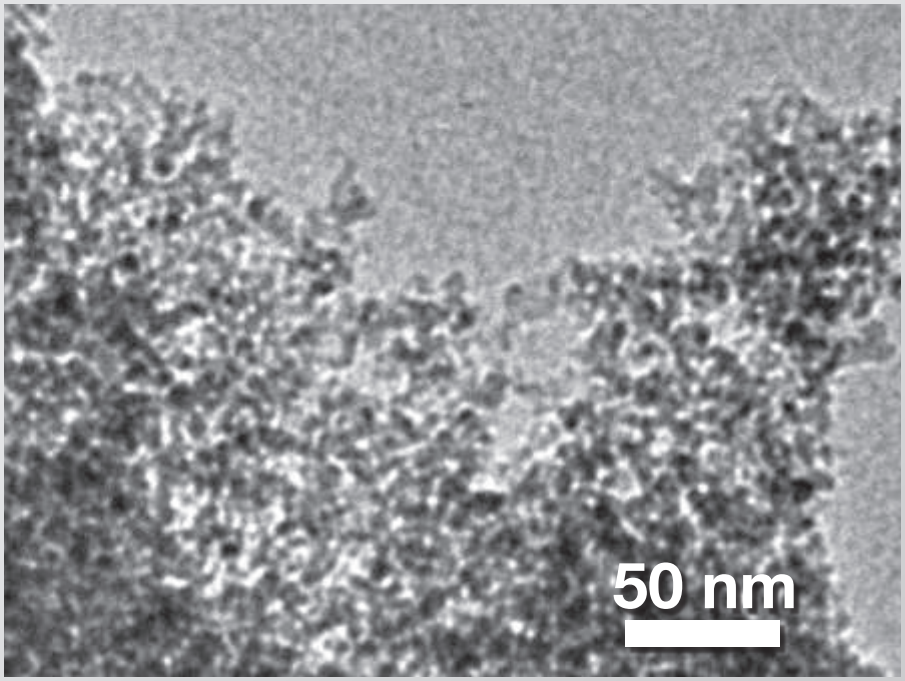


Outlook

Outlook

Aerogel

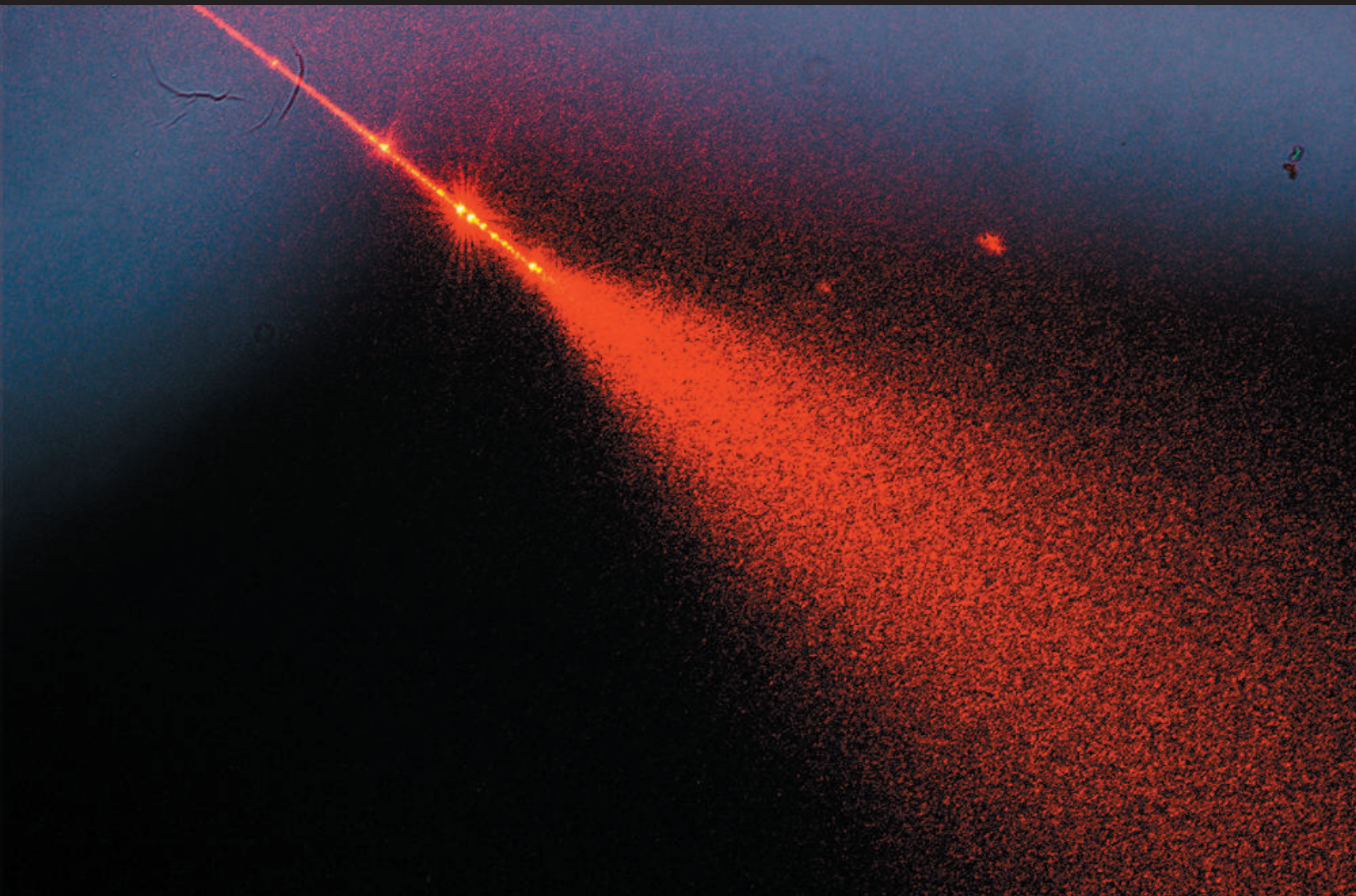




density: 1.9 kg/m^3

index of refraction: 1.03–1.08

Outlook



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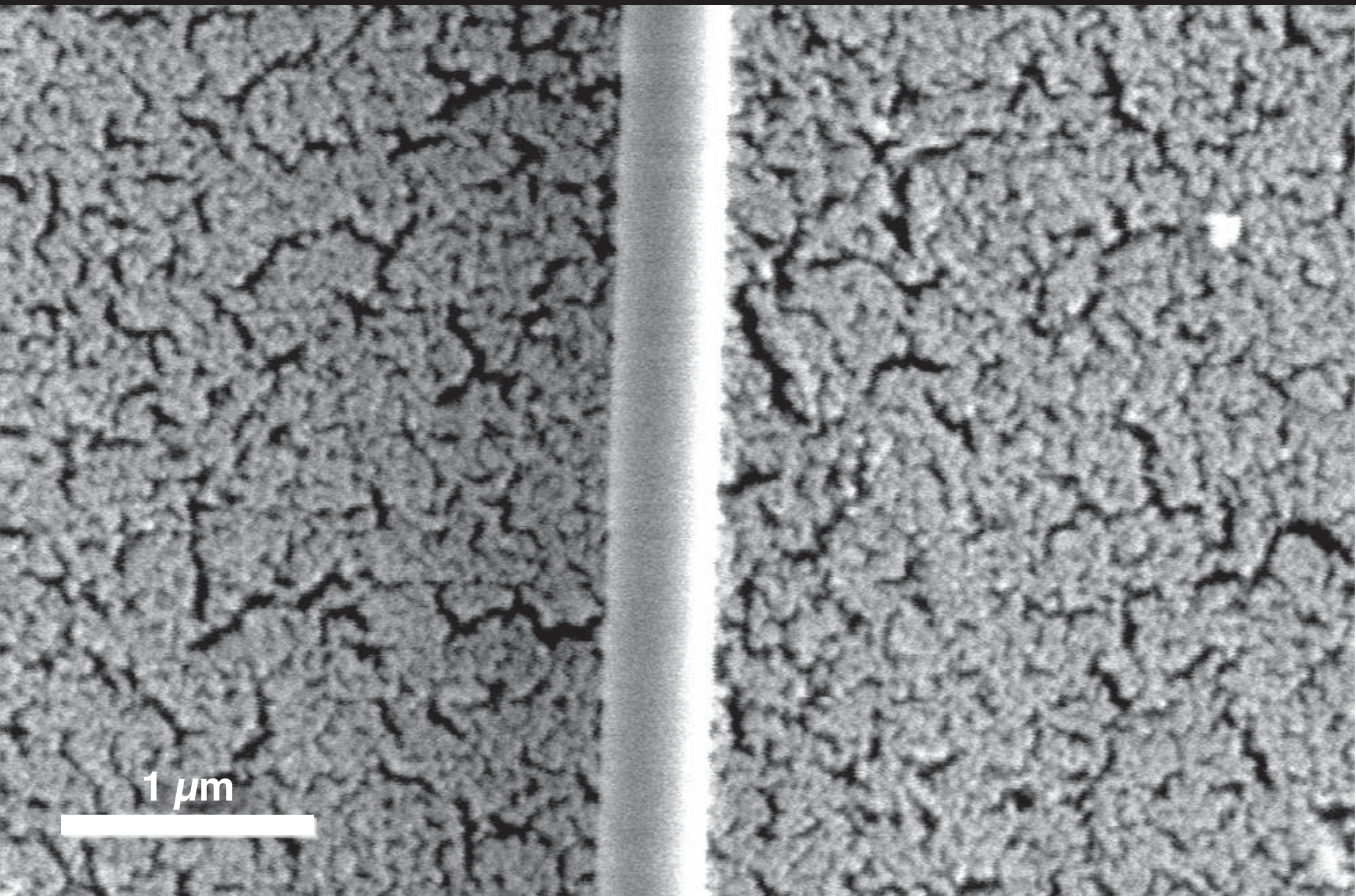

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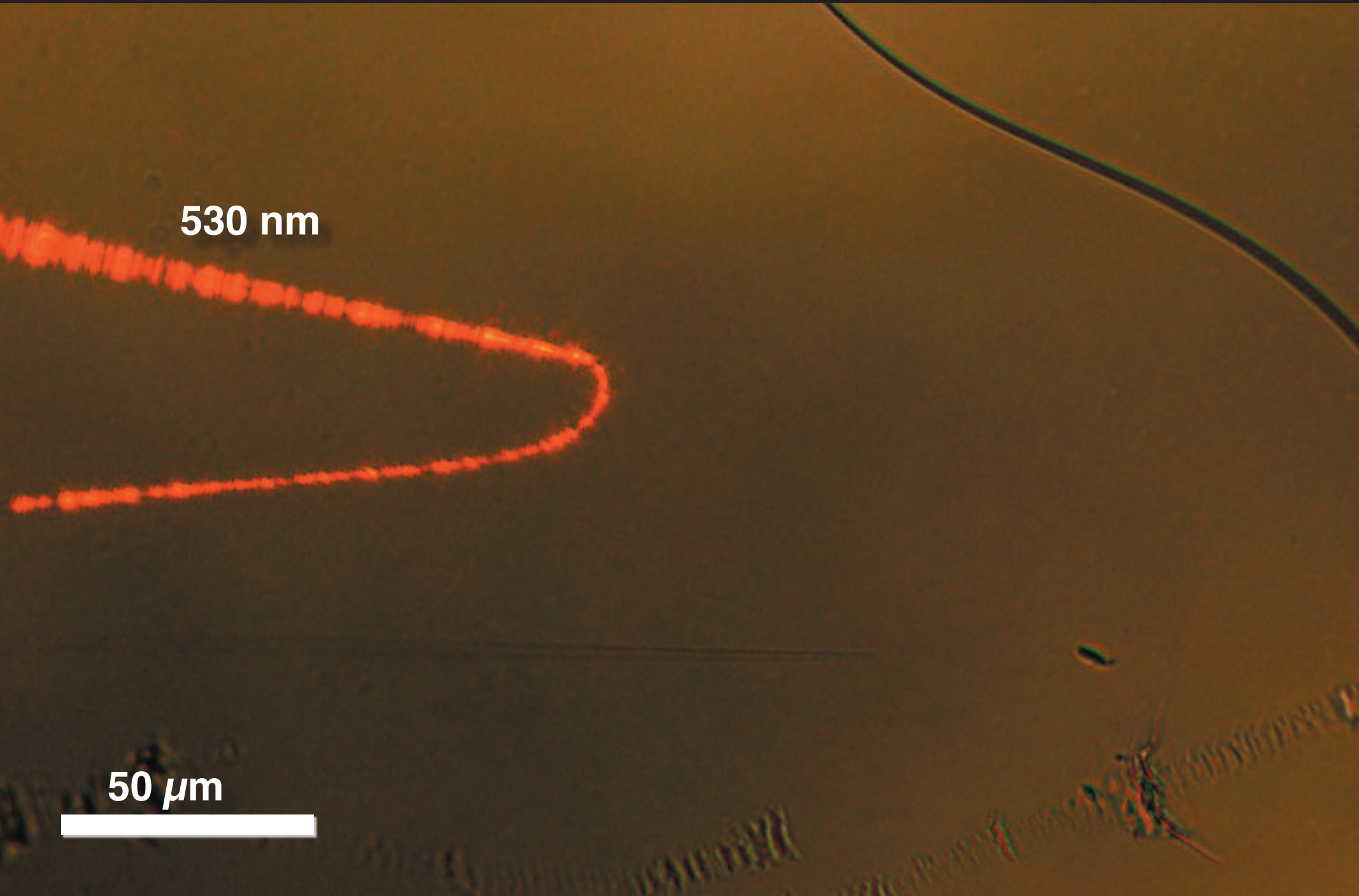

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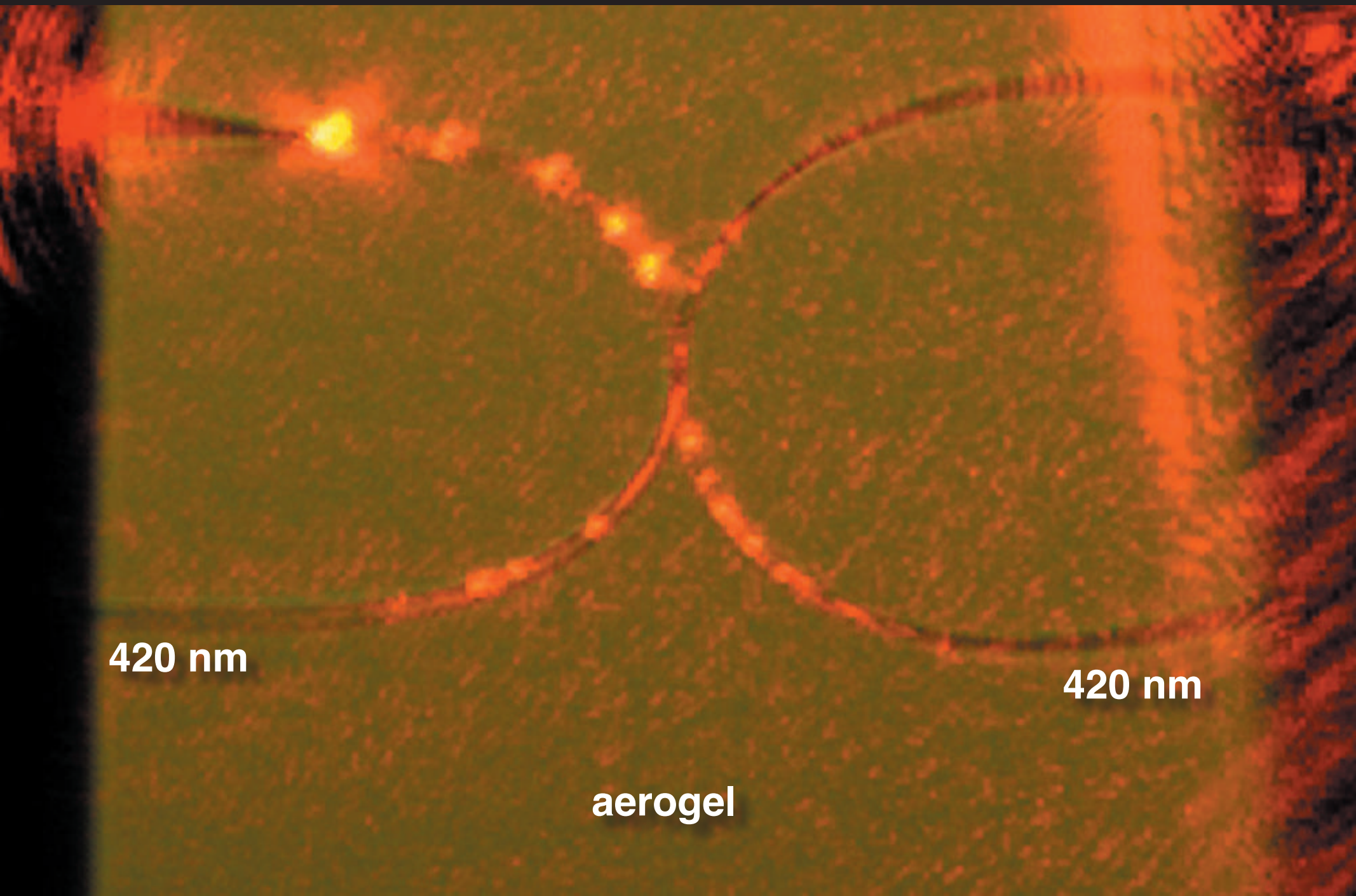

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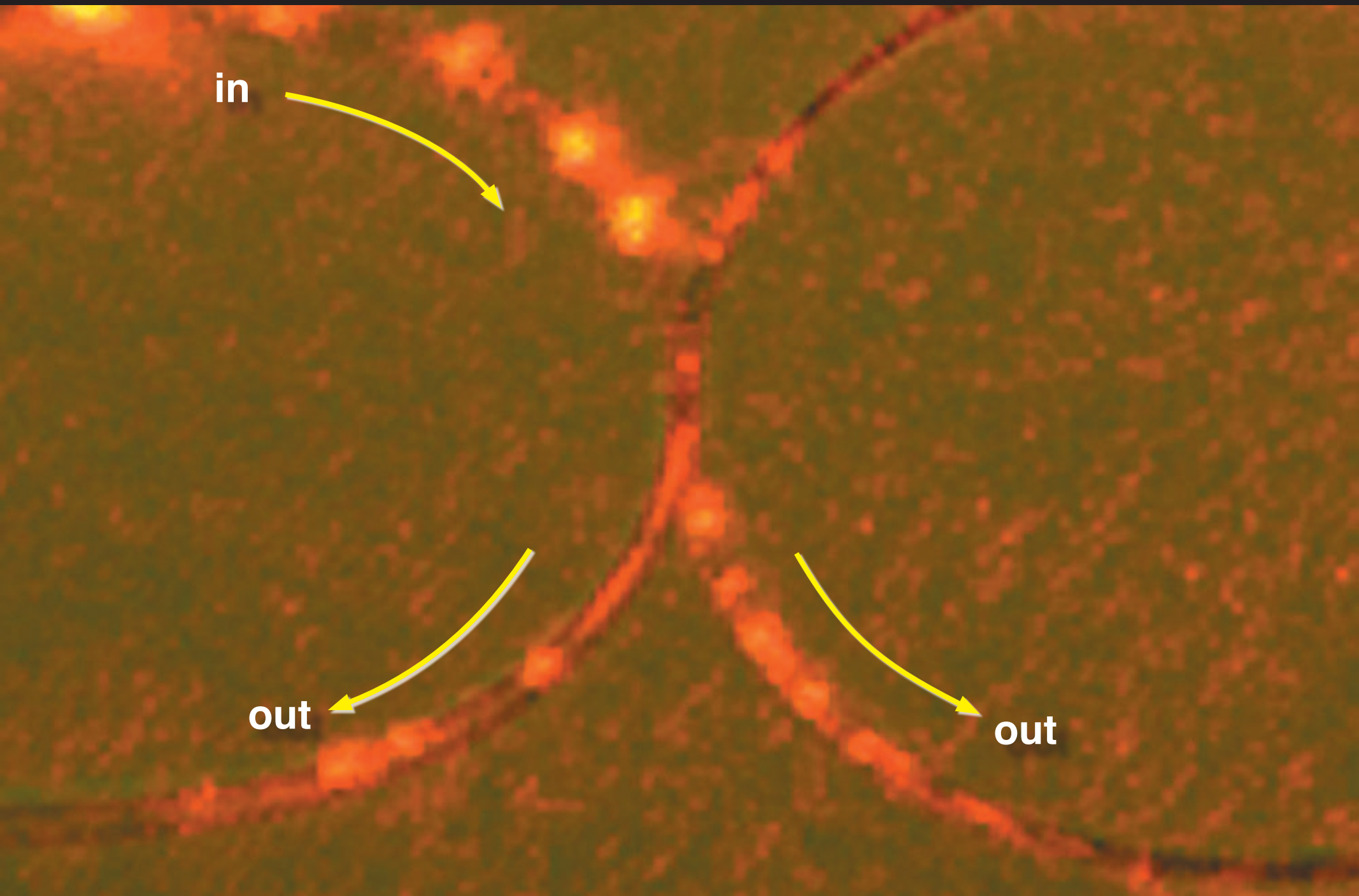

Outlook

biosensor

Outlook

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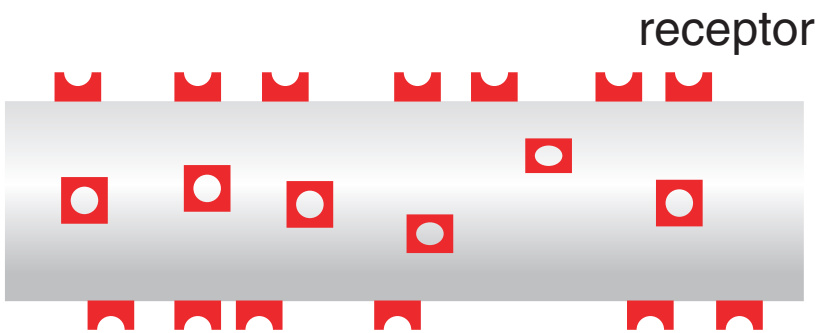

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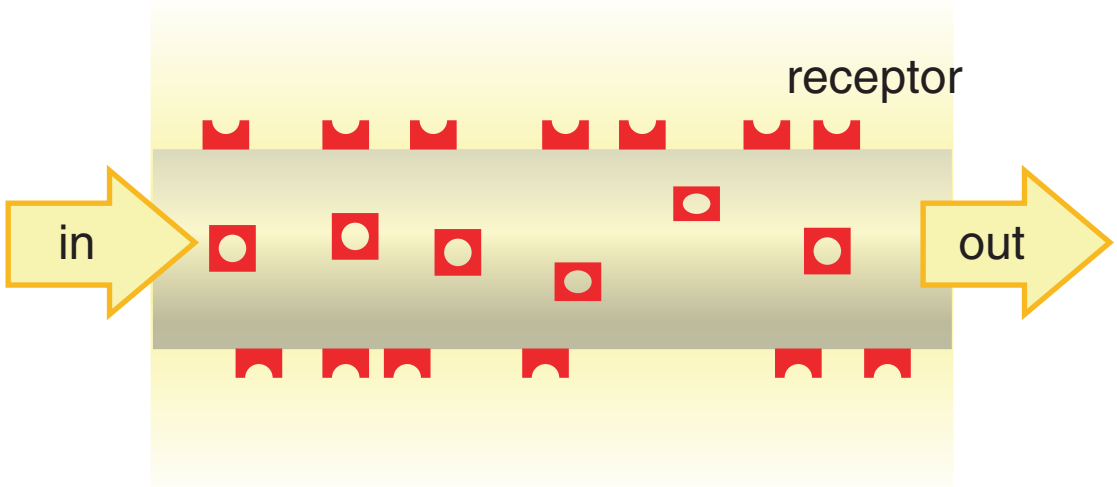

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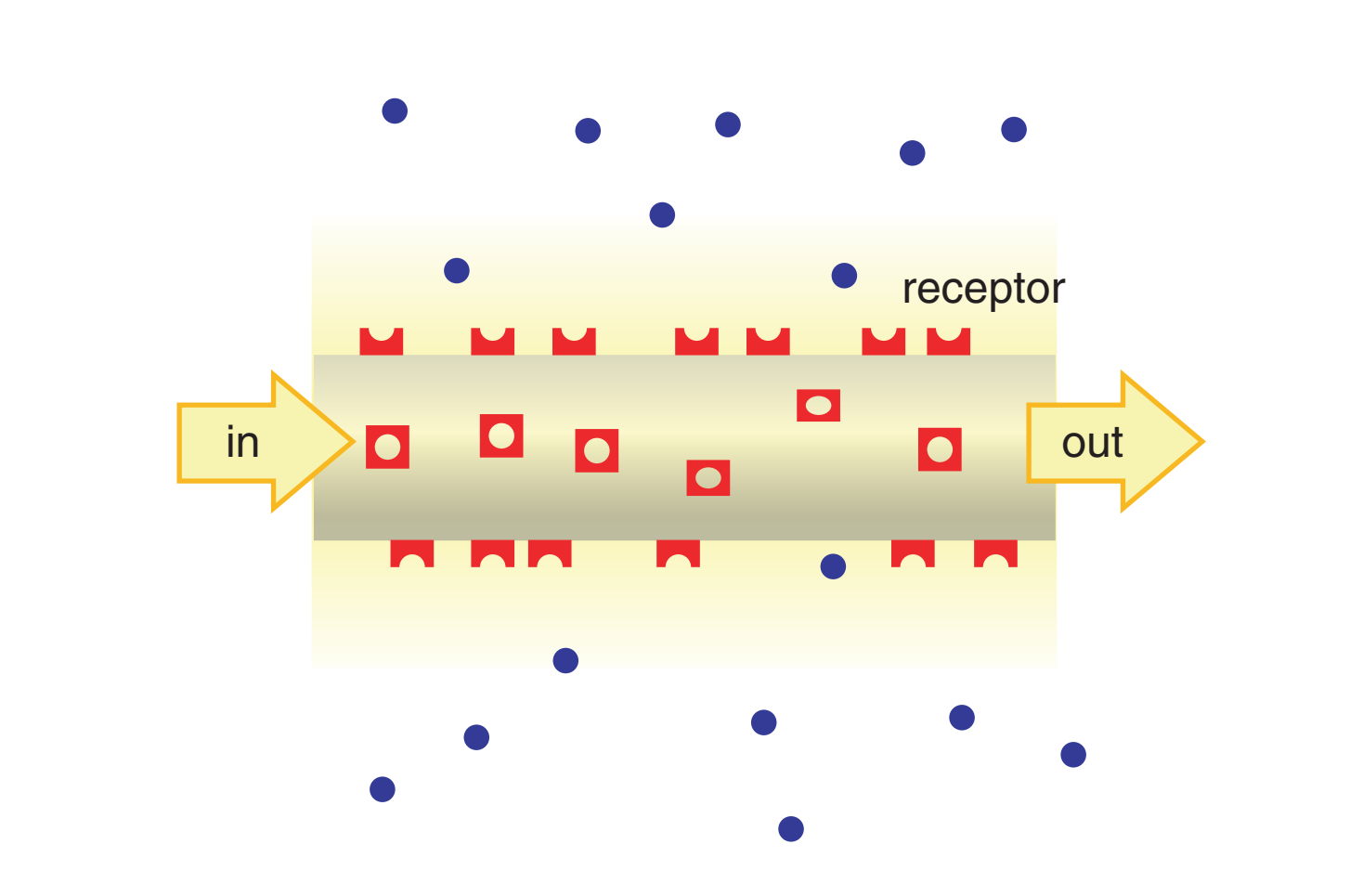

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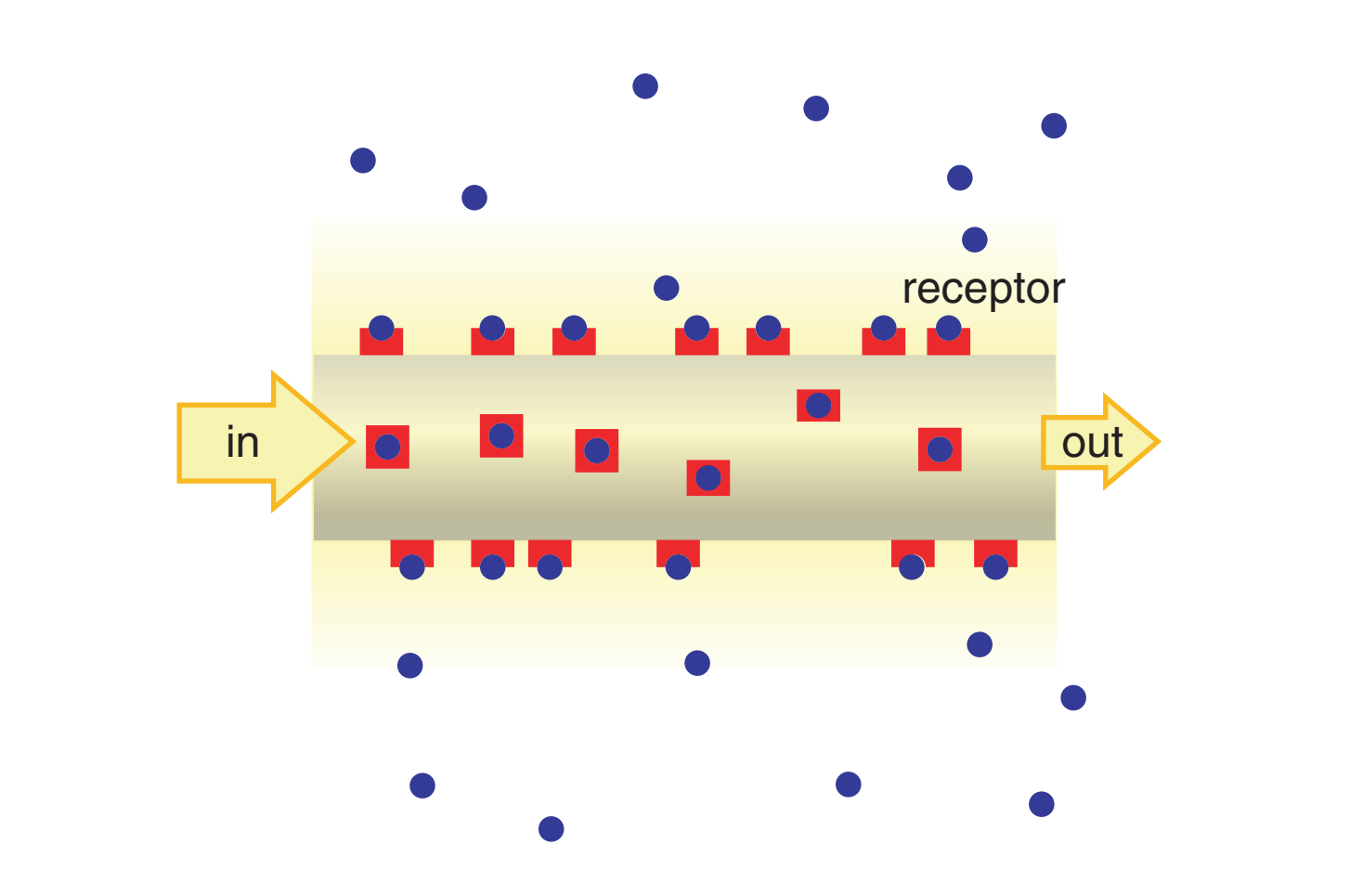
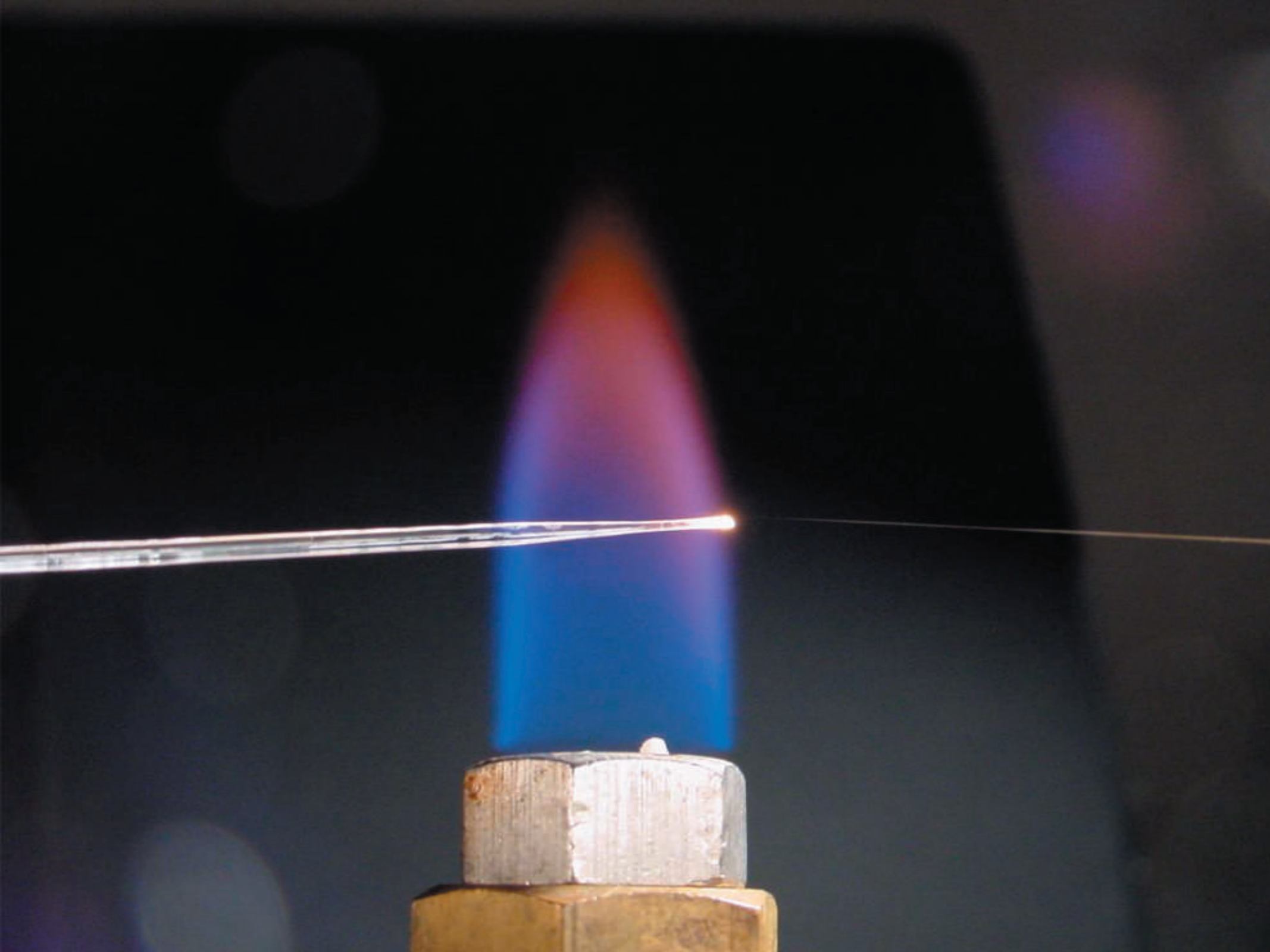




Epilogue

FastLane: Proposal Status Display

e l e c t r o n i c b u s i n e s s

Home News Comments nsf.gov

Proposal Information

Proposal Title	**Functionalized silica nanowires for high-sensitivity detection of biological pathogens and chemical agents**
Principal Investigator	**Eric Mazur**
Institution	**Harvard University**

Program Information

Program Name	**APPROACHES TO COMBAT TERRORISM**

Proposal Status

This proposal has been declined by NSF.

Epilogue

Proposal Status Inquiry: Panel Summary #1 Details of Proposal 0346487

e l e c t r o n i c b u s i n e s s

Home News Comments nsf.gov

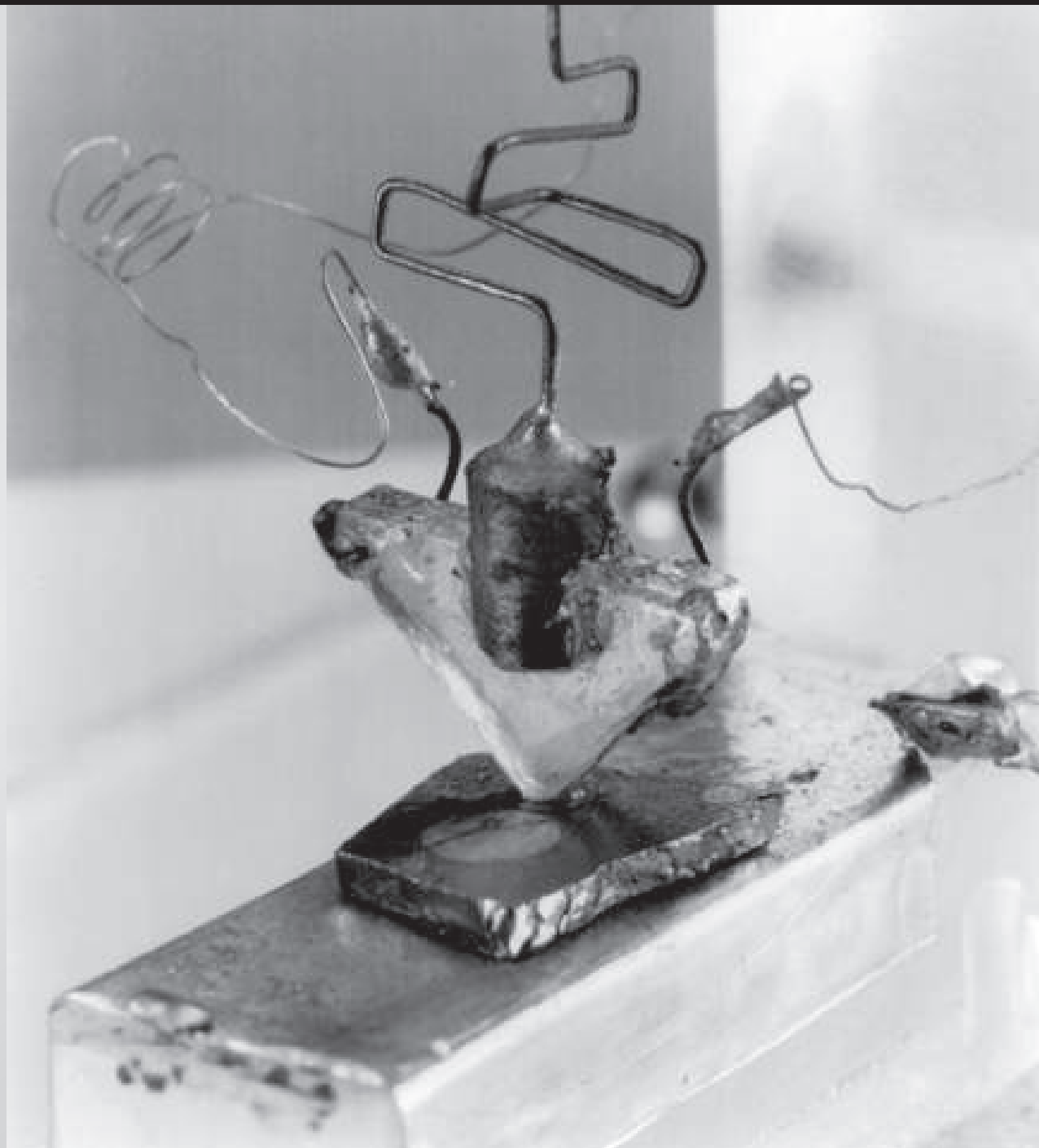
Panel Summary #1

PROPOSAL NO.: 0346487

PANEL SUMMARY:
Criterion I - novel, possibly of developing sensitive devices, outstanding track record from PI; concern raised about scale up
Criterion II - in terms of ACT
ACT Criterion - relevant to call, IC rating is medium-high
NOT RECOMMENDED FOR FUNDING

Back to Proposal Status

Epilogue



first transistor (1947)

Epilogue

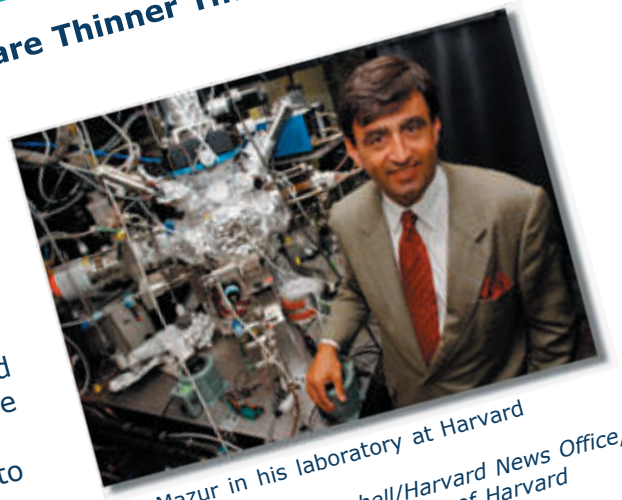
Office of Legislative and

NSF Press Release

Embargoed Until 1 p.m. Eastern Time:
NSF PR 03-147 - December 17, 2003

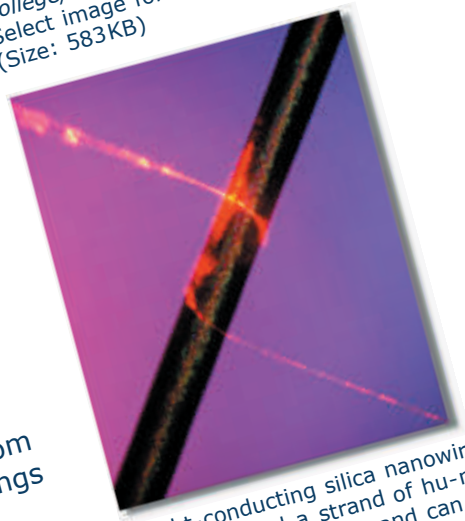
Researchers Develop Nanoscale Fibers That are Thinner Than the Wavelengths of Light They Carry

Arlington, Va.—Researchers have developed a process to create wires only 50 nanometers (billionths of a meter) thick. Made from silica, the same mineral found in quartz, the wires carry light in an unusual way. Because the wires are thinner than the wavelengths of light they transport, the material serves as a guide around which light waves flow. In addition, because the researchers can fabricate the wires with a uniform diameter and smooth surfaces down to the atomic level, the light waves remain coherent as they travel.



Eric Mazur in his laboratory at Harvard University.
Credit: Stephanie Mitchell/Harvard News Office, © 2001 President and Fellows of Harvard College/National Science Foundation
Select image for larger version
(Size: 583KB)

The smaller fibers will allow devices to transmit more information while using less space. The new material may have applications in ever-shrinking medical products and tiny photonics equipment such as nanoscale laser systems, tools for communications and sensors. Size is of critical importance to sensing—with more, smaller-diameter fibers packed into the same area, sensors could detect many toxins, for example, at once and with greater precision and accuracy.



A light-conducting silica nanowire wraps a beam around a strand of hu-man hair. The flexible and can be as slender as about one-thousandth

Researchers at Harvard University led by Eric Limin Tong (also of Zhejiang along with colleagues from report their findings

Epilogue

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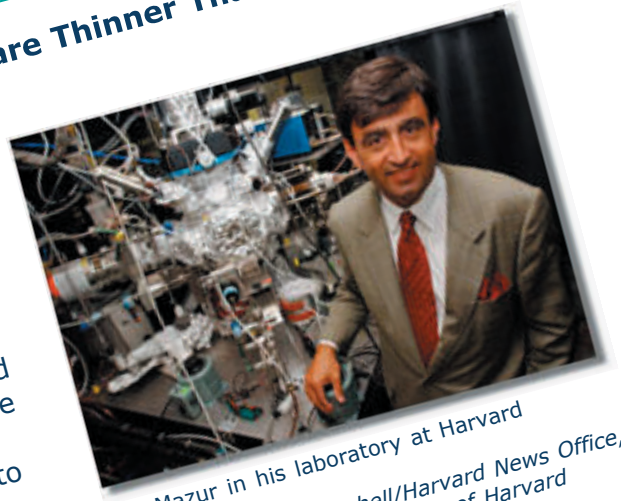

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Credit: Stephanie Mitchell/Harvard News Office,
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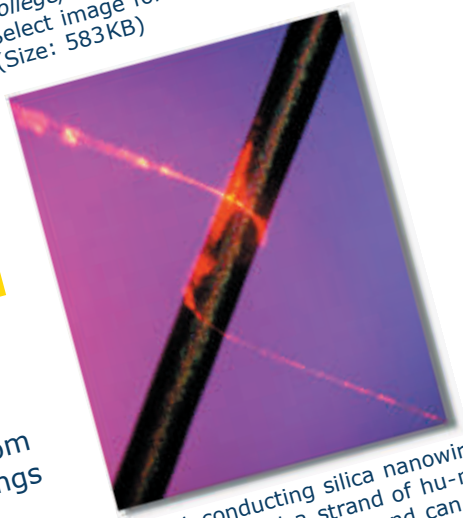

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report their findings
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Epilogue

new technologies foster innovation

Funding:

Harvard Center for Imaging and Mesoscopic Structures
National Science Foundation
National Natural Science Foundation of China

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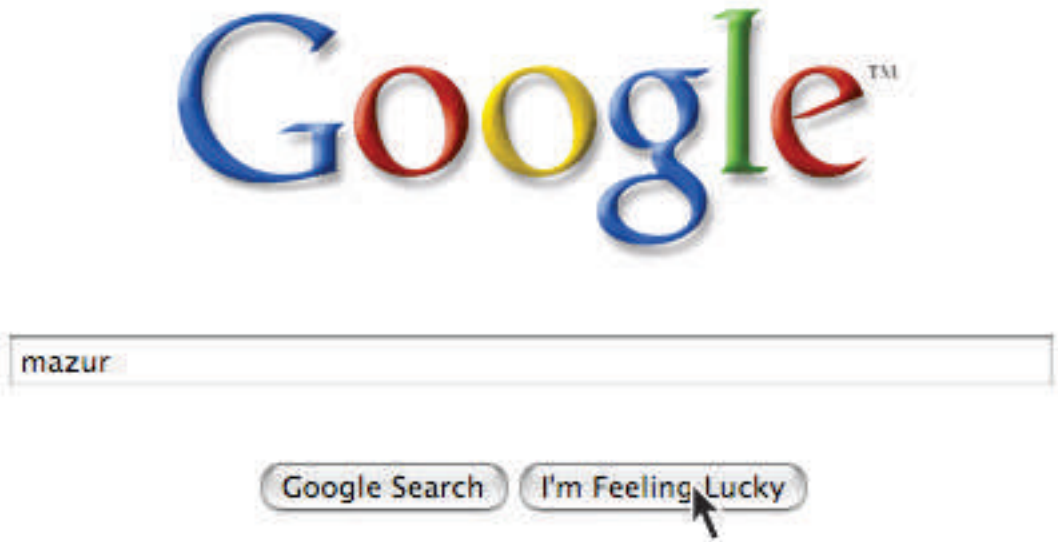
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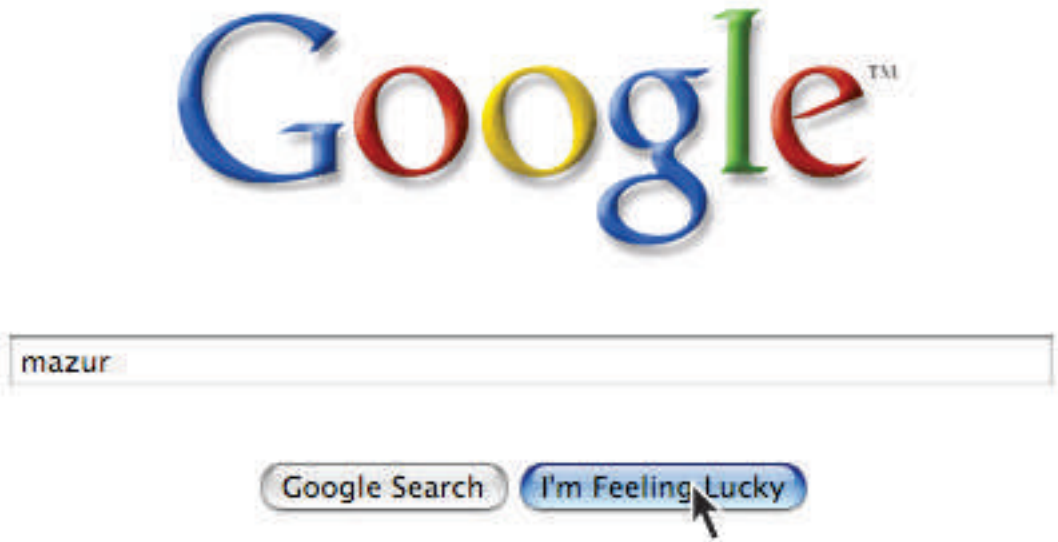
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