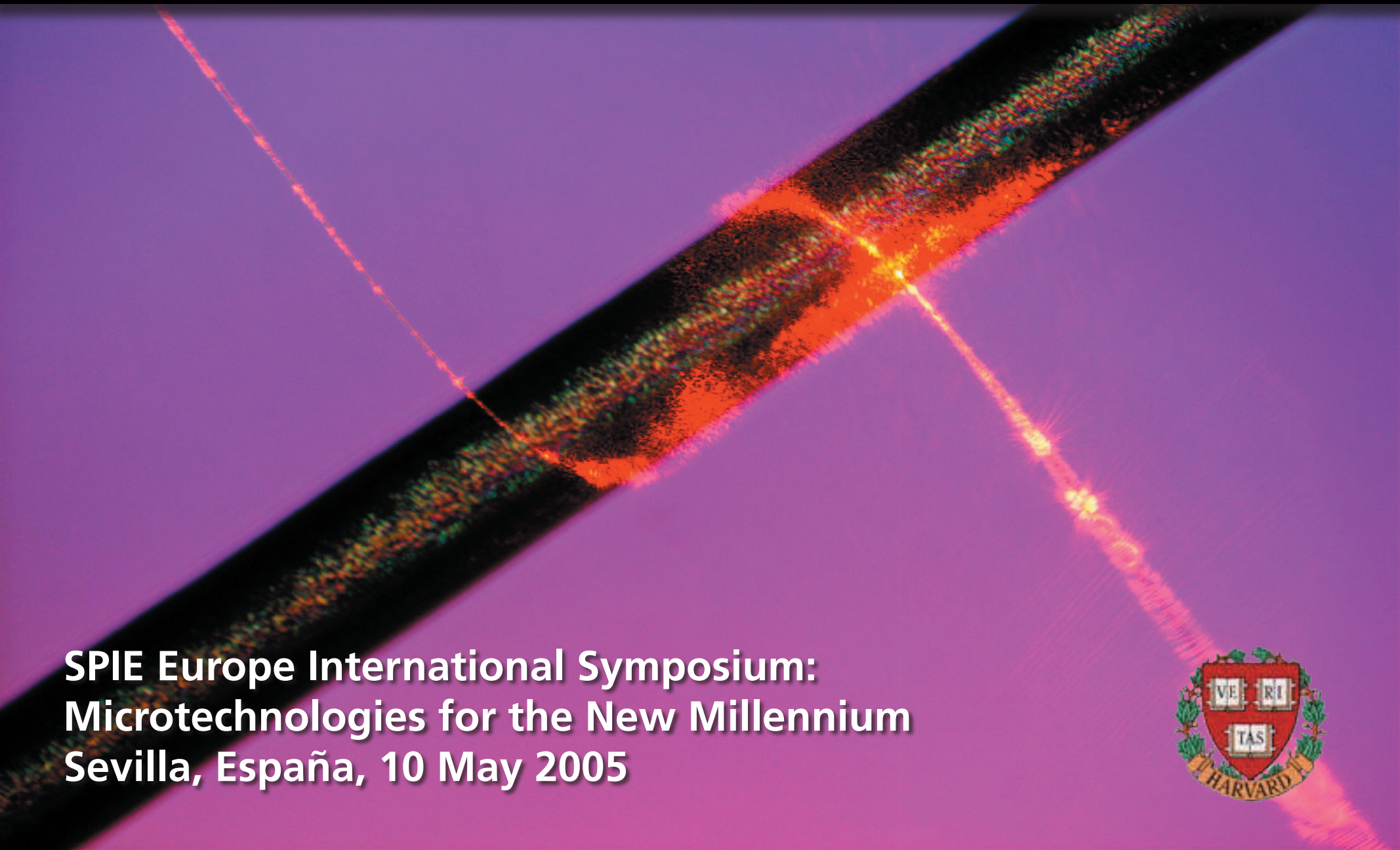
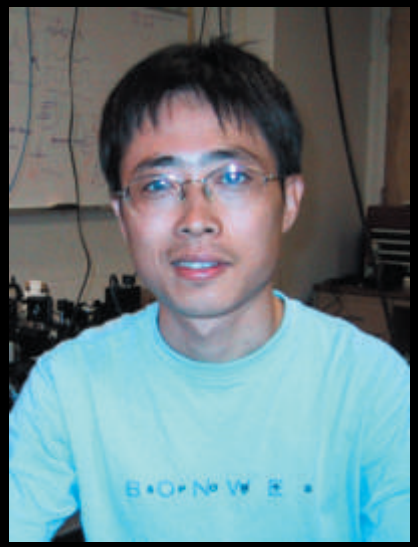
Subwavelength-diameter silica wires for microscale optical components



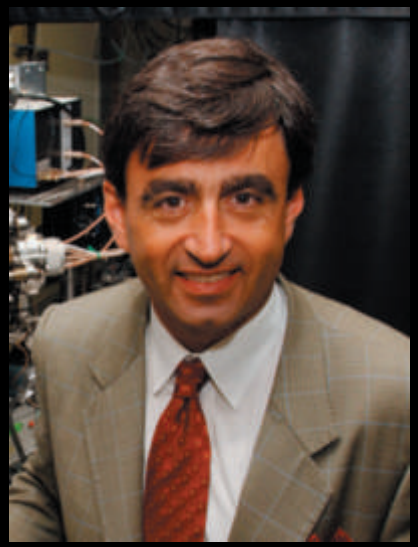
SPIE Europe International Symposium:
Microtechnologies for the New Millennium
Sevilla, España, 10 May 2005



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

Waveguiding

single mode condition for 600-nm light:

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

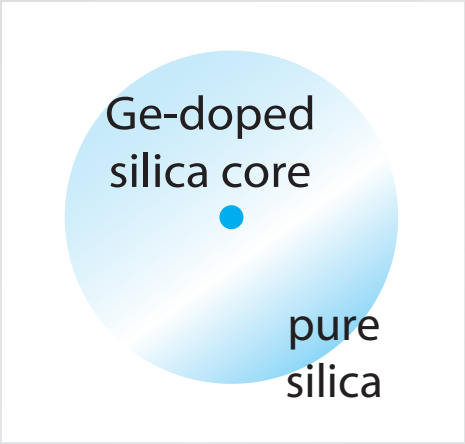
without cladding: $d < 268\ \text{nm}$

Add cladding with 0.4% index difference:

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

Waveguiding

commercial single-mode fiber (Corning Titan®)



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

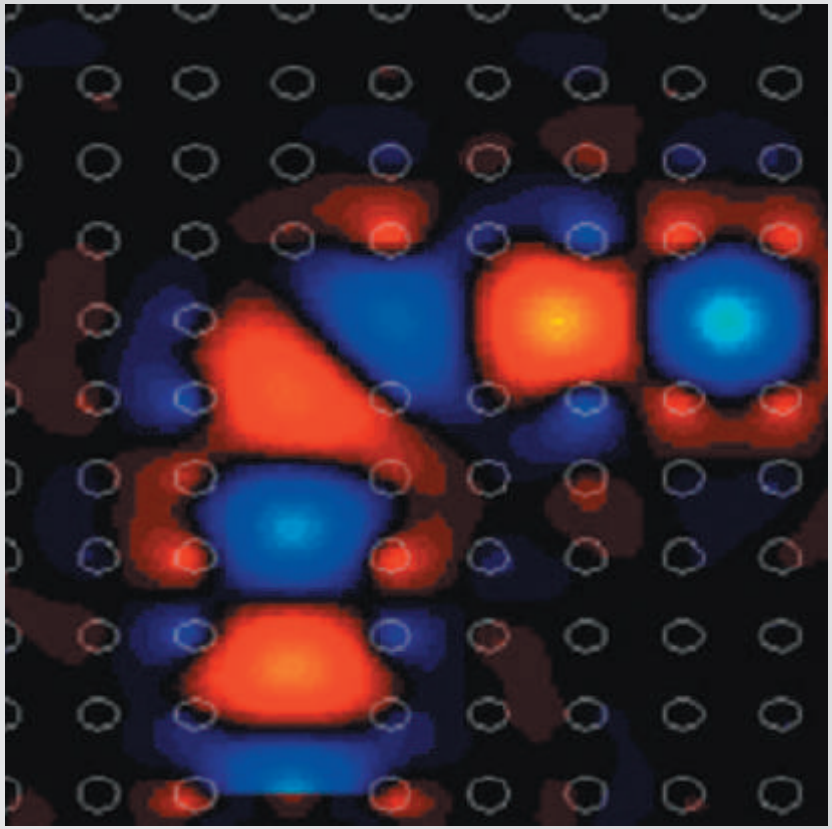
operating wavelength: $\lambda = 1310\ \text{nm}/1550\ \text{nm}$

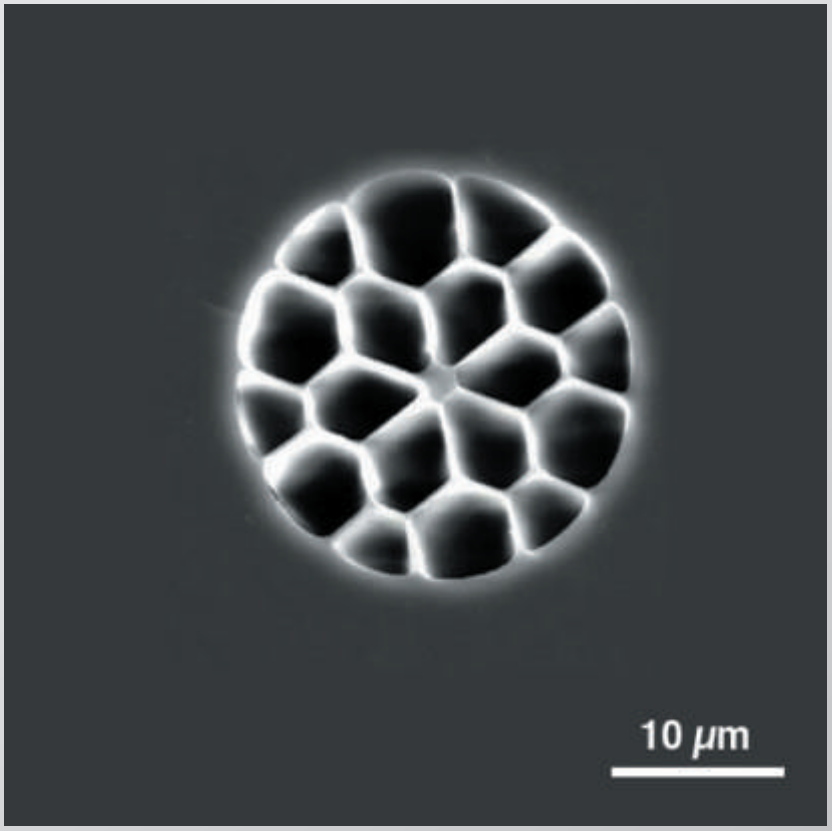
Waveguiding

drawbacks of clad fibers:

- weak confinement
- no tight bending
- coupling requires splicing

Waveguiding



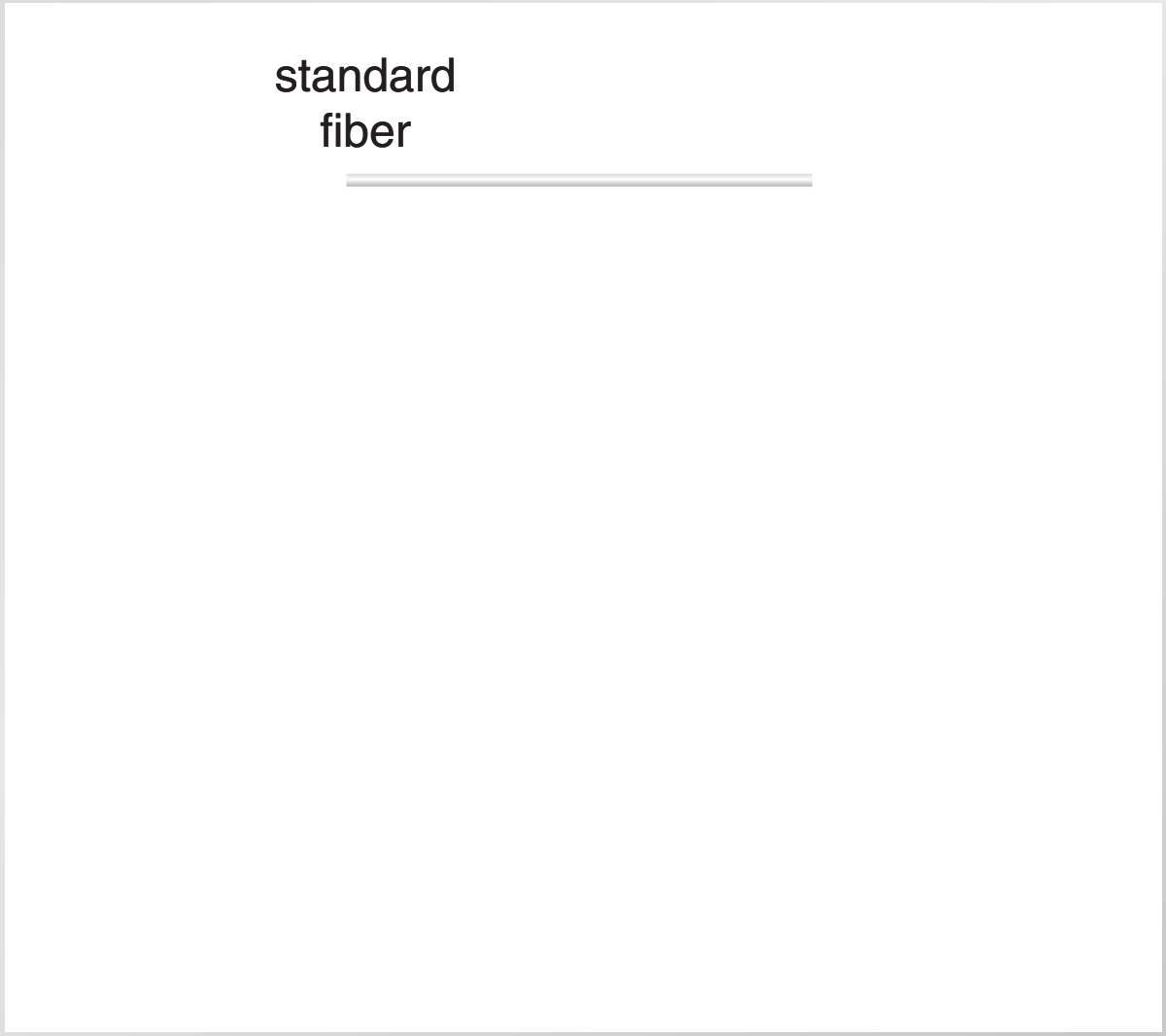


Outline

- waveguiding
- **nanowire fabrication**
- optical properties

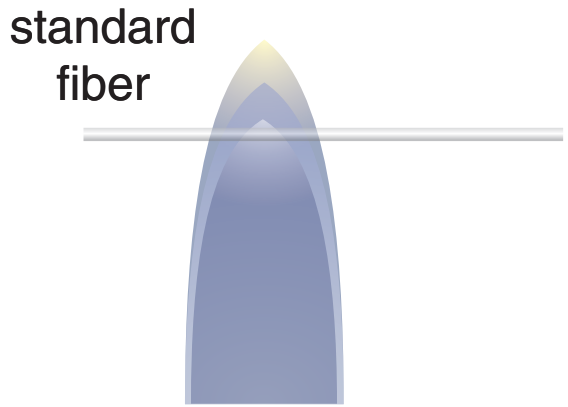
Nanowire fabrication

two-step drawing process



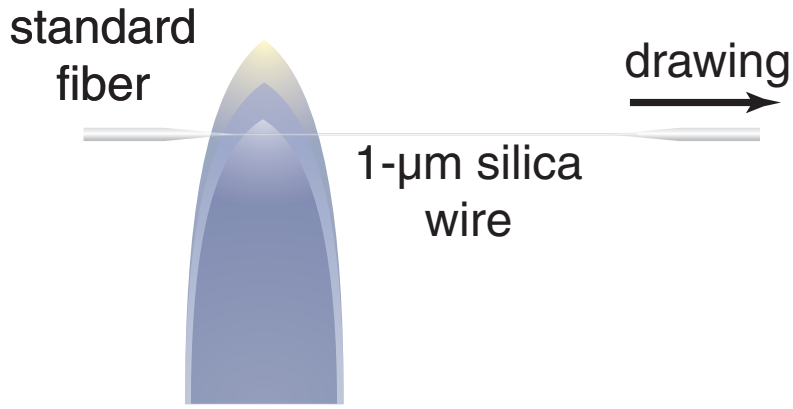
Nanowire fabrication

two-step drawing process



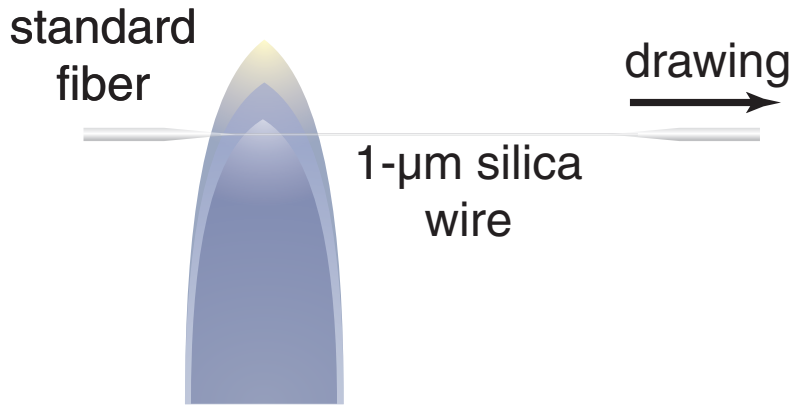
Nanowire fabrication

two-step drawing process



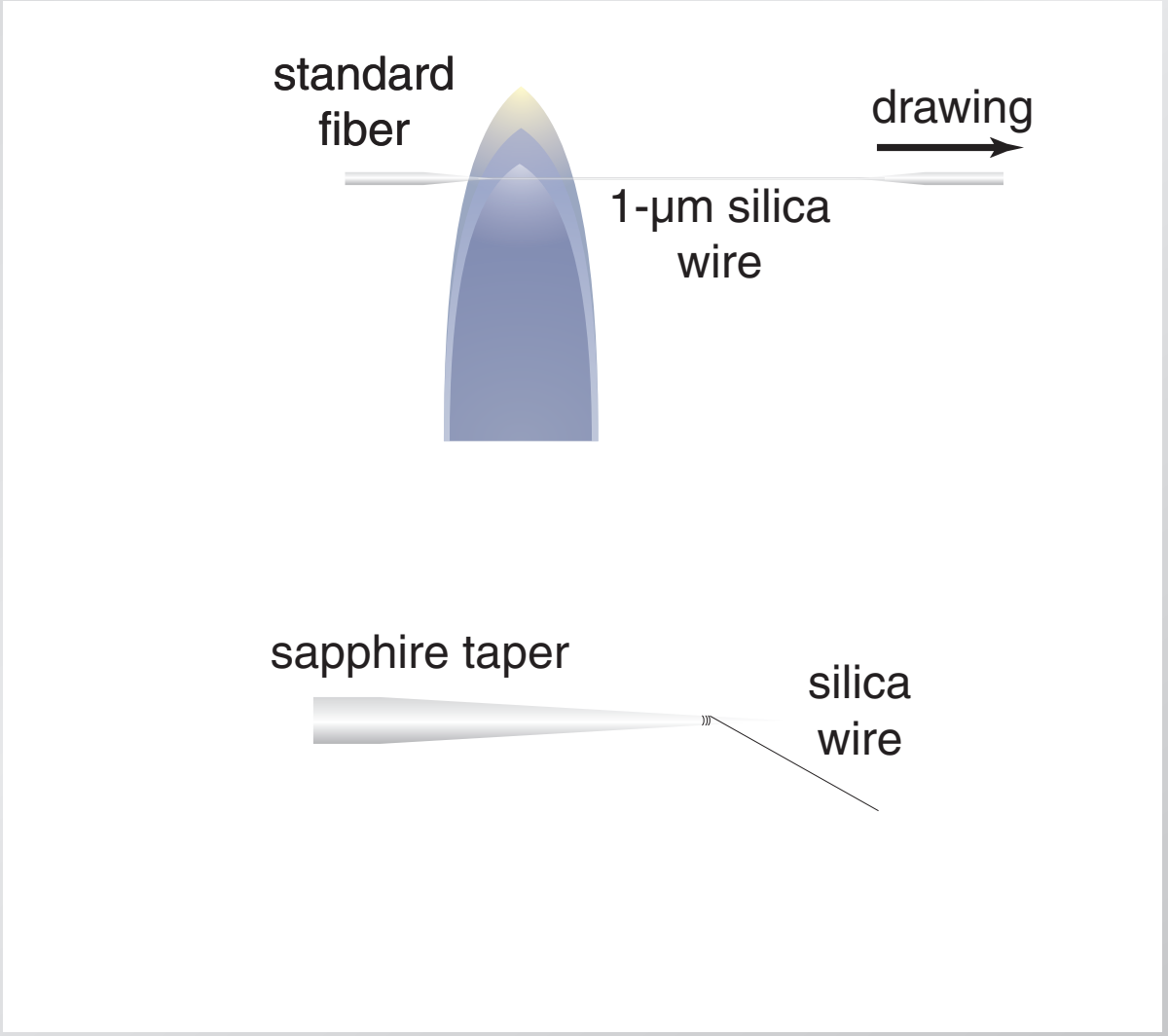
Nanowire fabrication

two-step drawing process



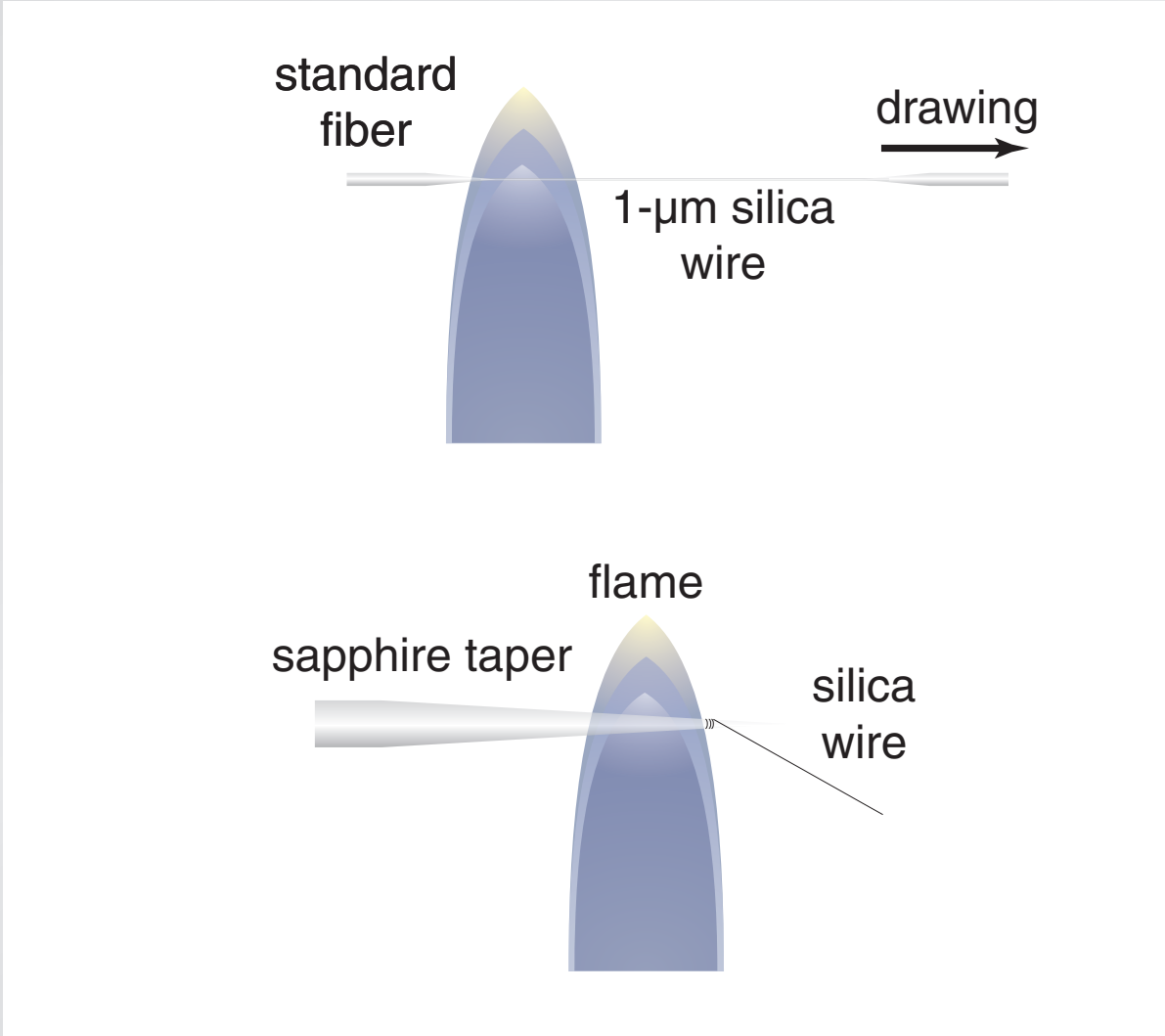
Nanowire fabrication

two-step drawing process



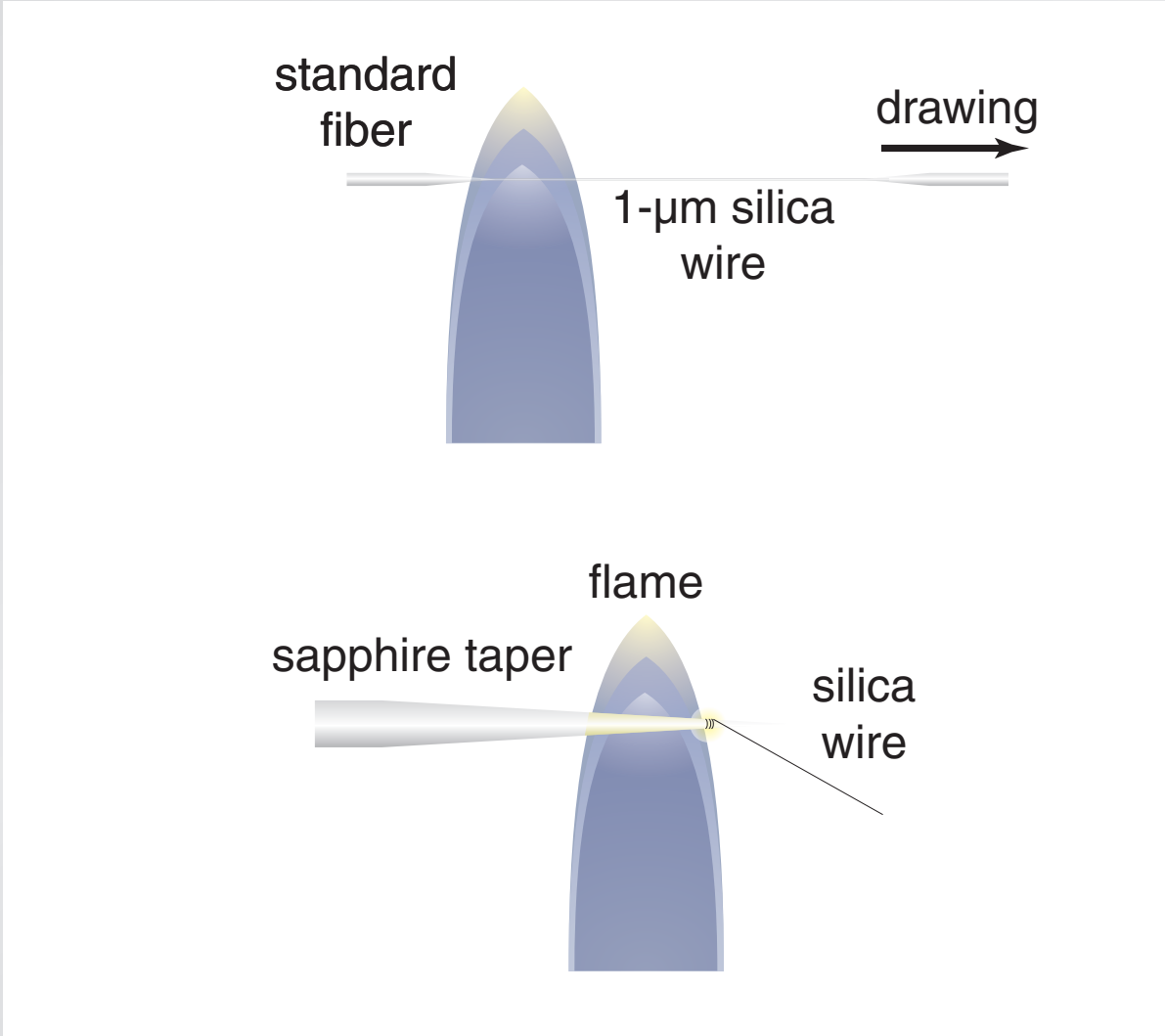
Nanowire fabrication

two-step drawing process



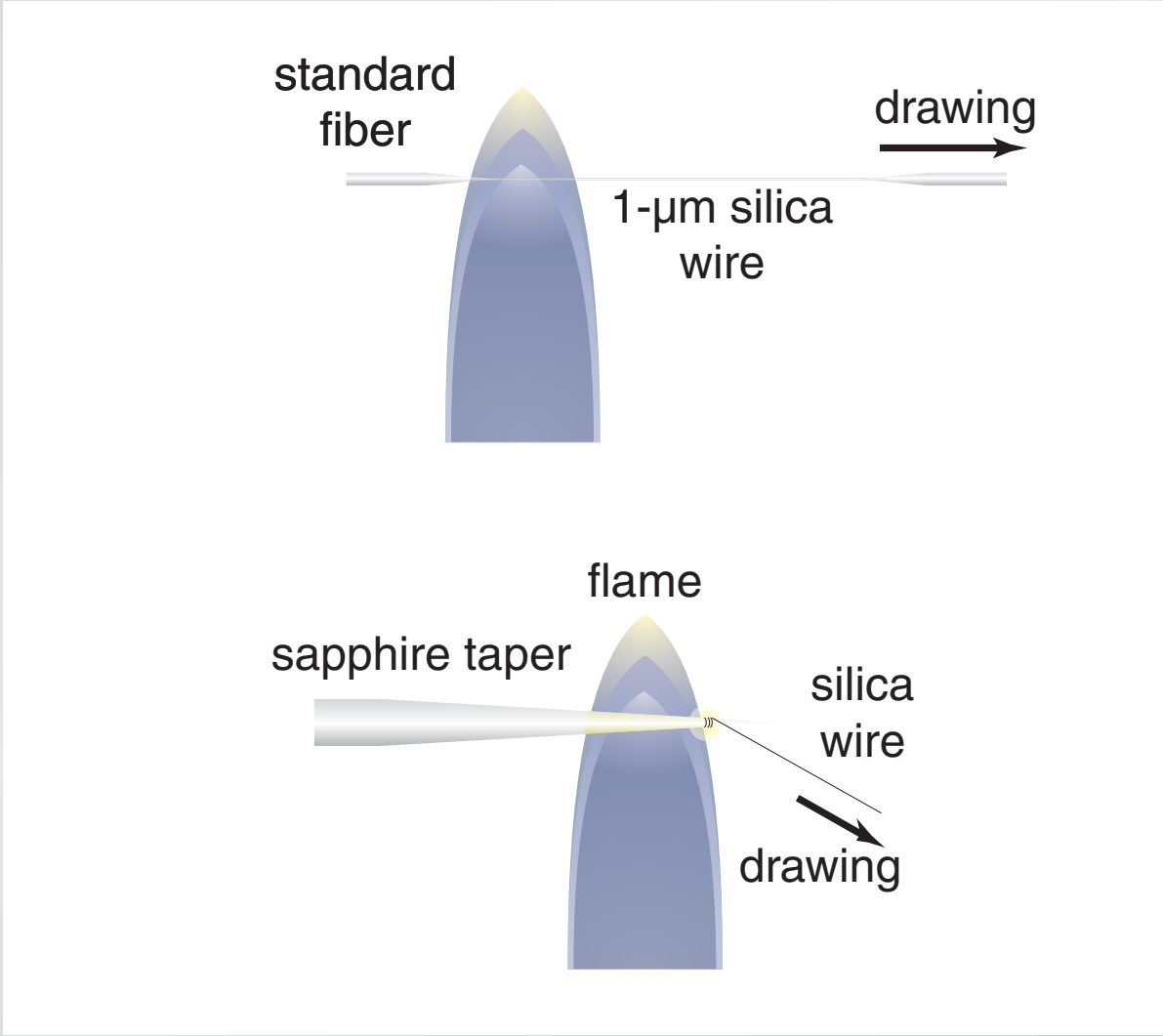
Nanowire fabrication

two-step drawing process

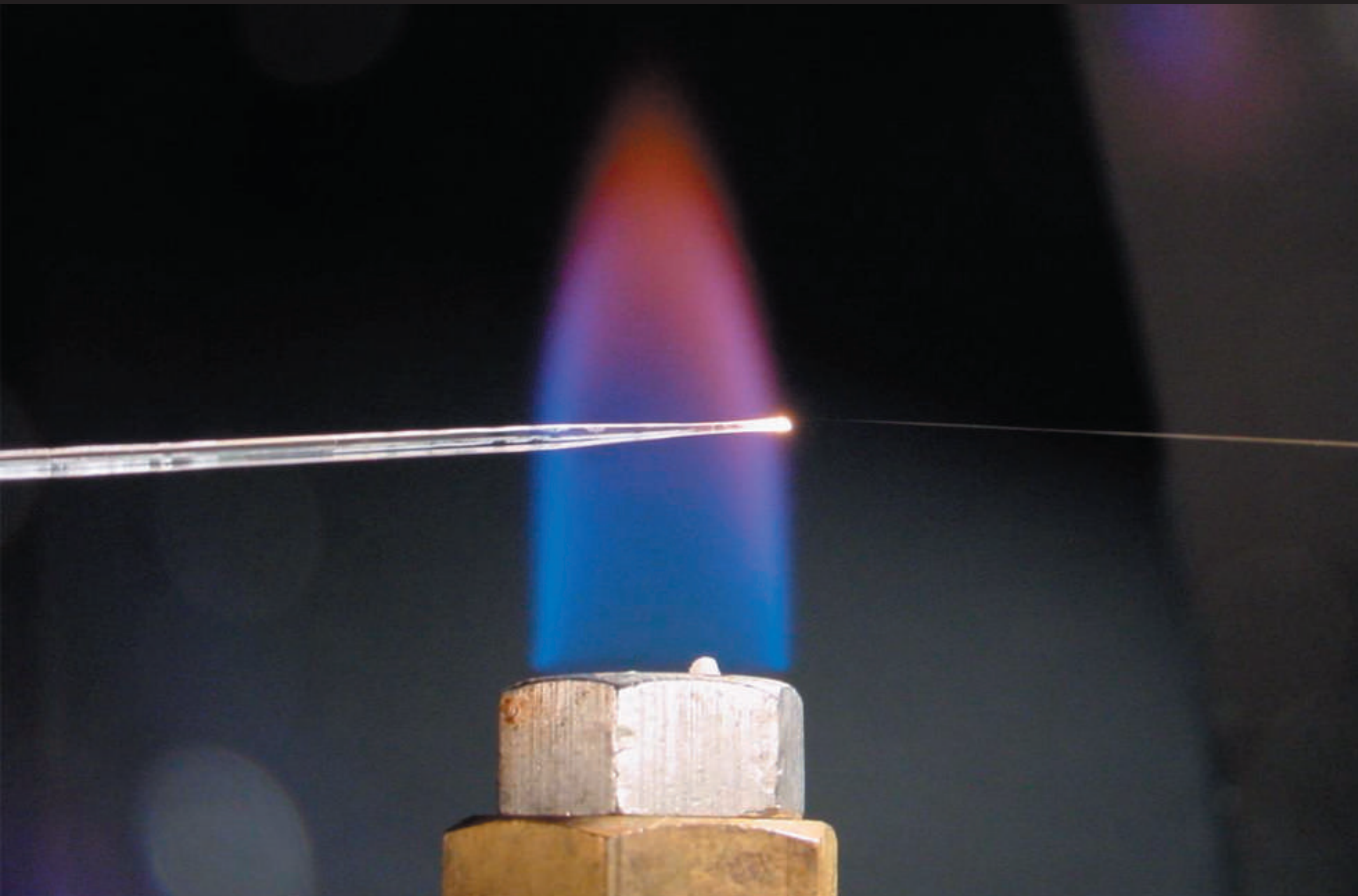


Nanowire fabrication

two-step drawing process



Nanowire fabrication

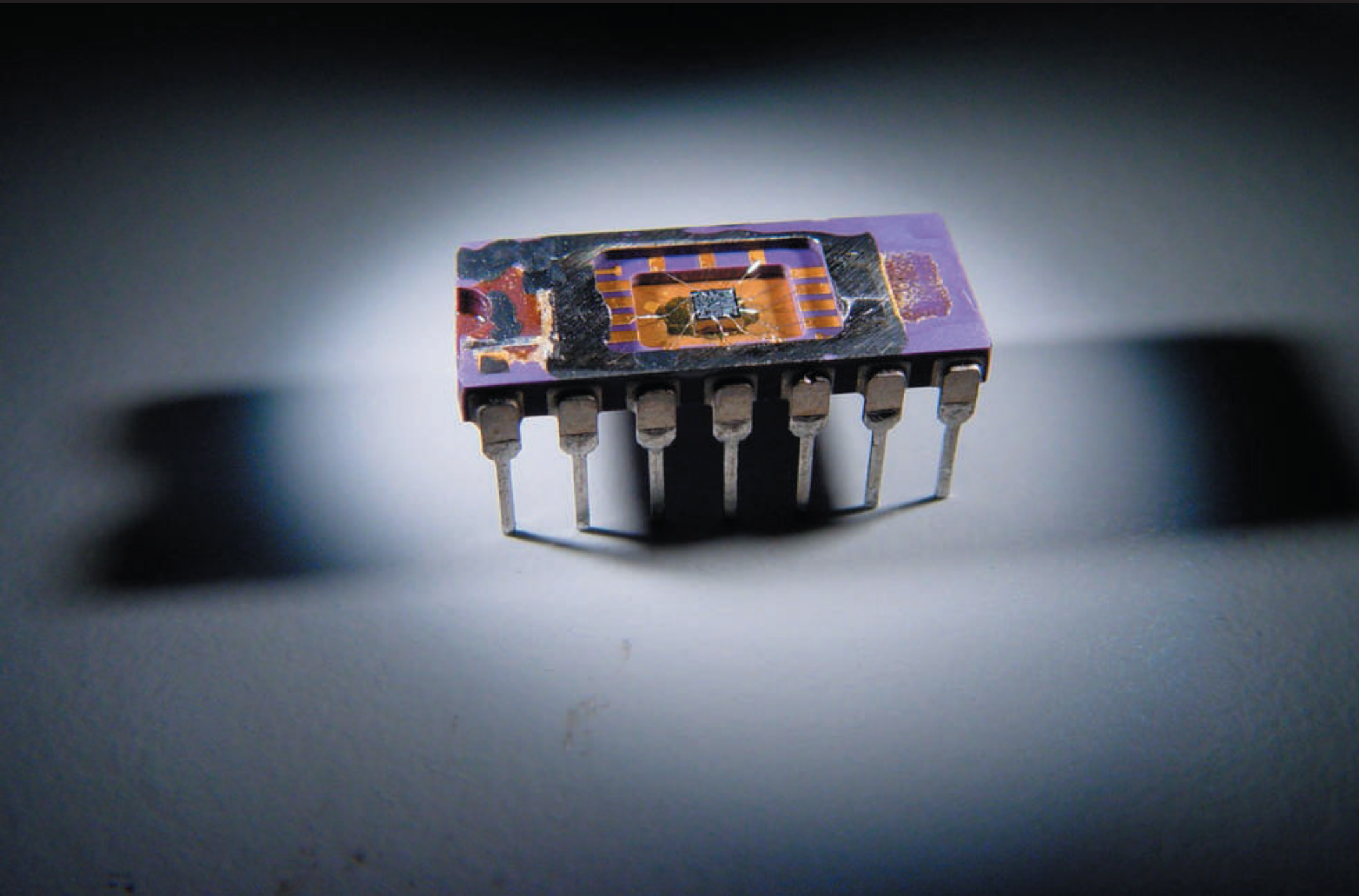


Nanowire fabrication

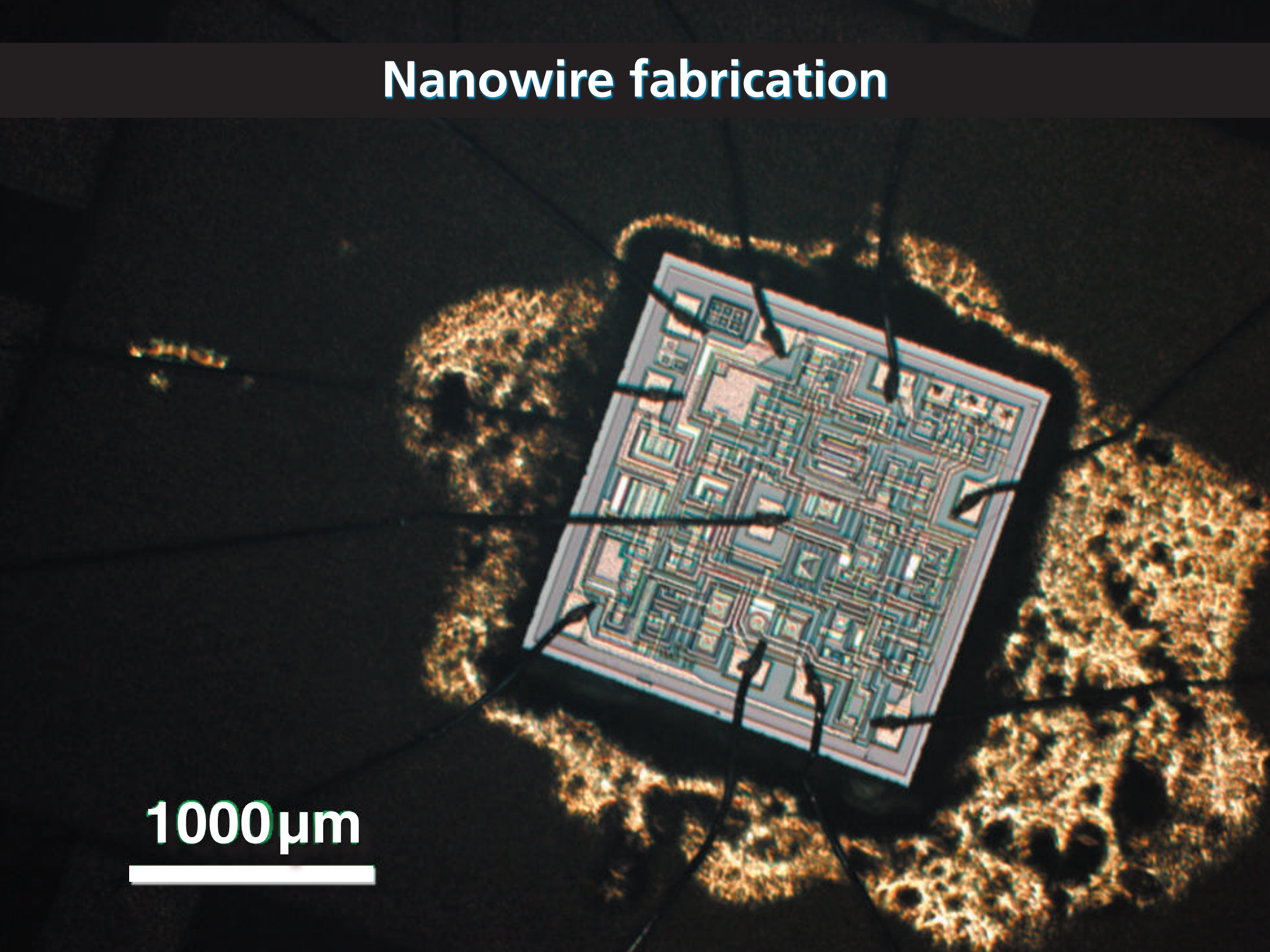
1 μm

Nature, 426, 816 (2003)

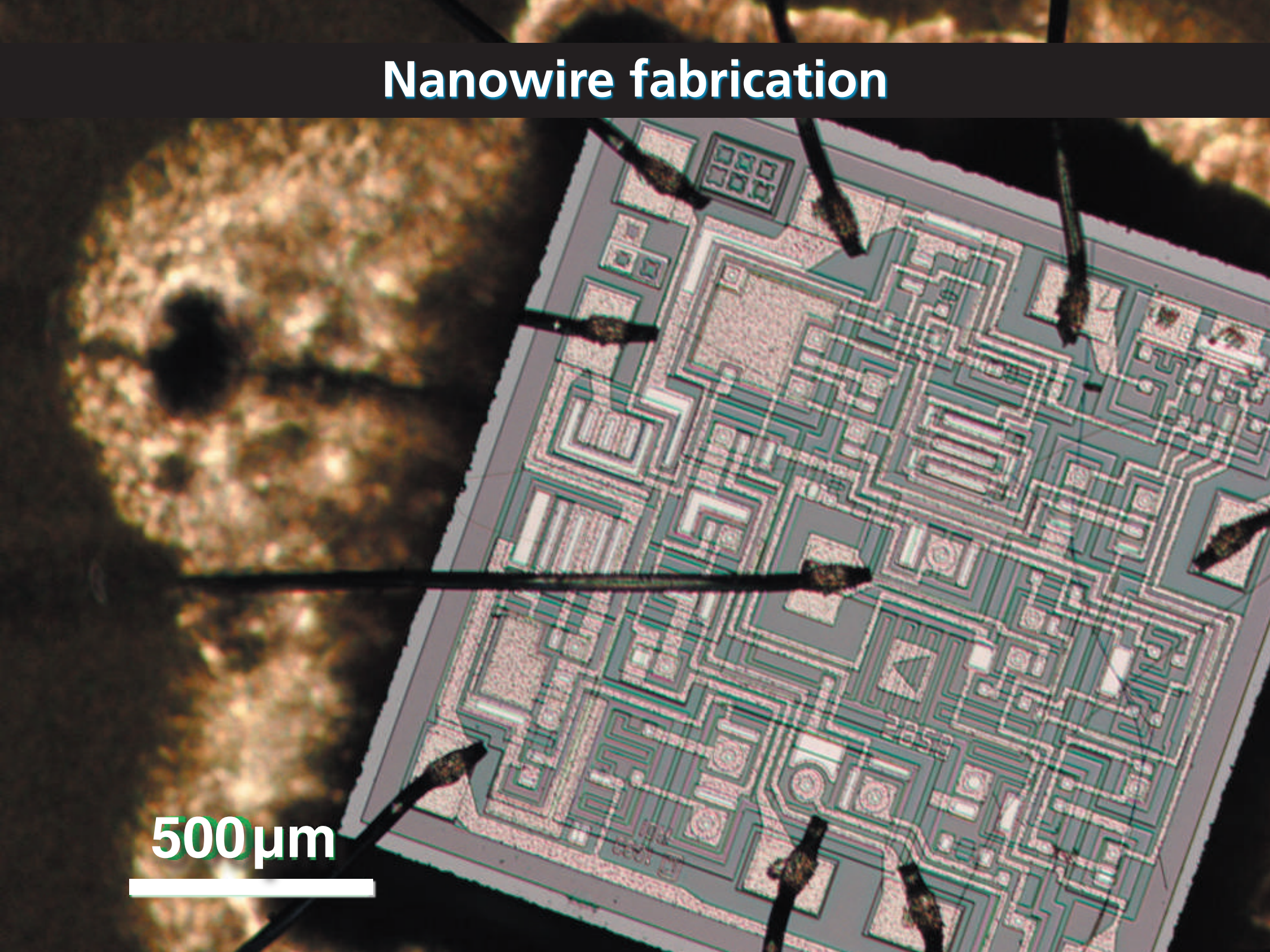
Nanowire fabrication



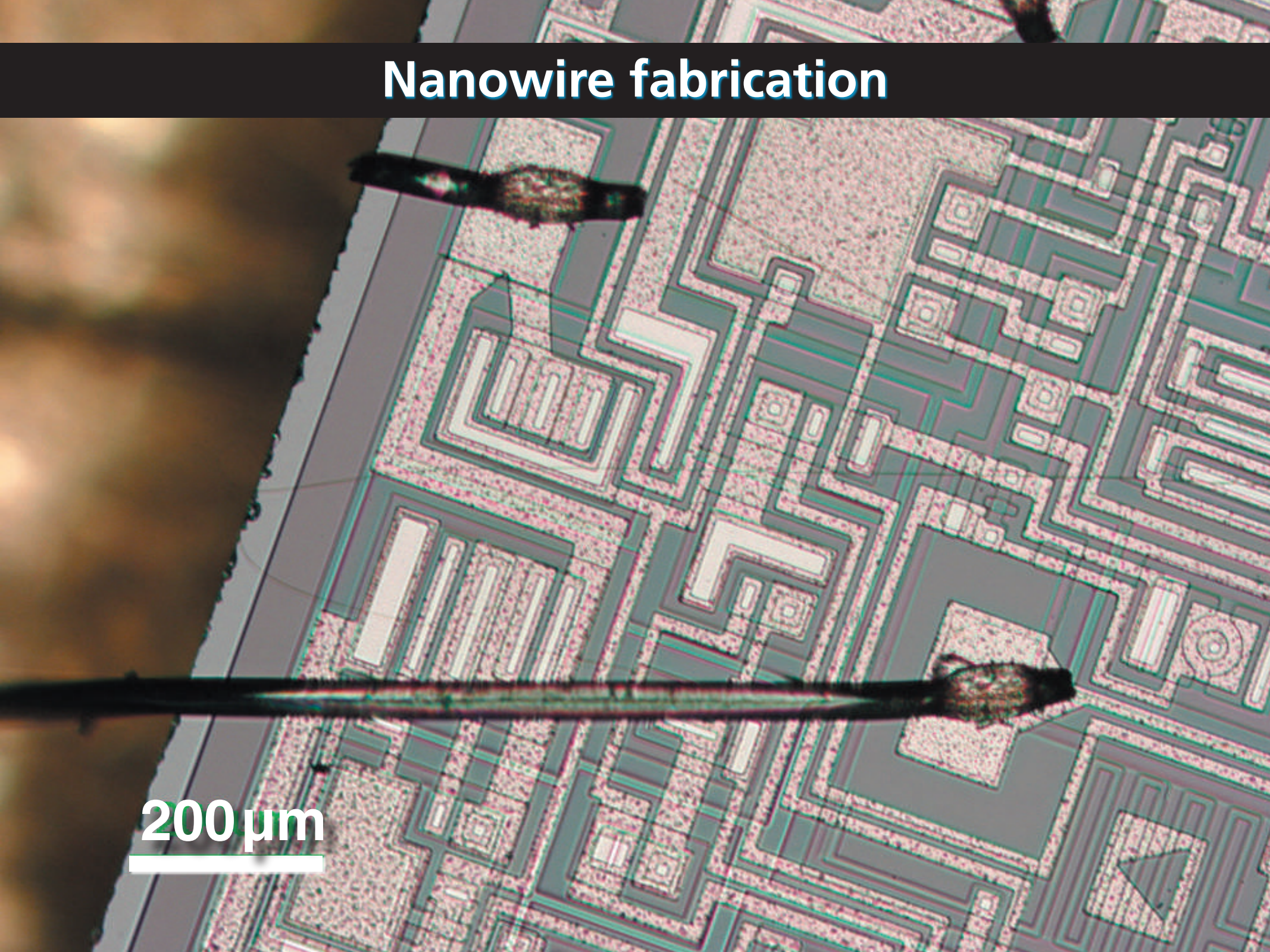
Nanowire fabrication



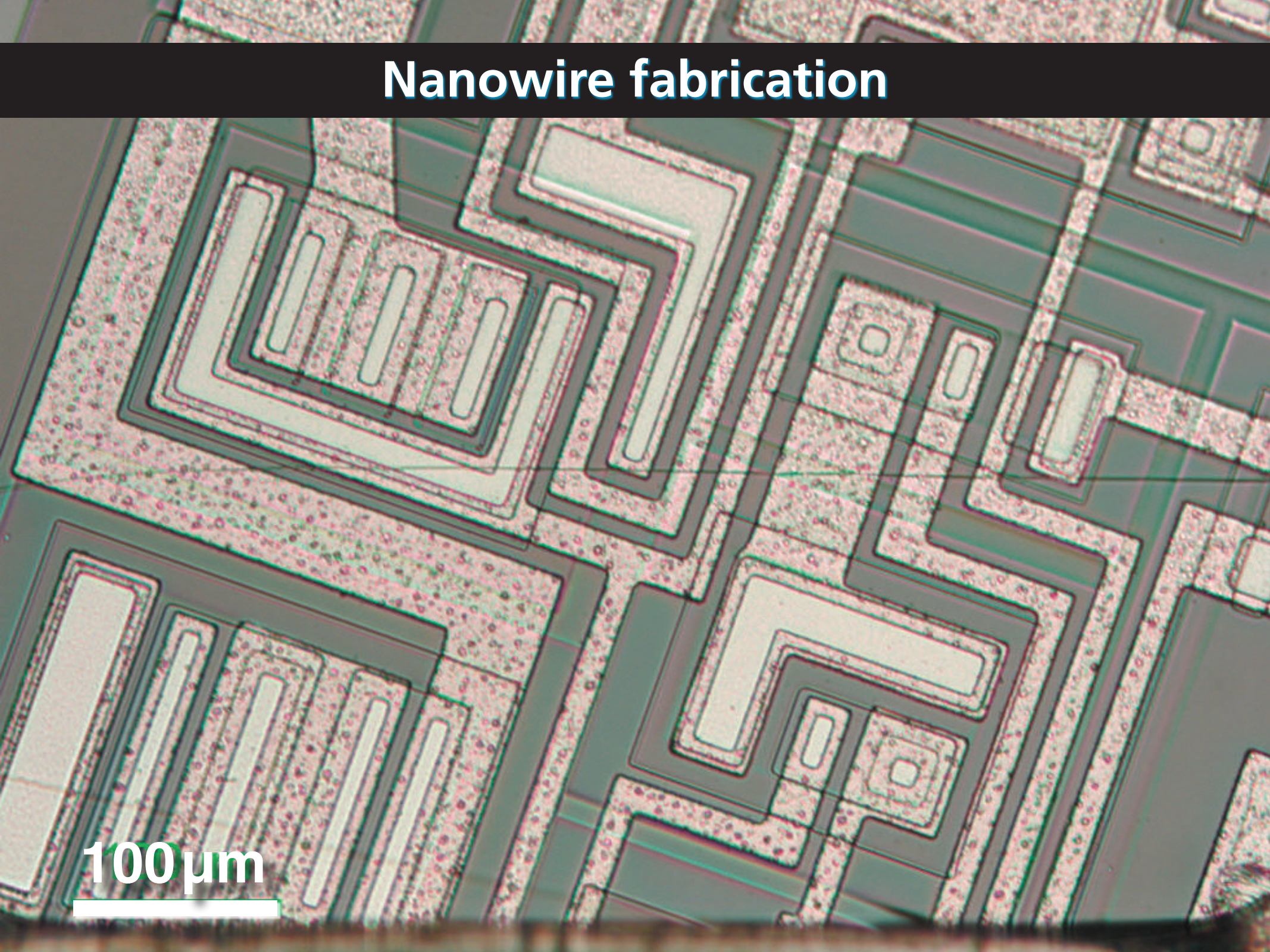
Nanowire fabrication



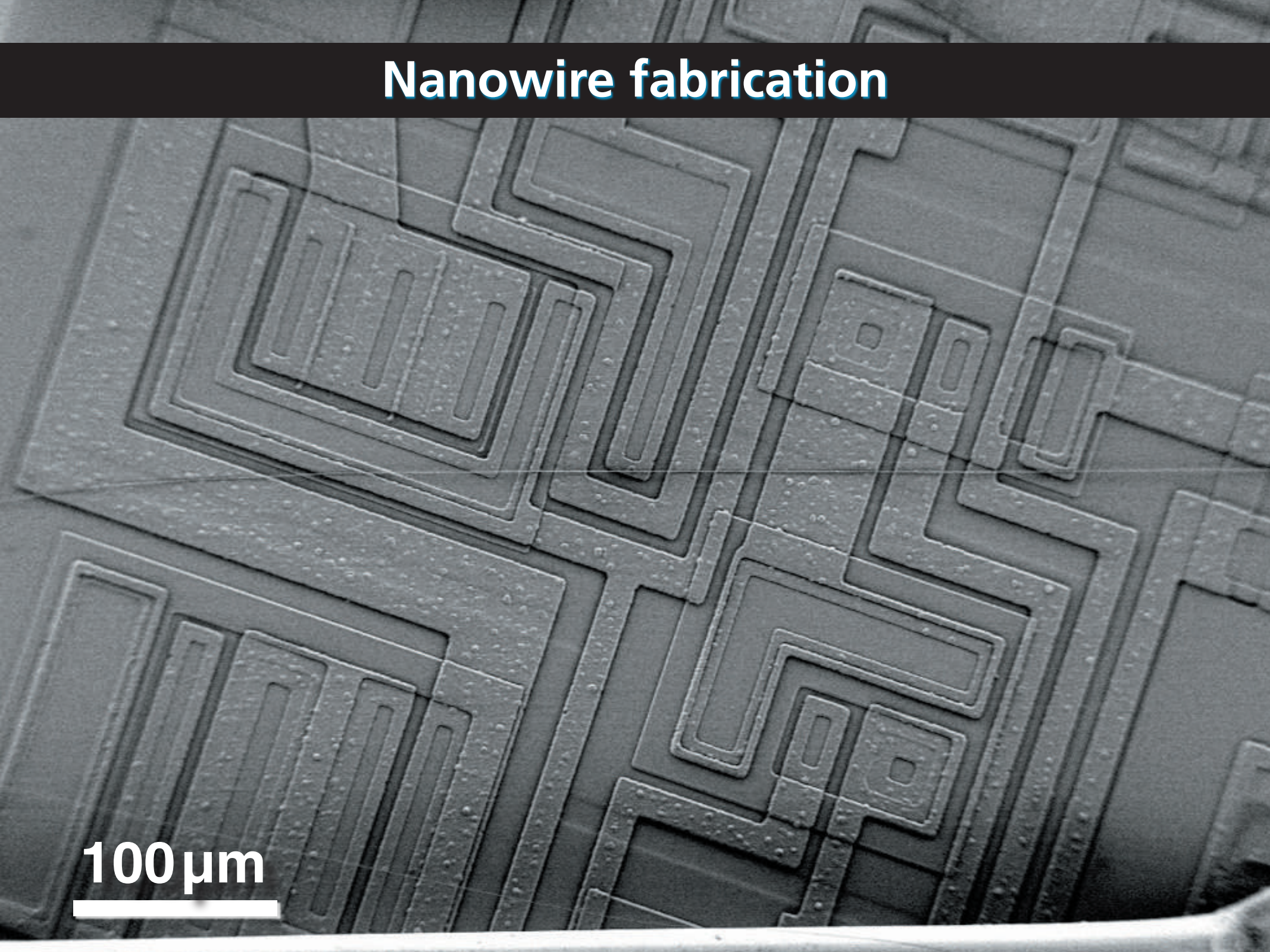
Nanowire fabrication



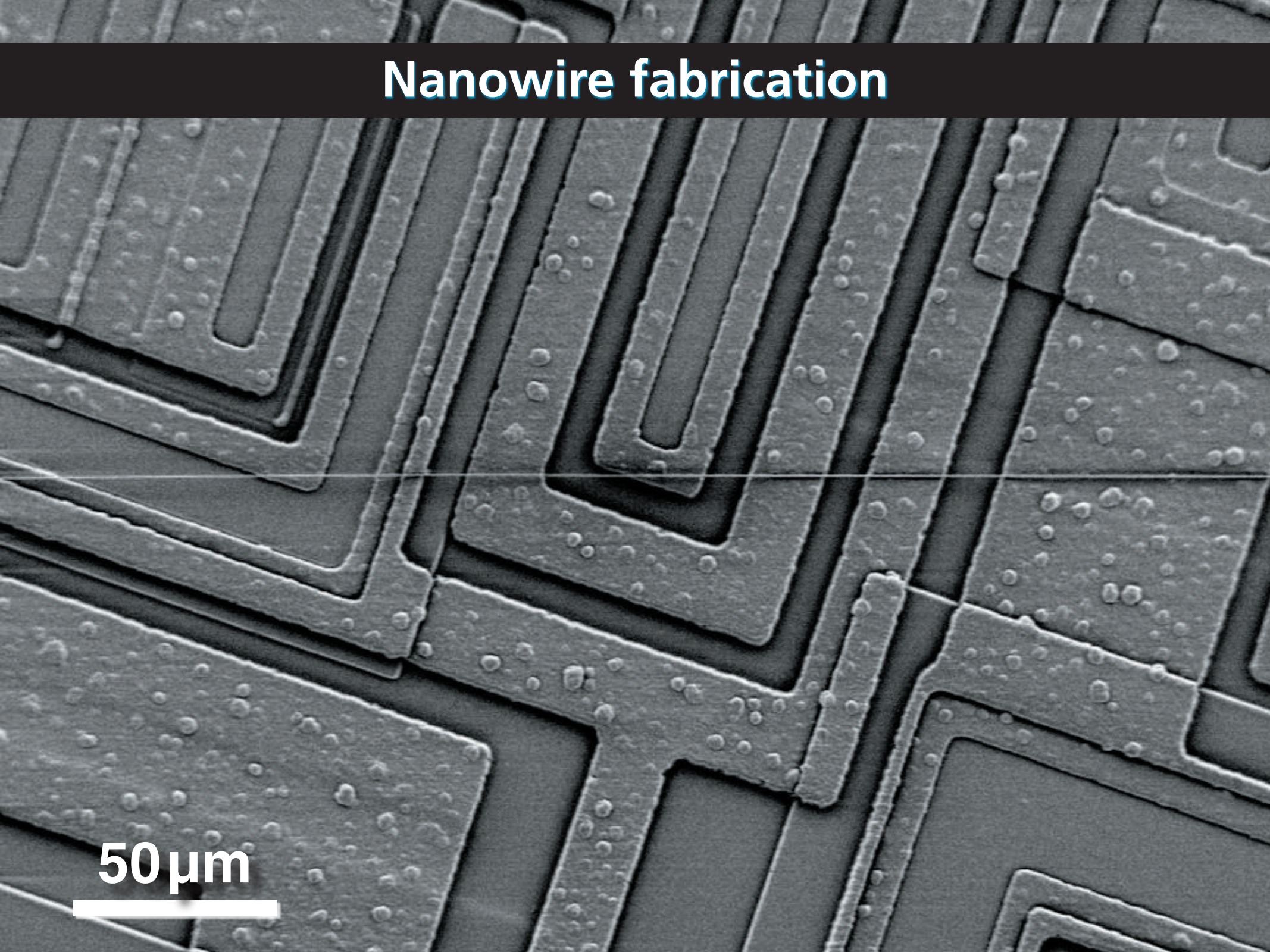
Nanowire fabrication



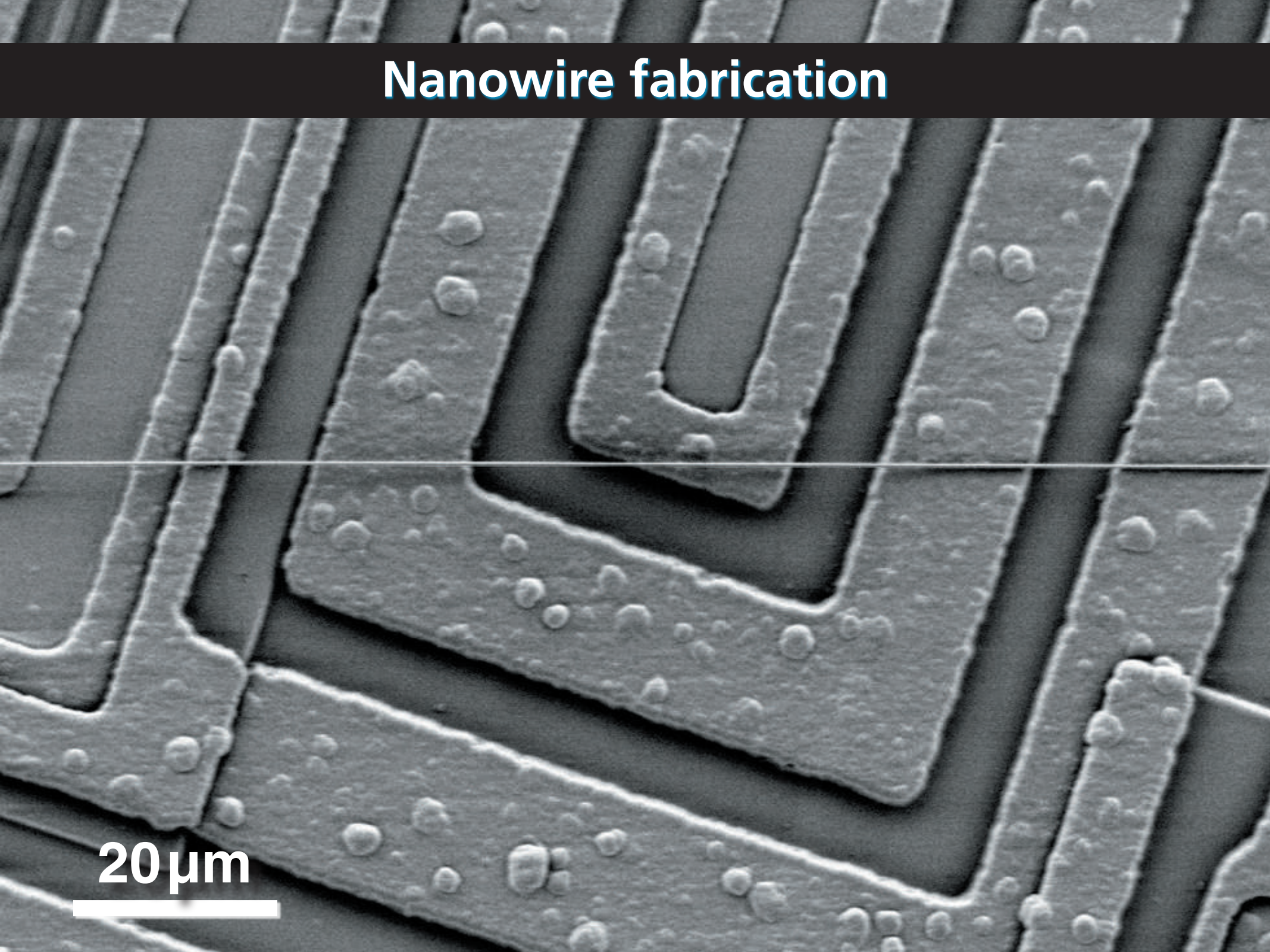
Nanowire fabrication



Nanowire fabrication



Nanowire fabrication



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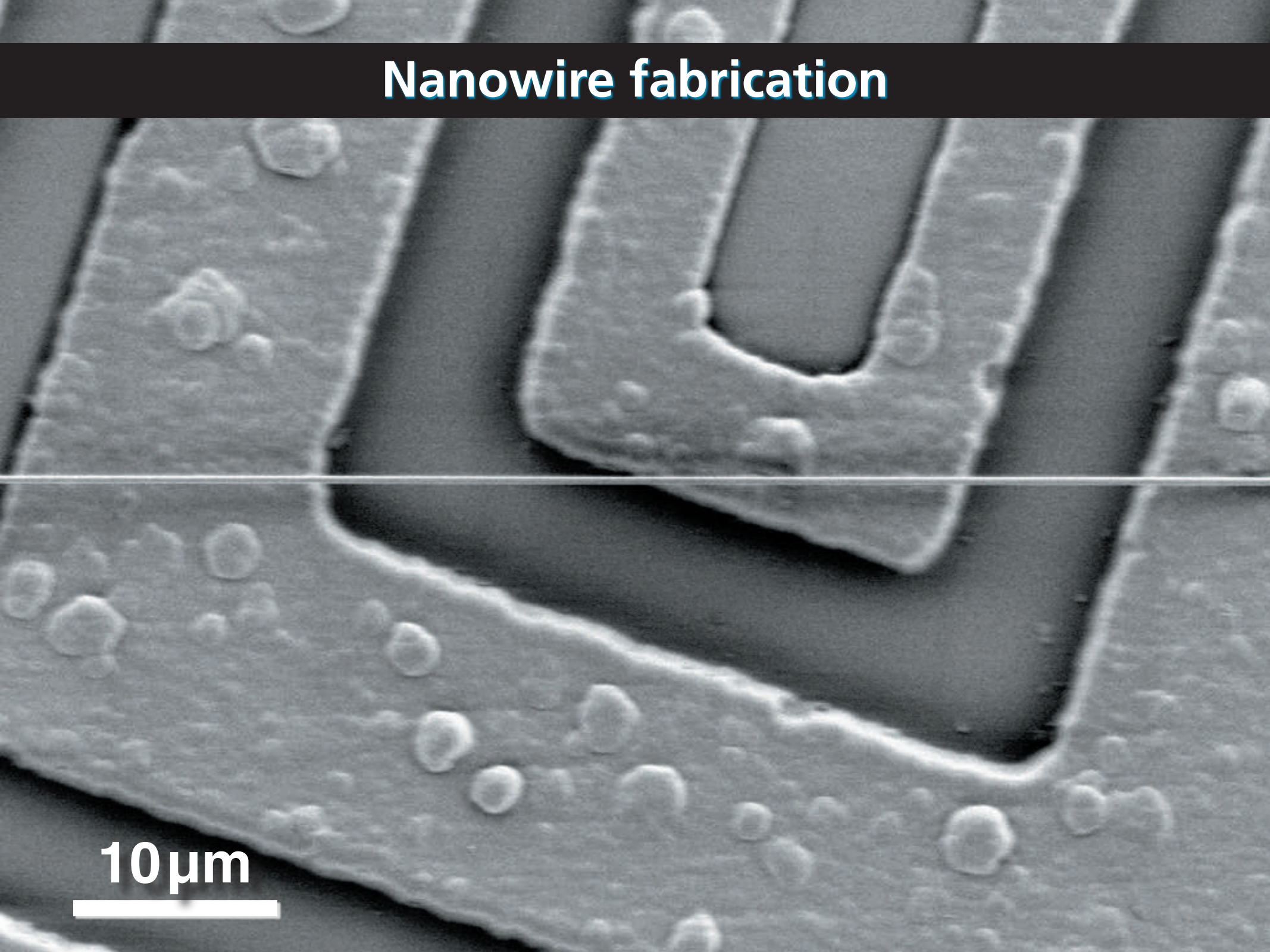
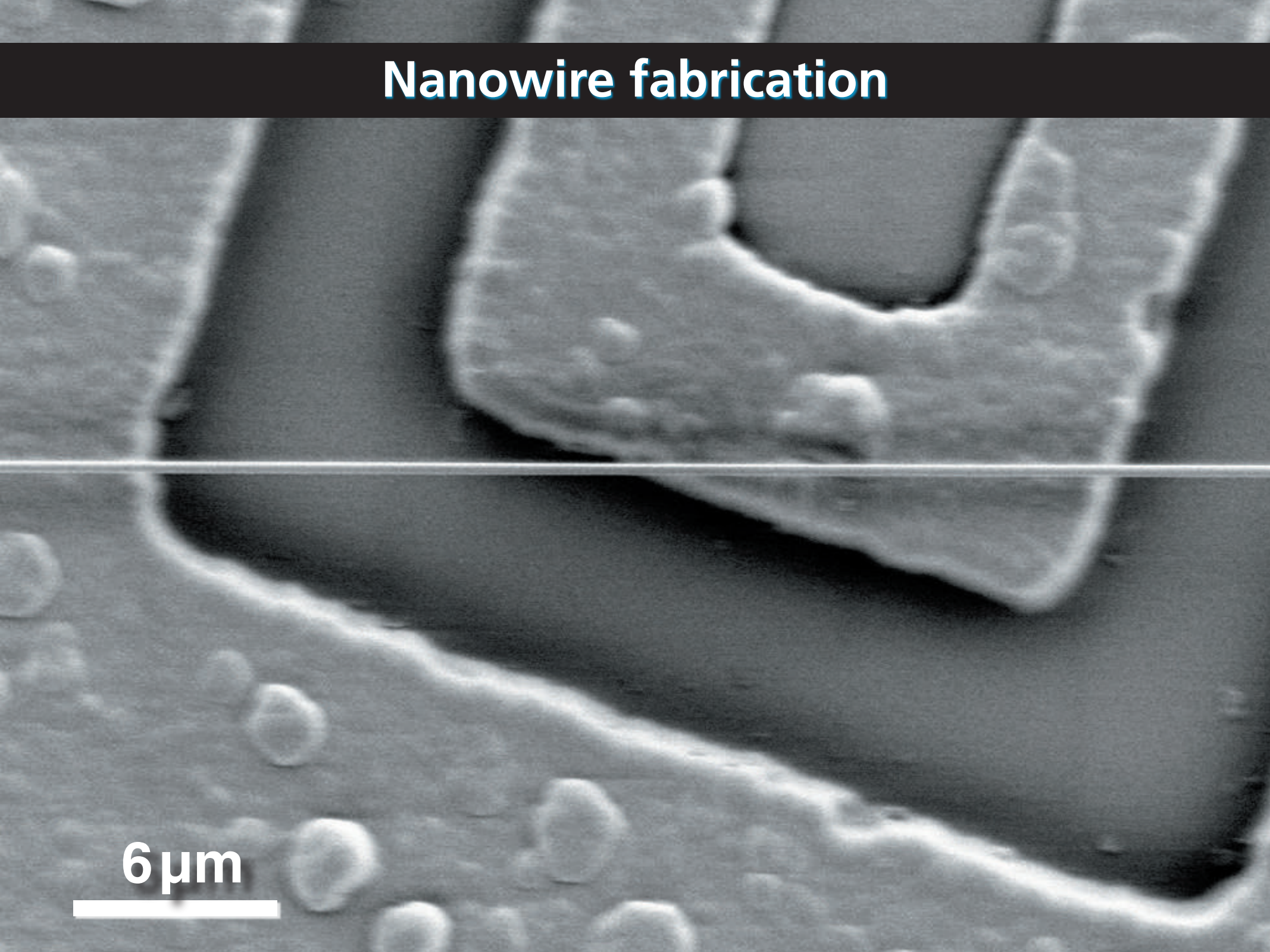
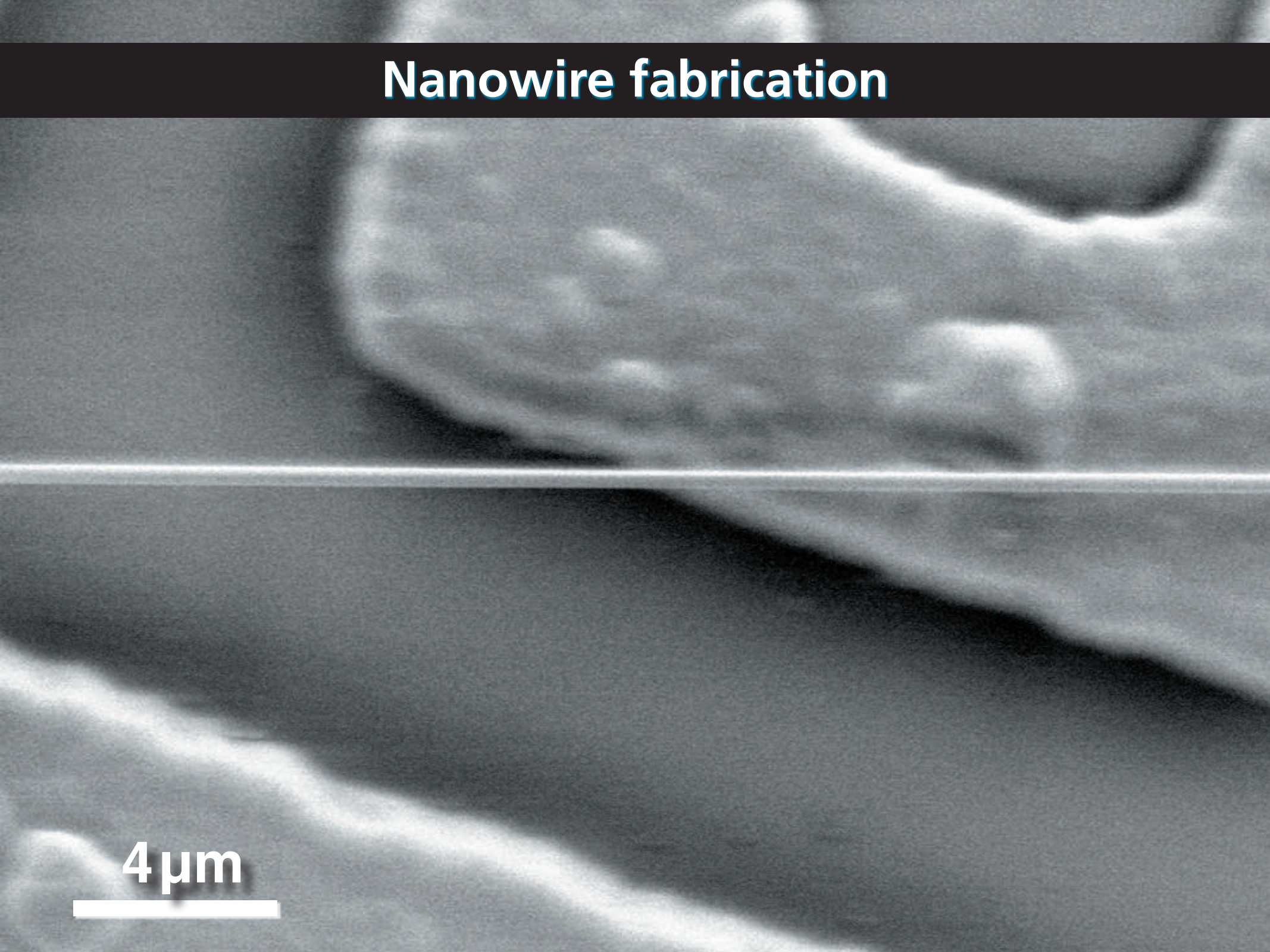


Nanowire fabrication



Nanowire fabrication



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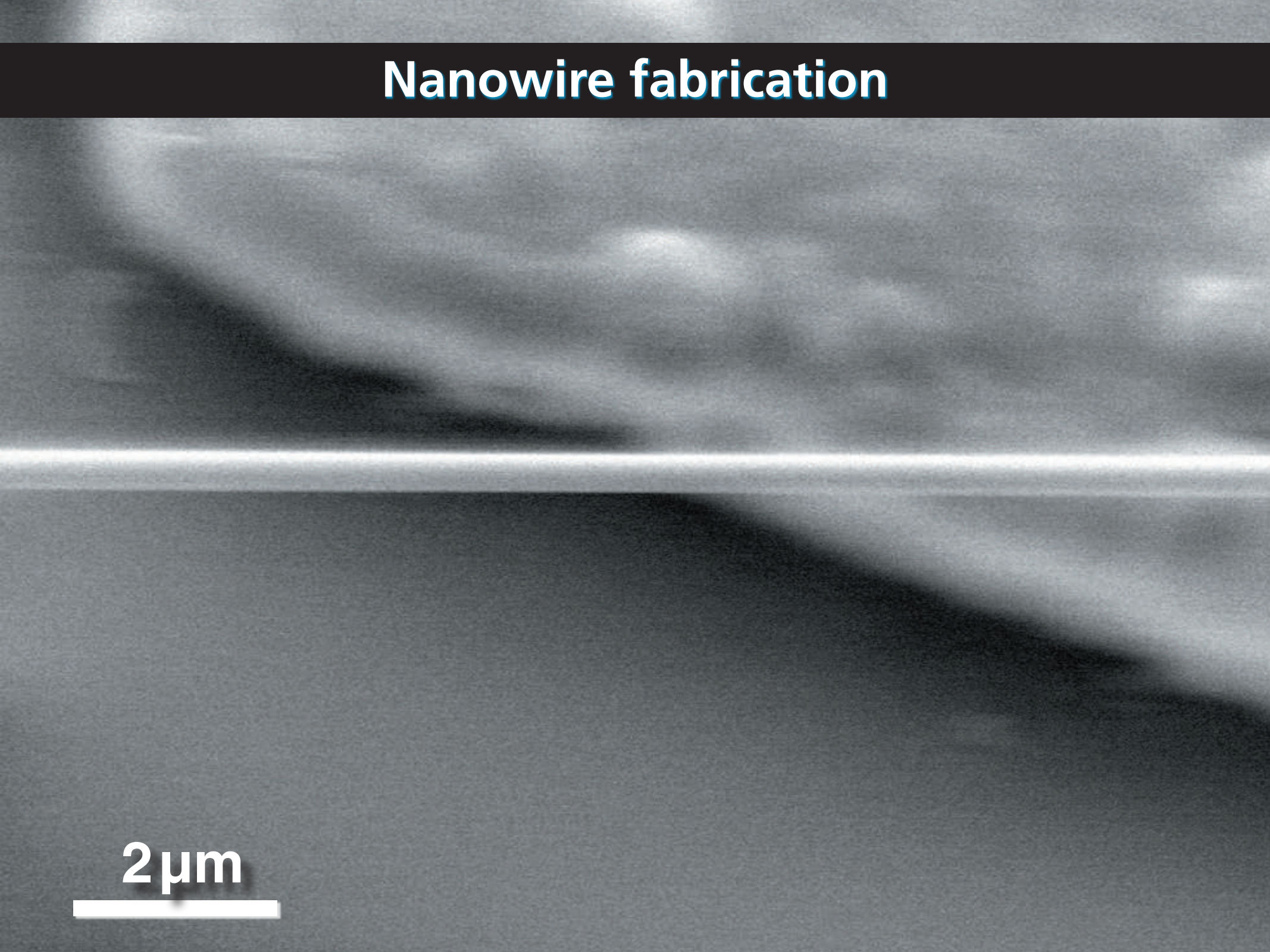

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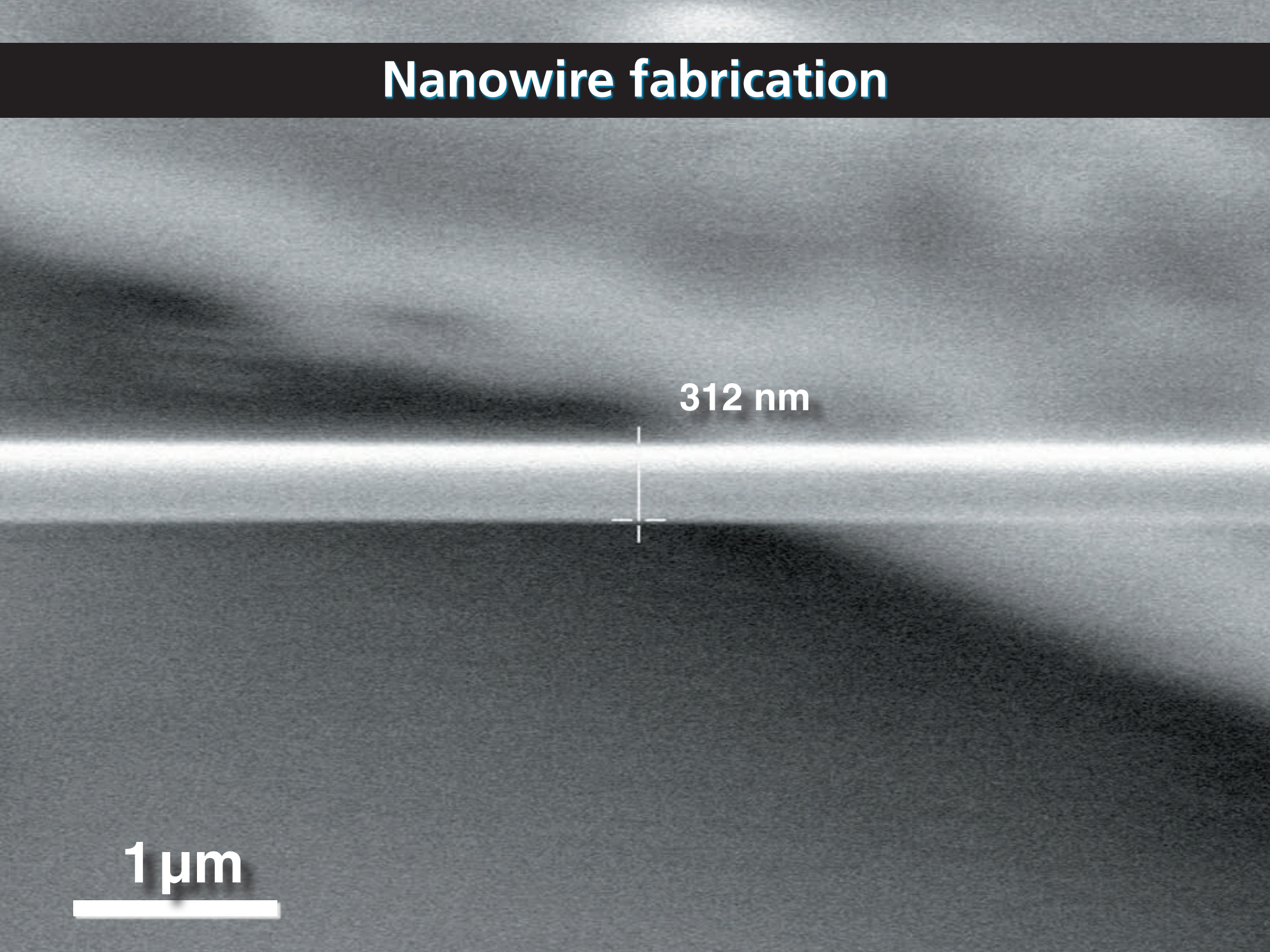
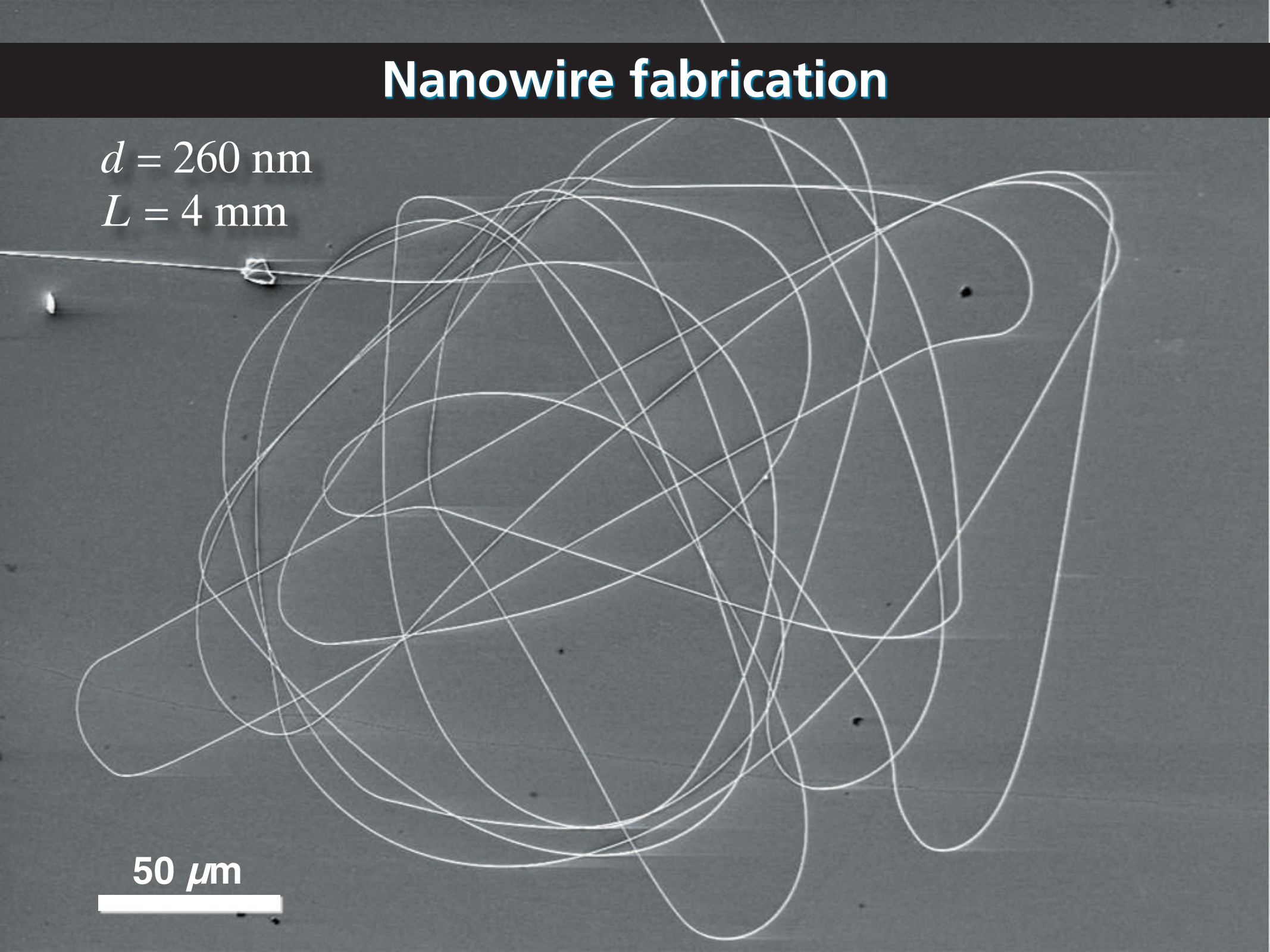


Waveguiding

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 x 10^{-6}

Nanowire fabrication



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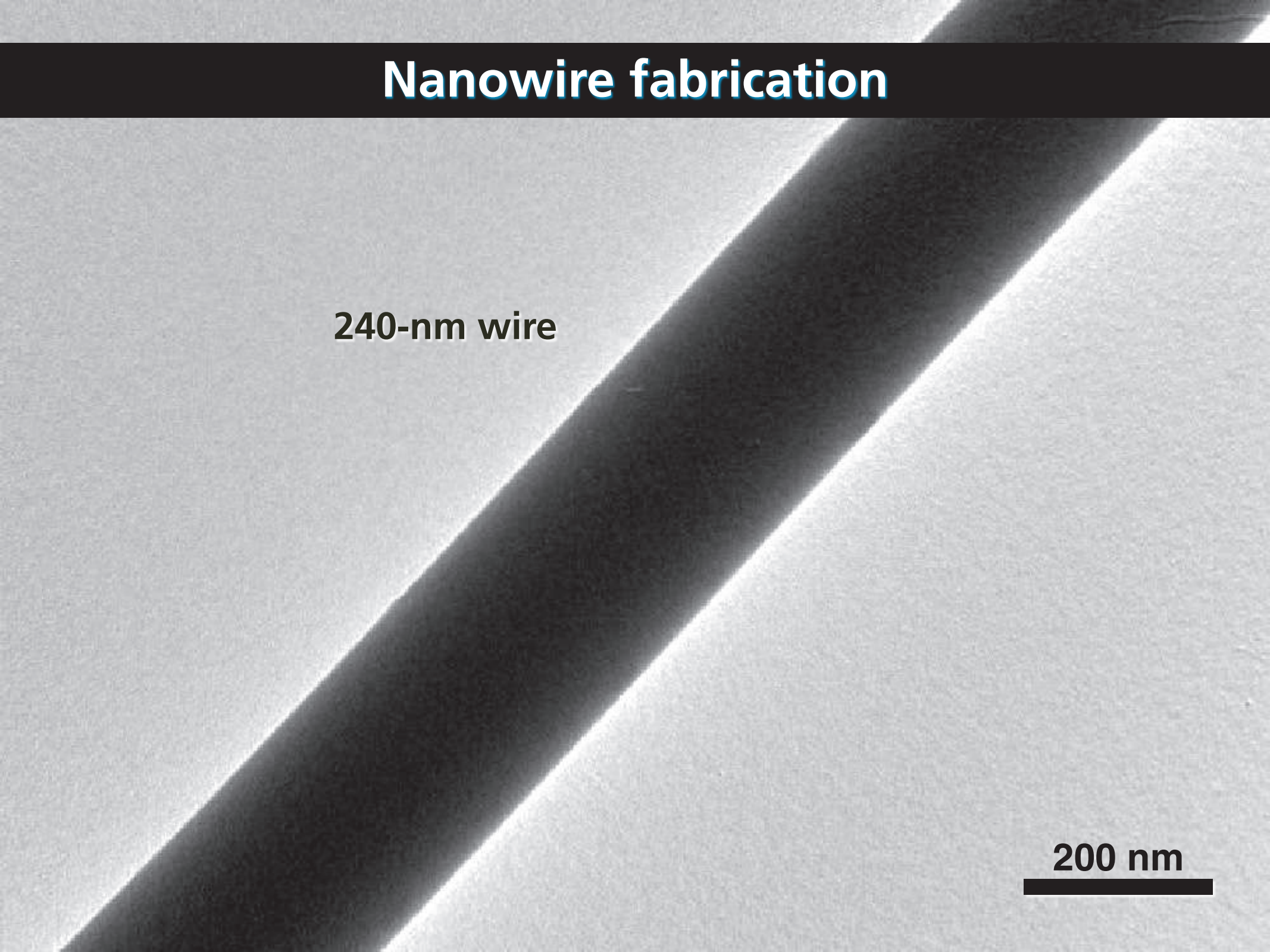

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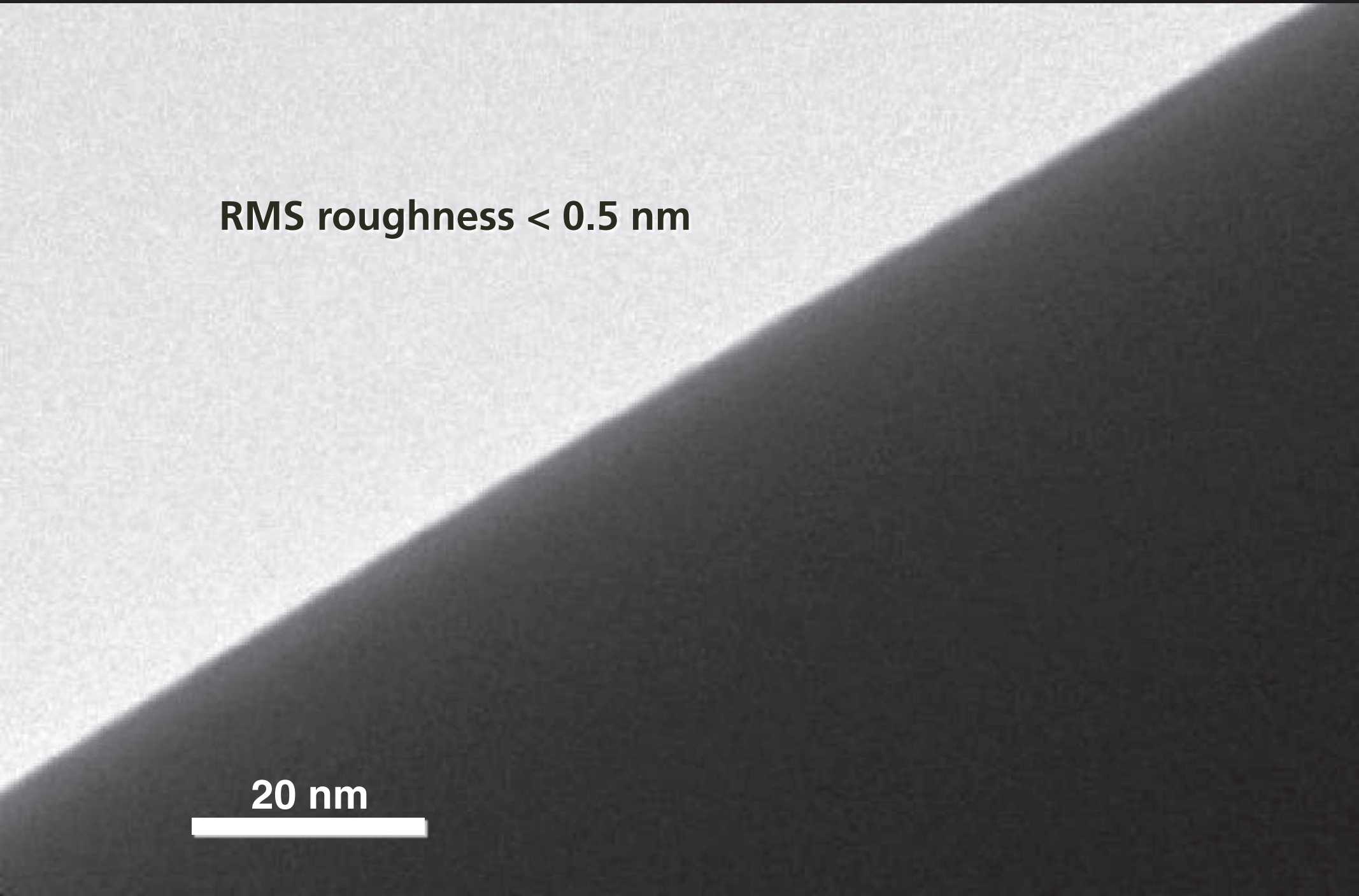
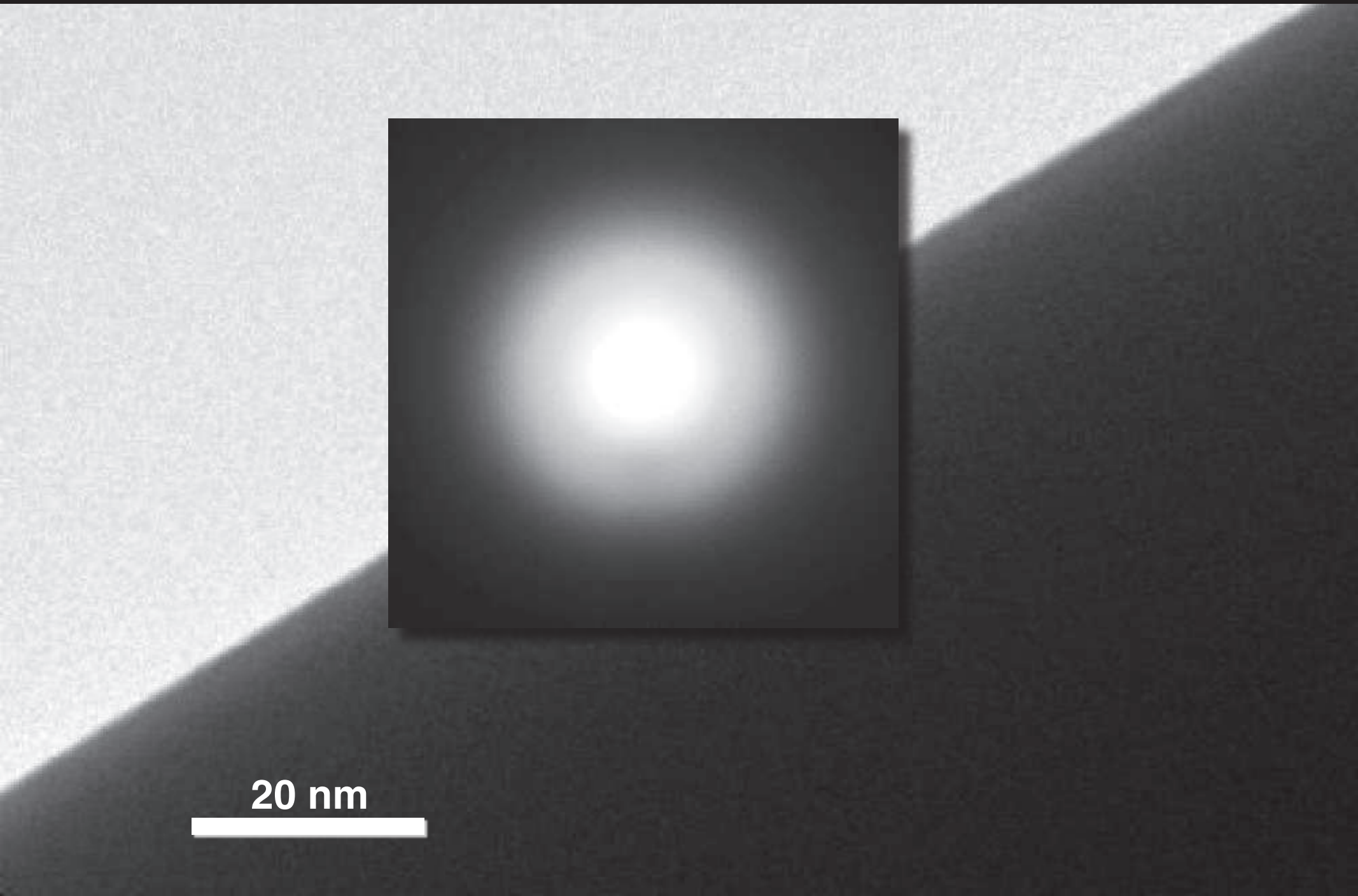


Nanowire fabrication



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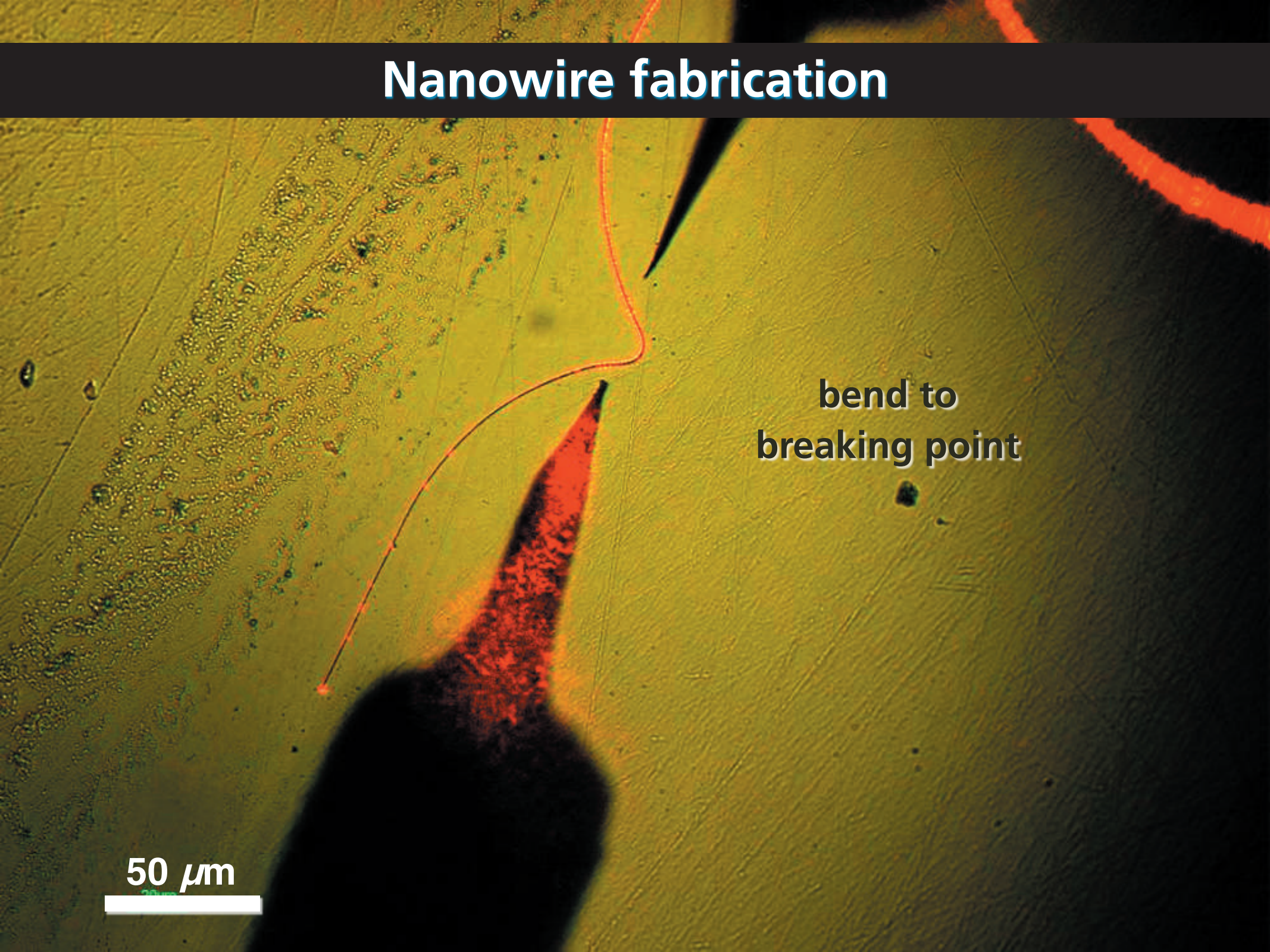
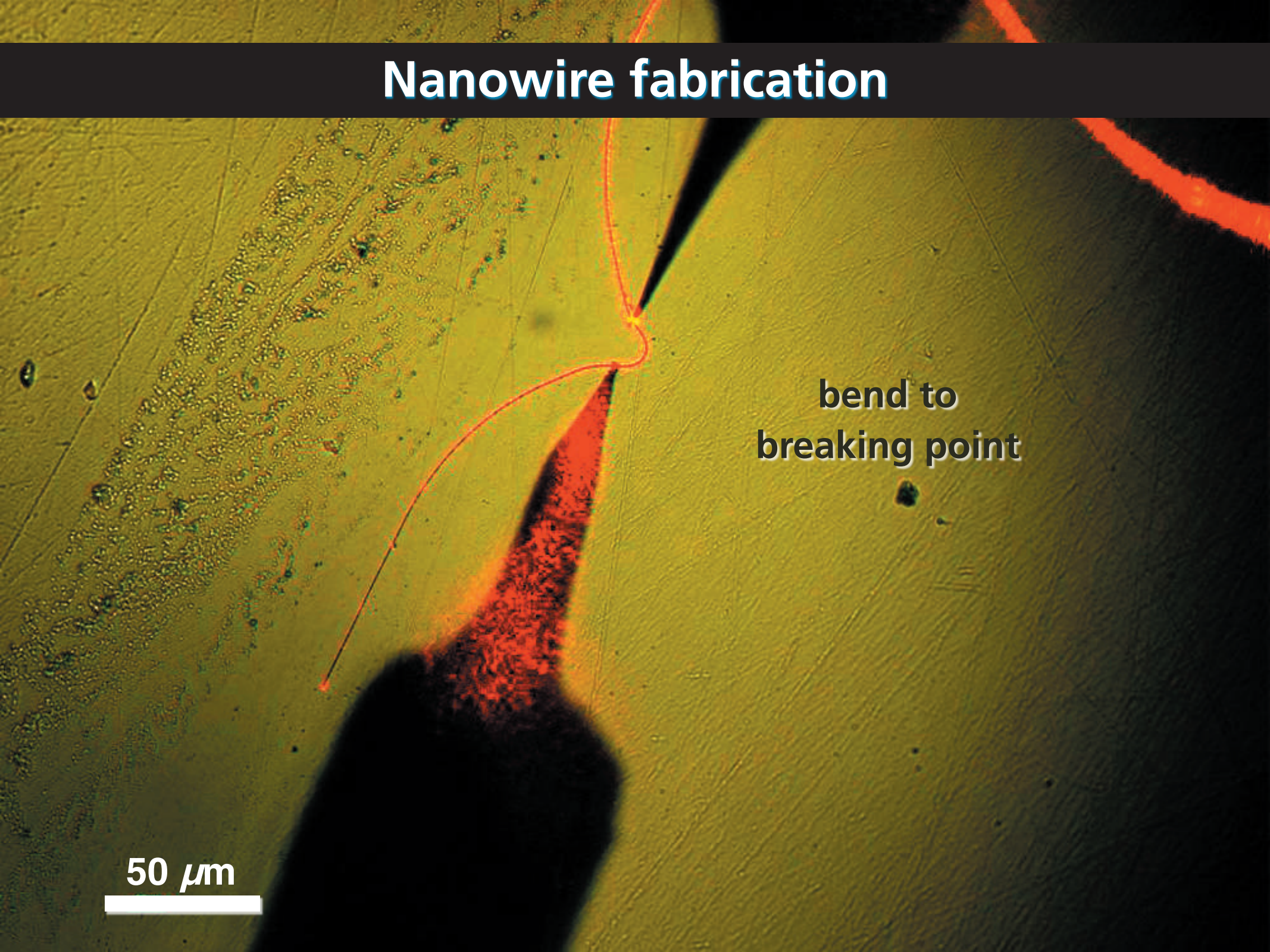


Nanowire fabrication



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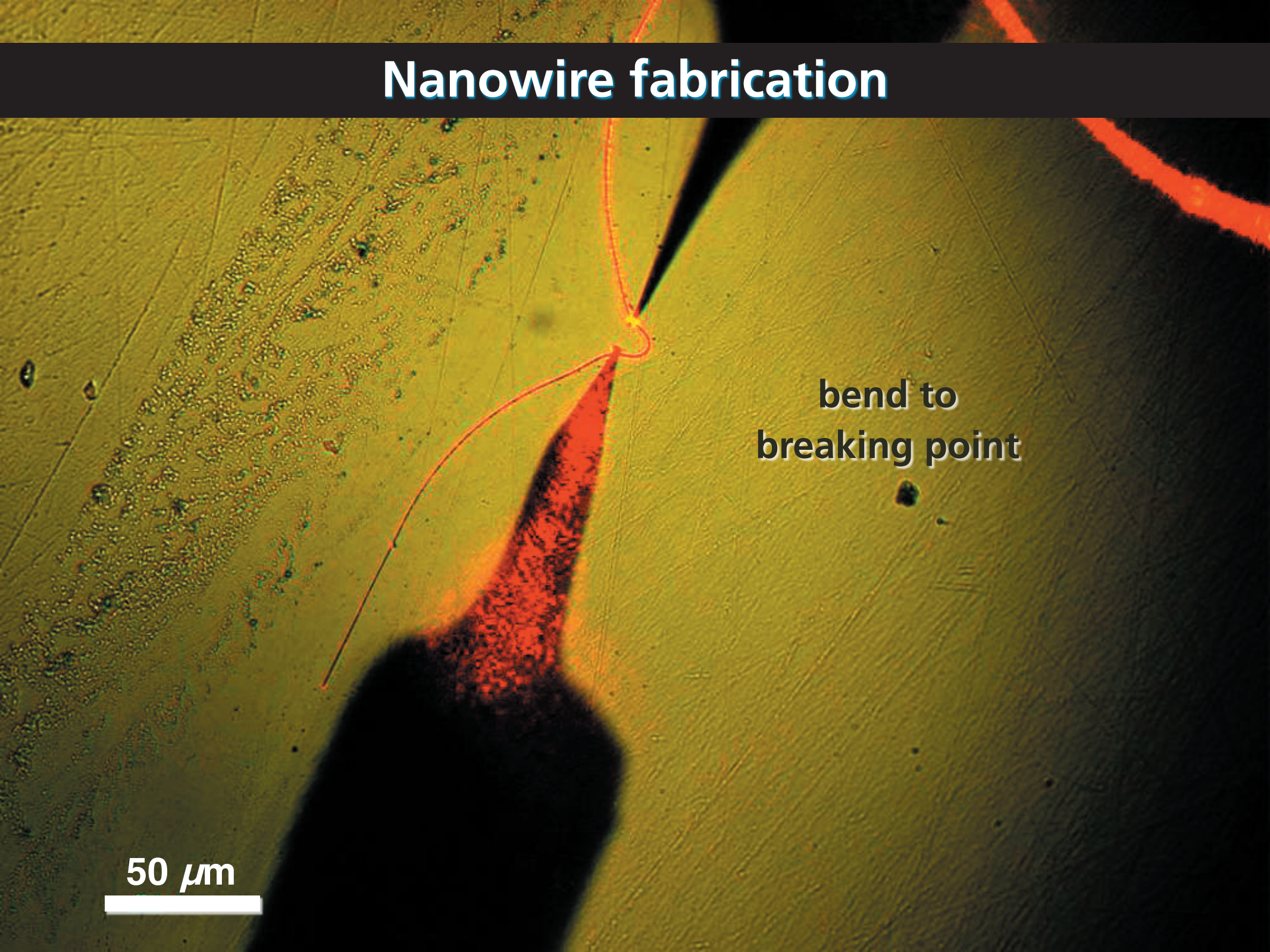
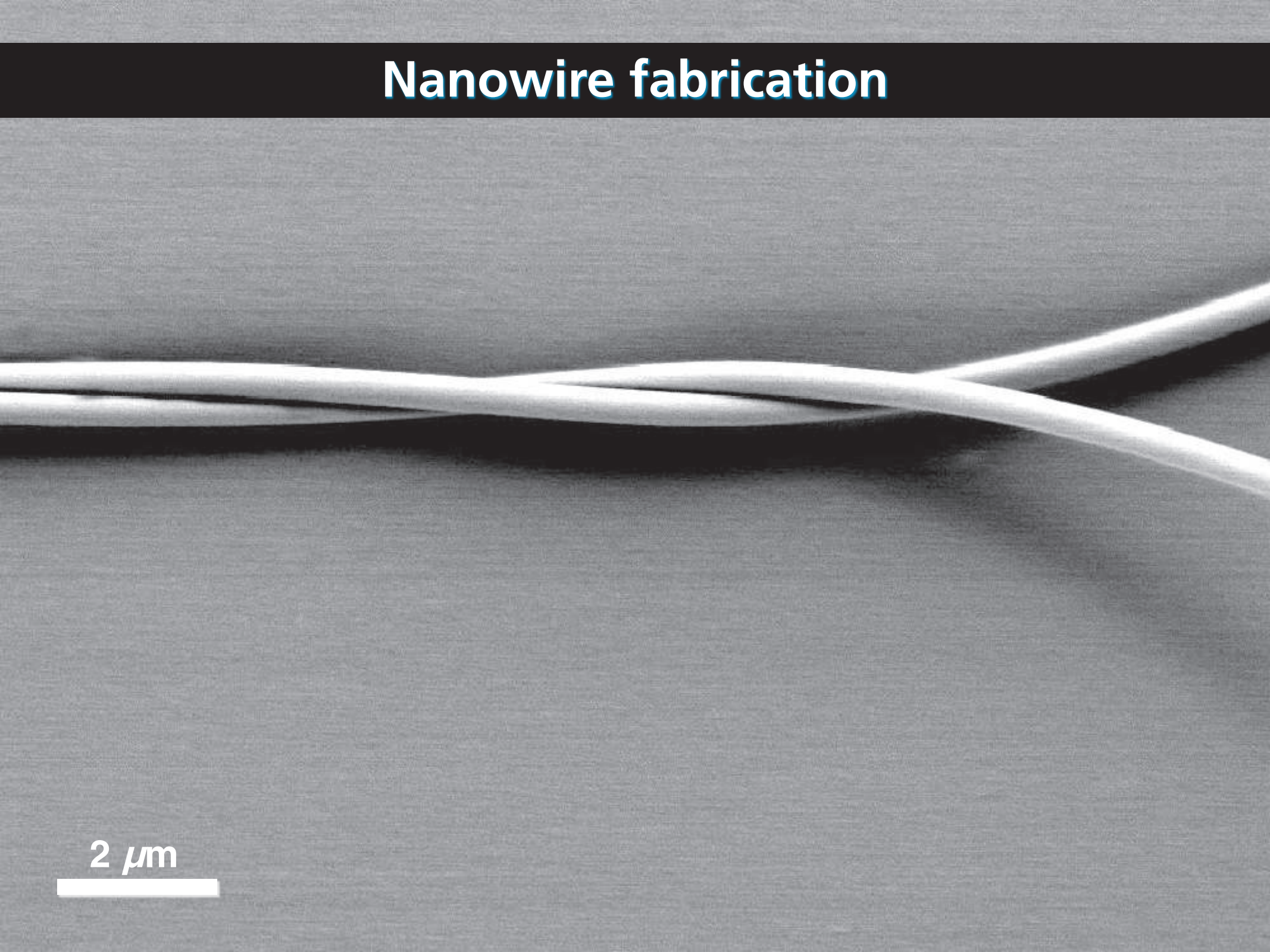
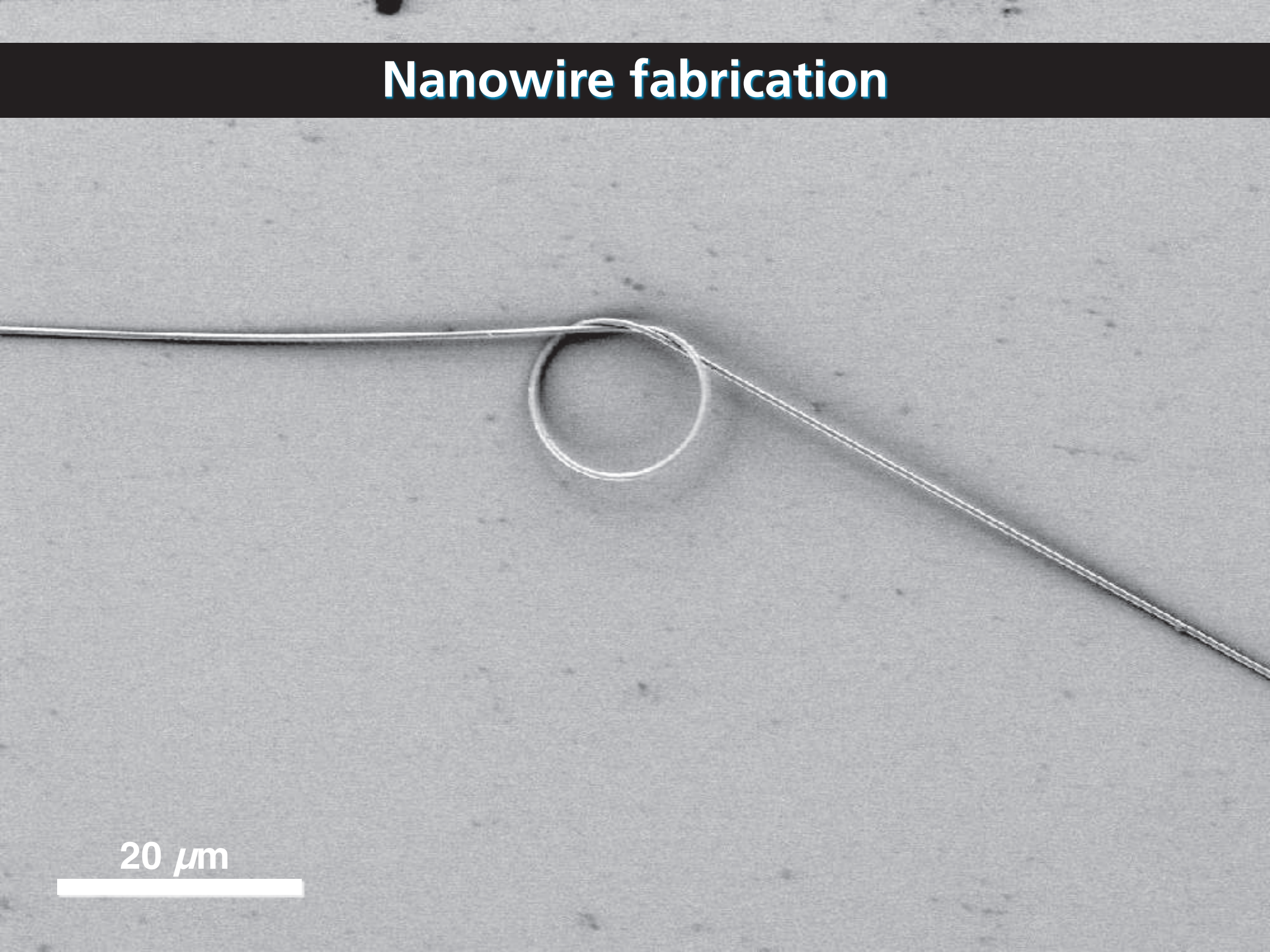


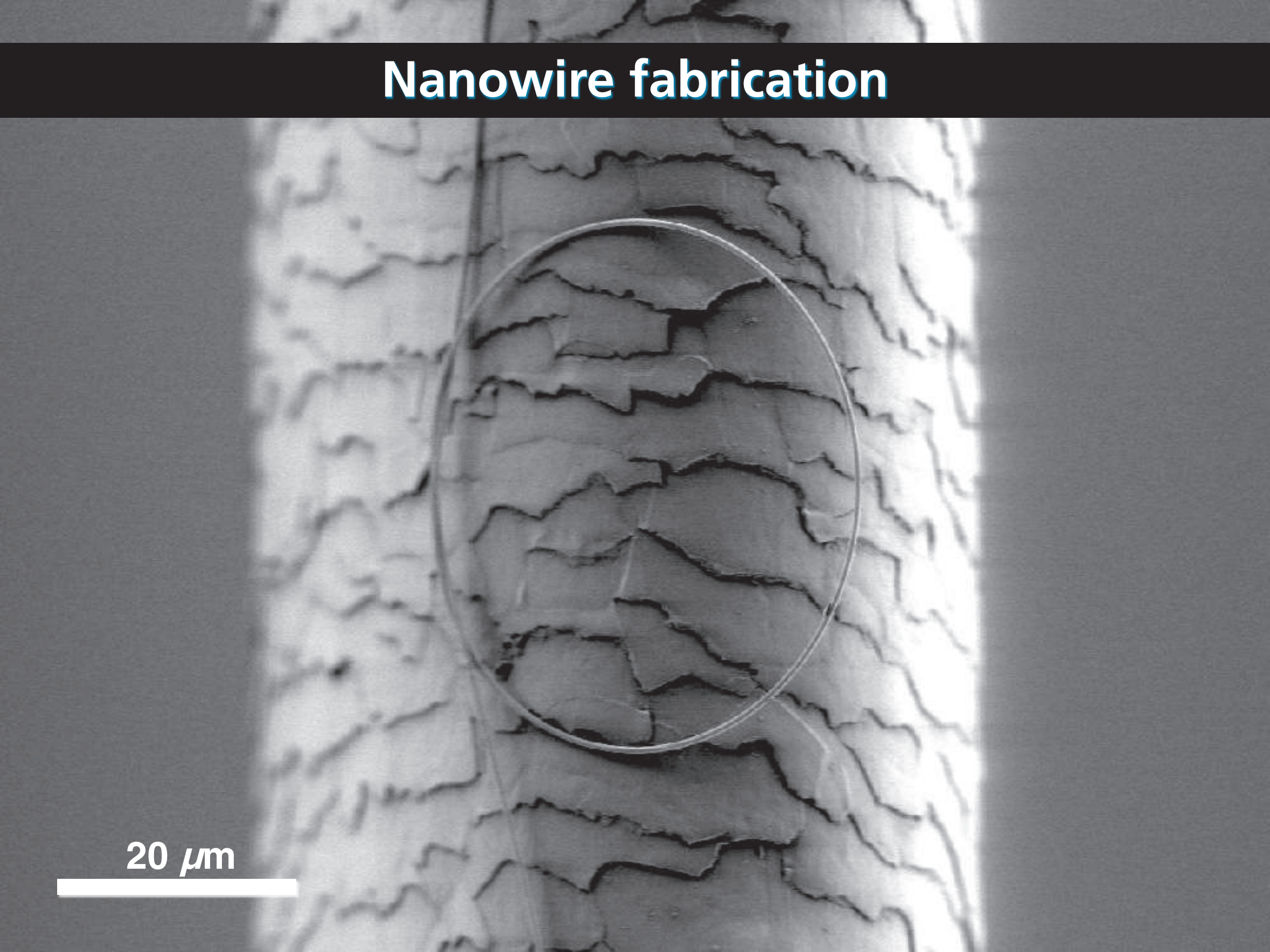
Nanowire fabrication



Nanowire fabrication



Nanowire fabrication

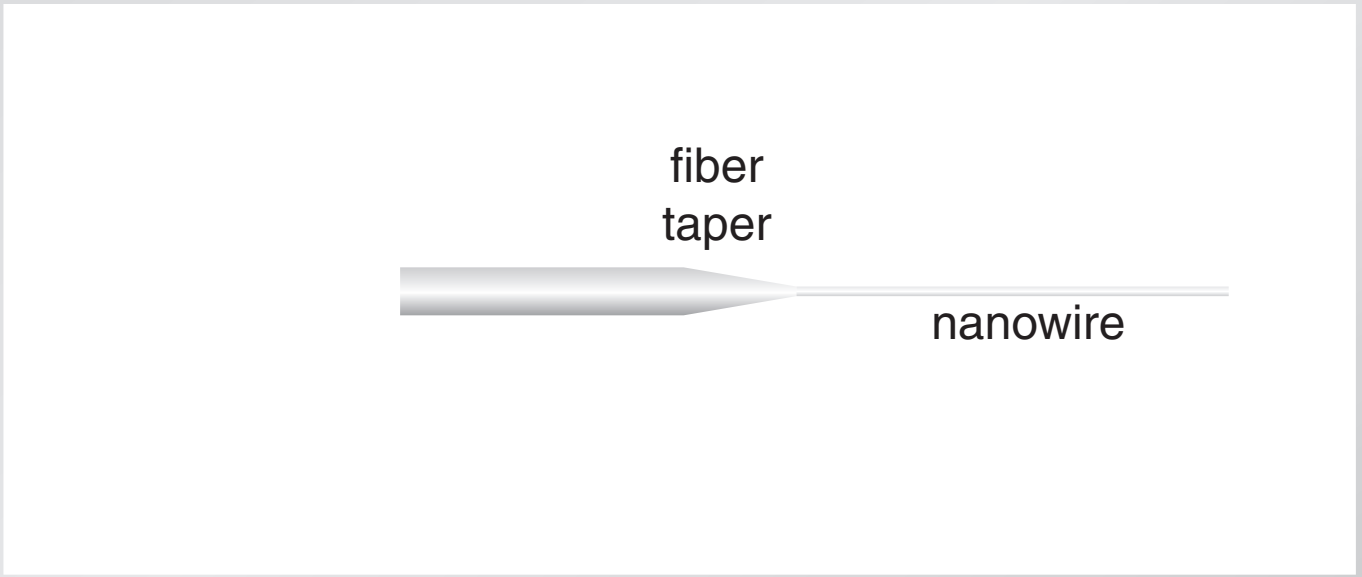


Outline

- waveguiding
- nanowire fabrication
- optical properties

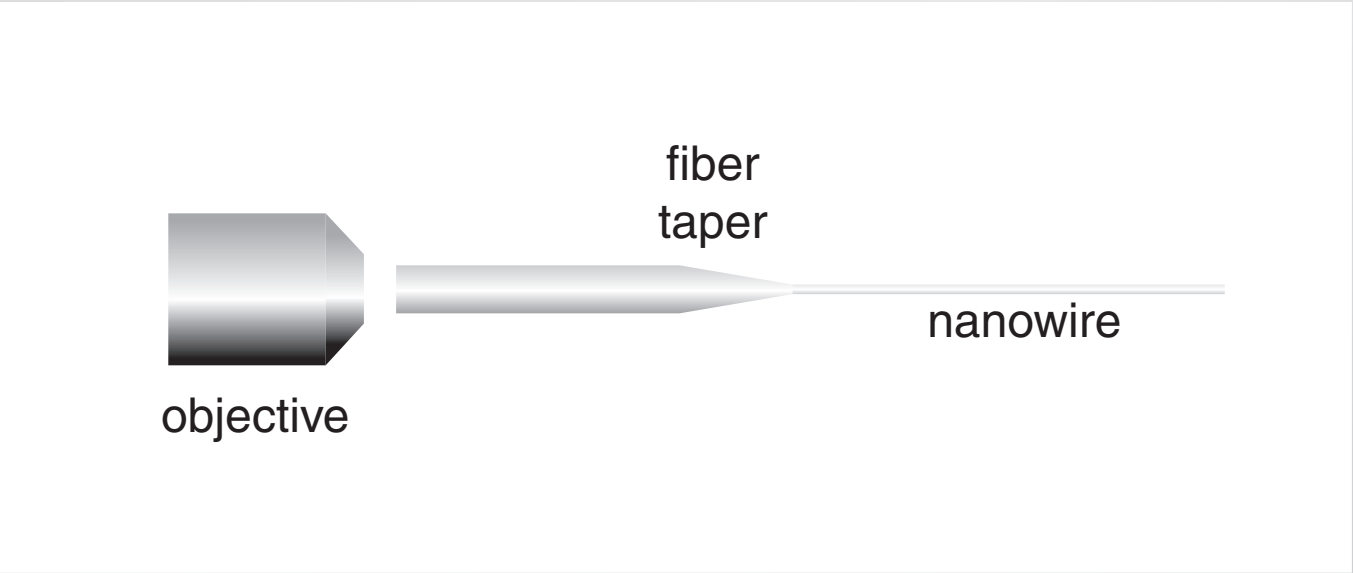
Optical properties

coupling light into nanowires



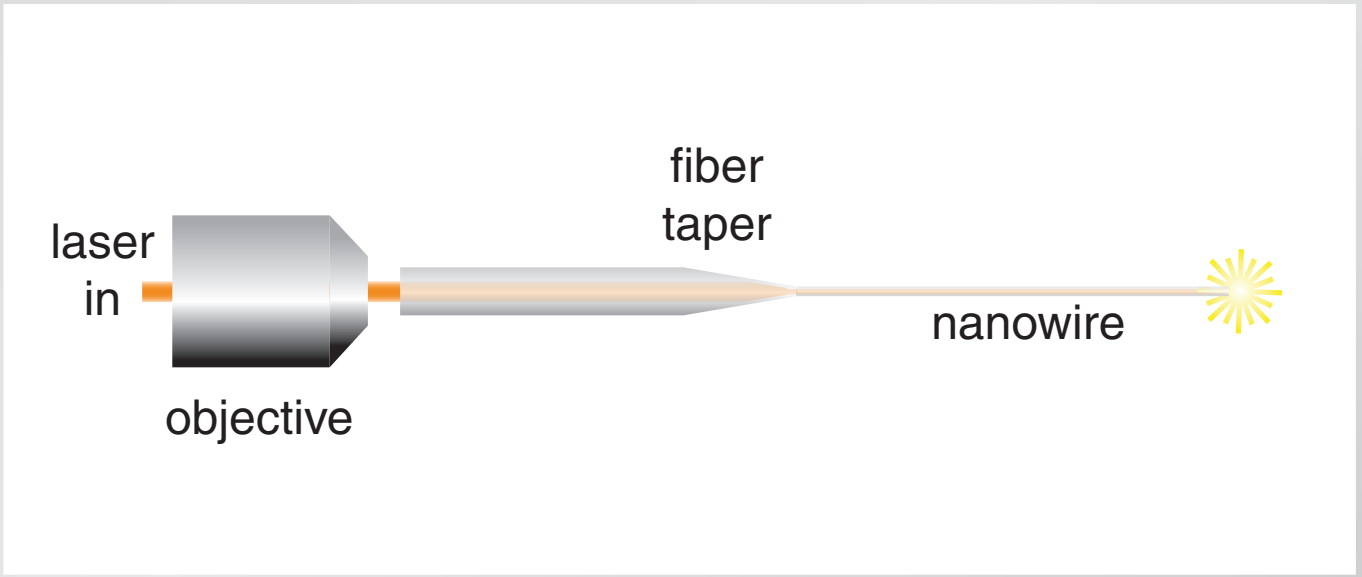
Optical properties

coupling light into nanowires

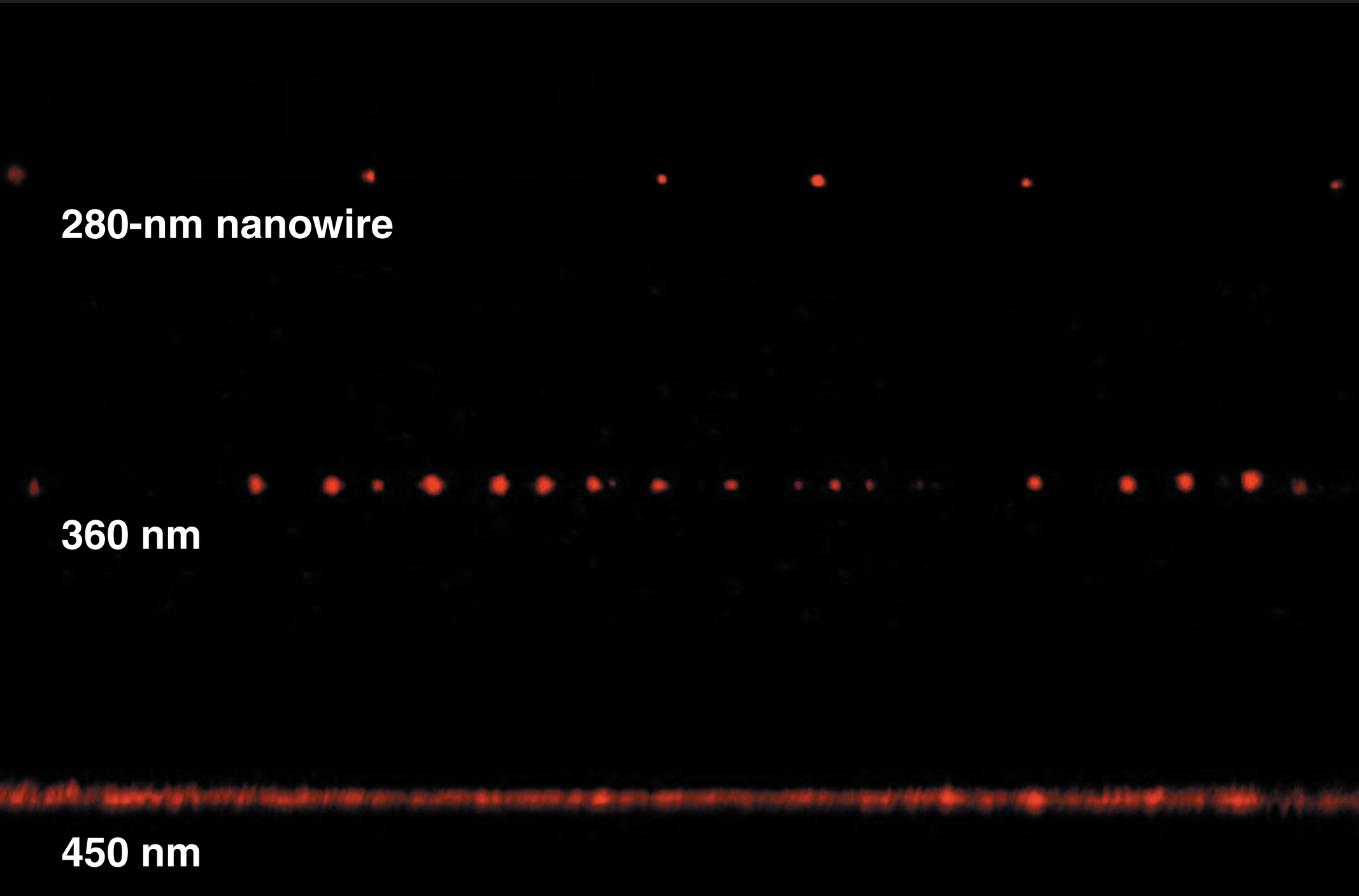


Optical properties

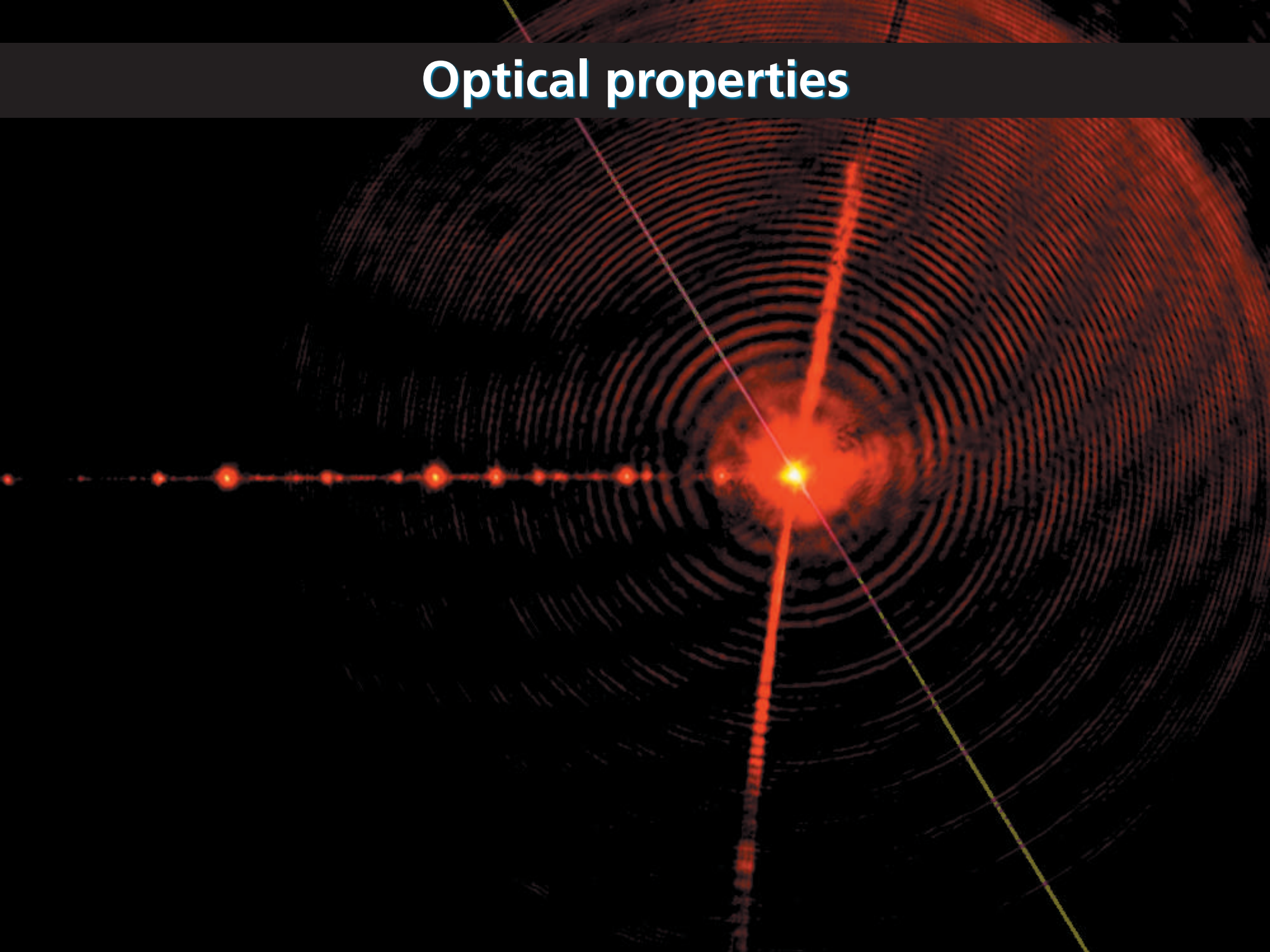
coupling light into nanowires



Optical properties



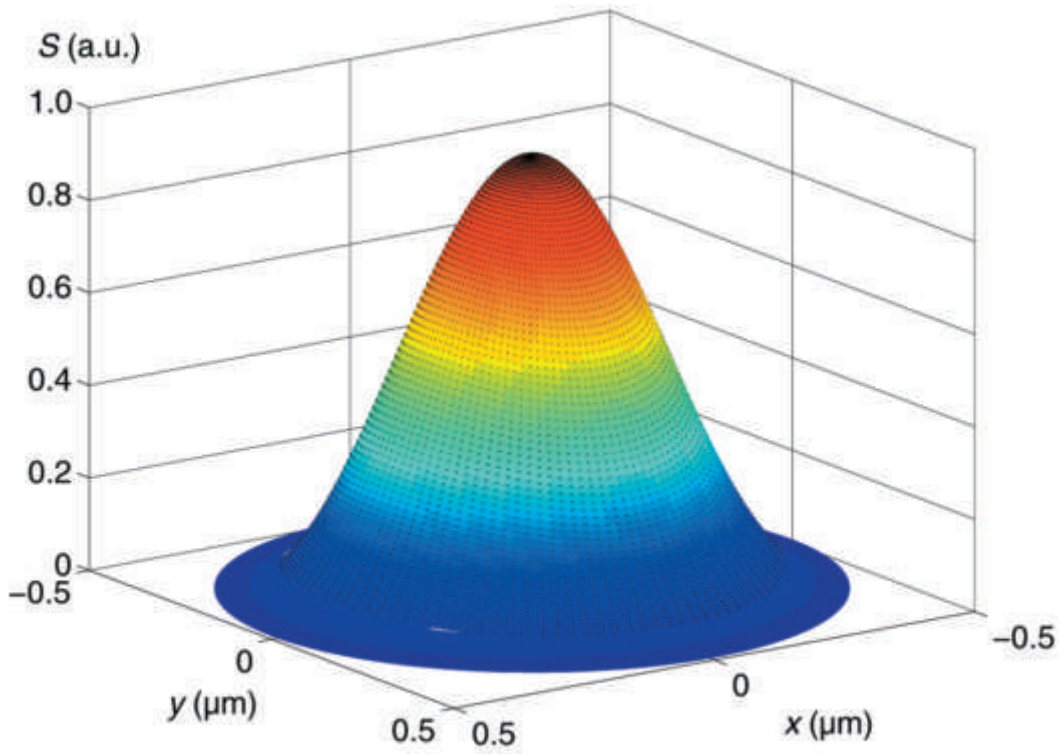
Optical properties



Optical properties

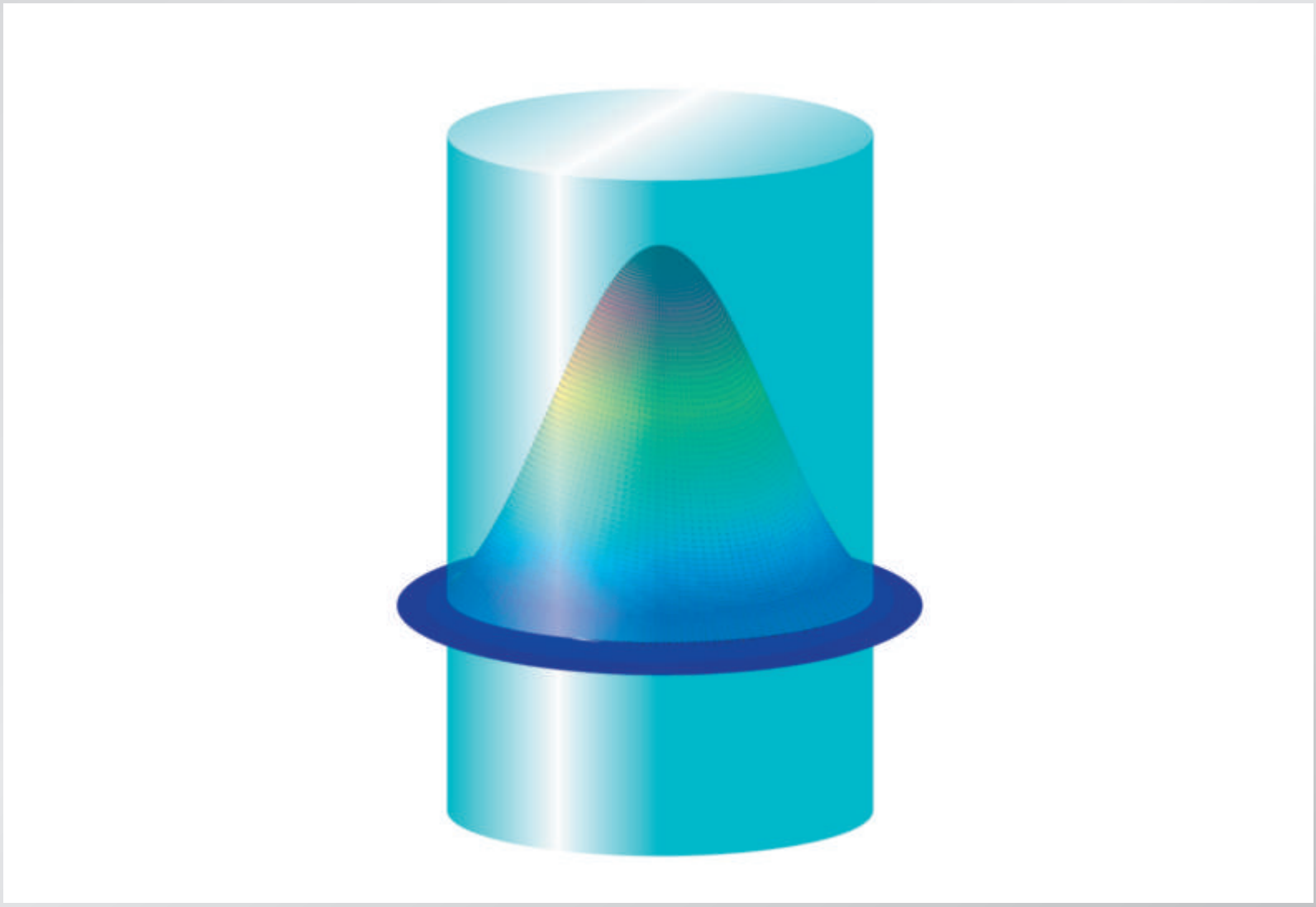
Optical properties

Poynting vector profile for 800-nm nanowire



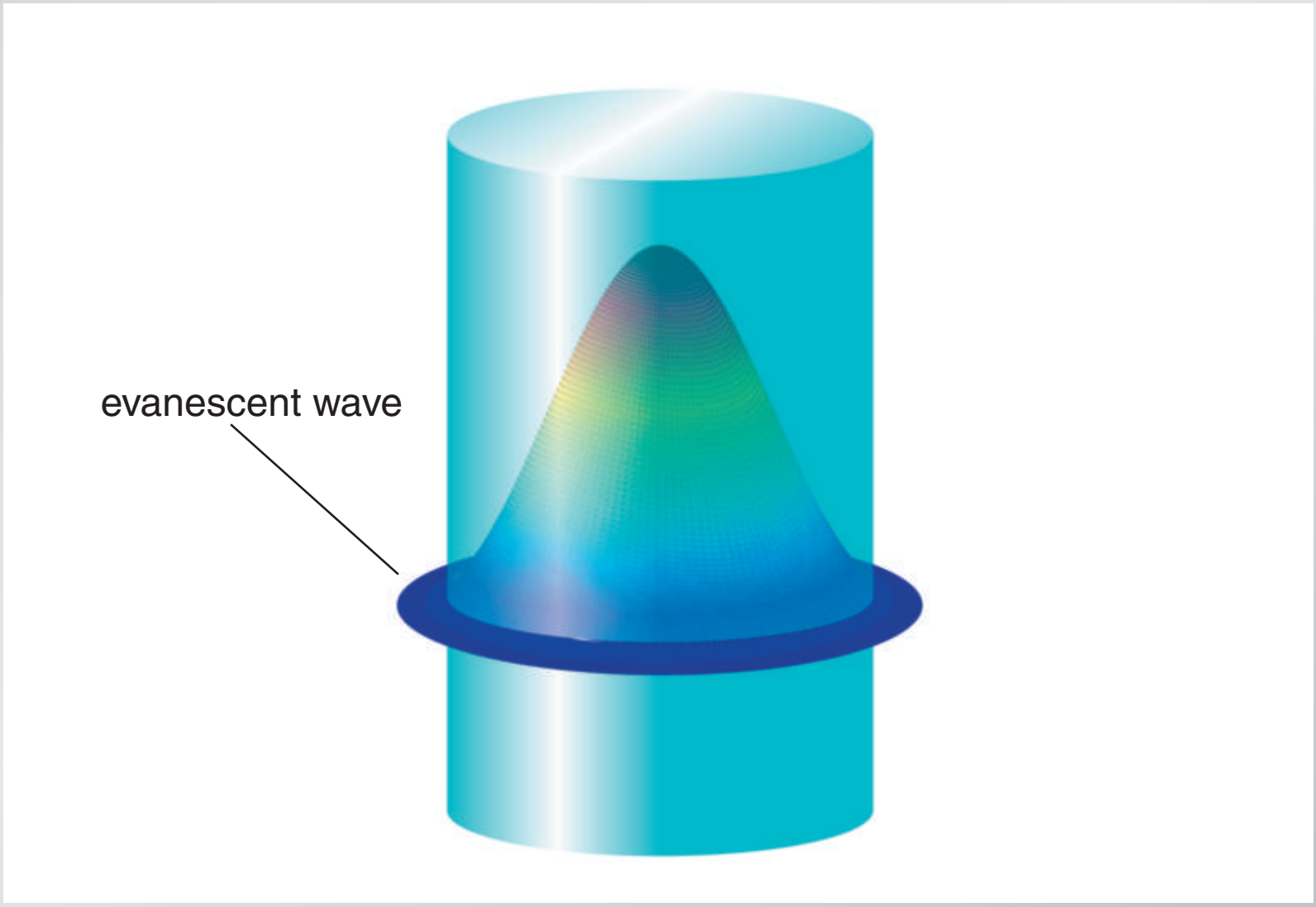
Optical properties

Poynting vector profile for 800-nm nanowire



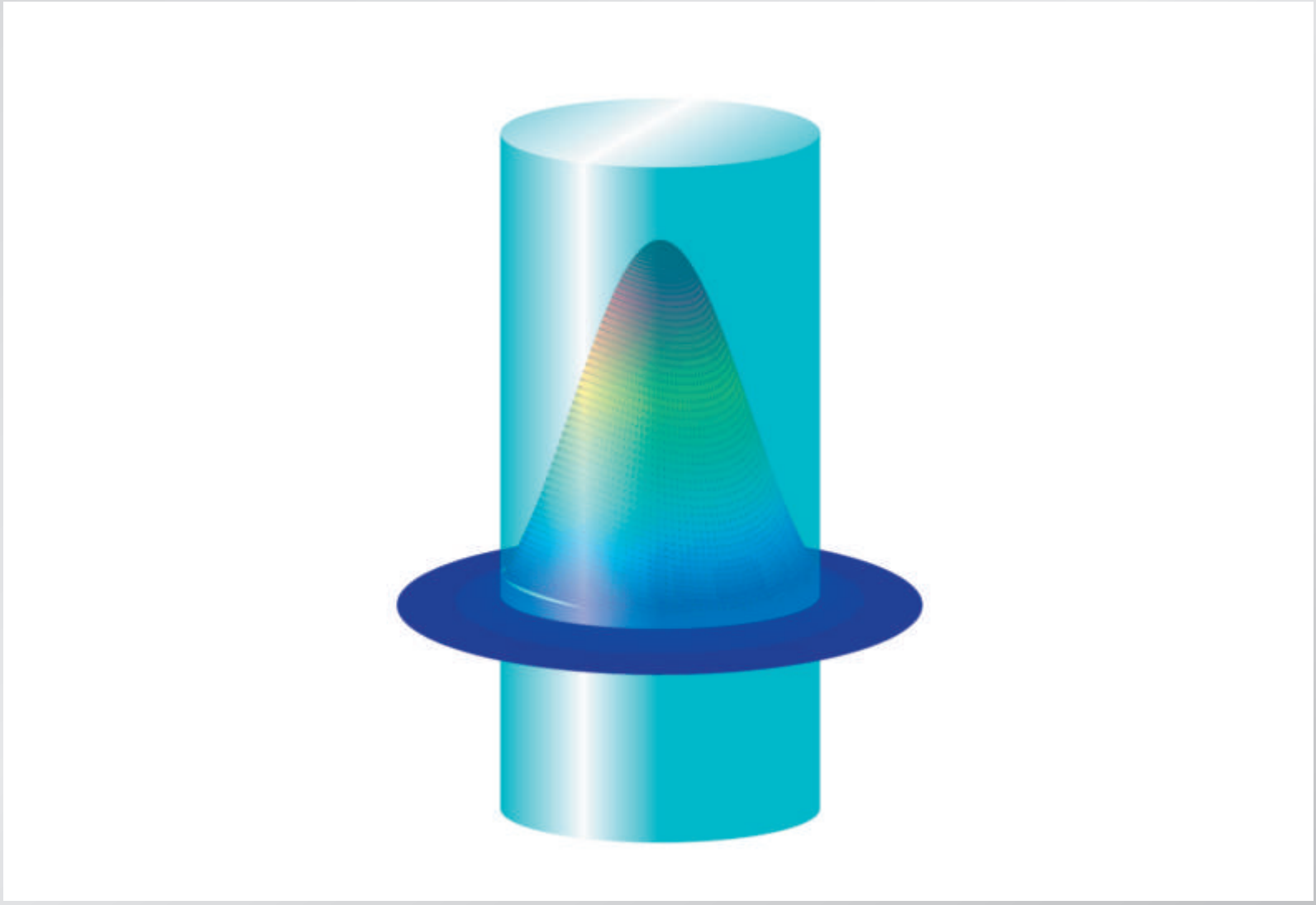
Optical properties

Poynting vector profile for 800-nm nanowire



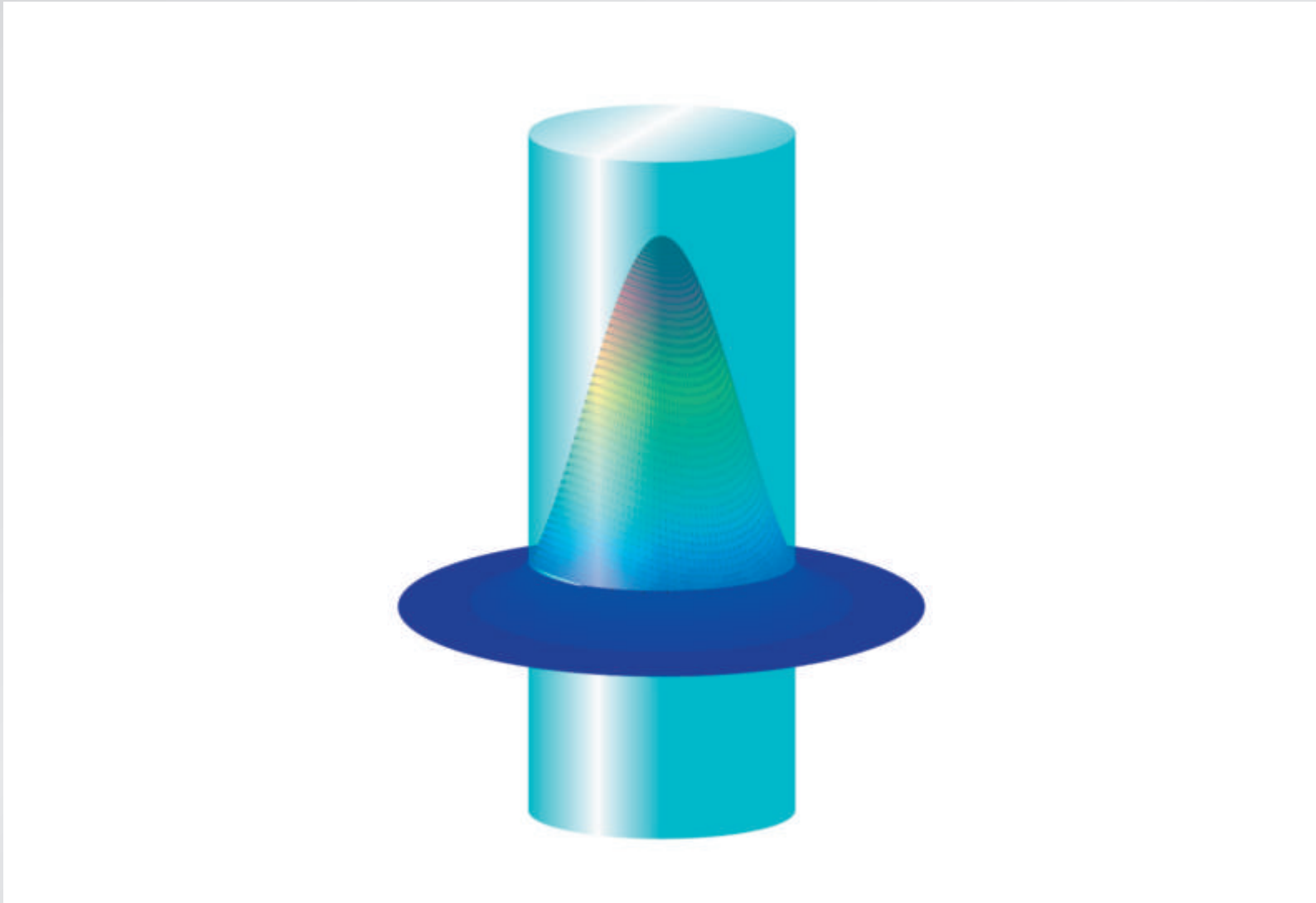
Optical properties

Poynting vector profile for 600-nm nanowire



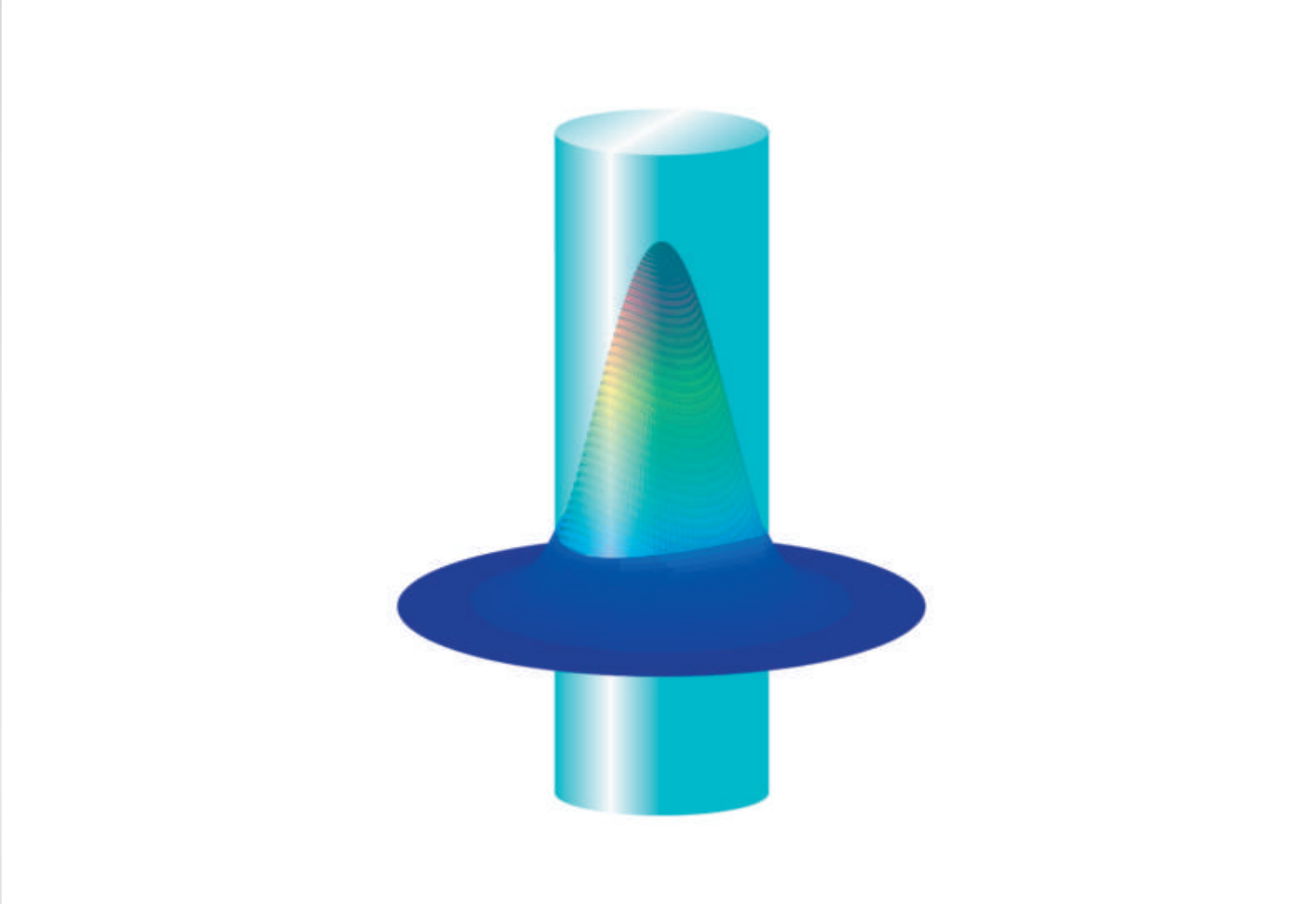
Optical properties

Poynting vector profile for 500-nm nanowire



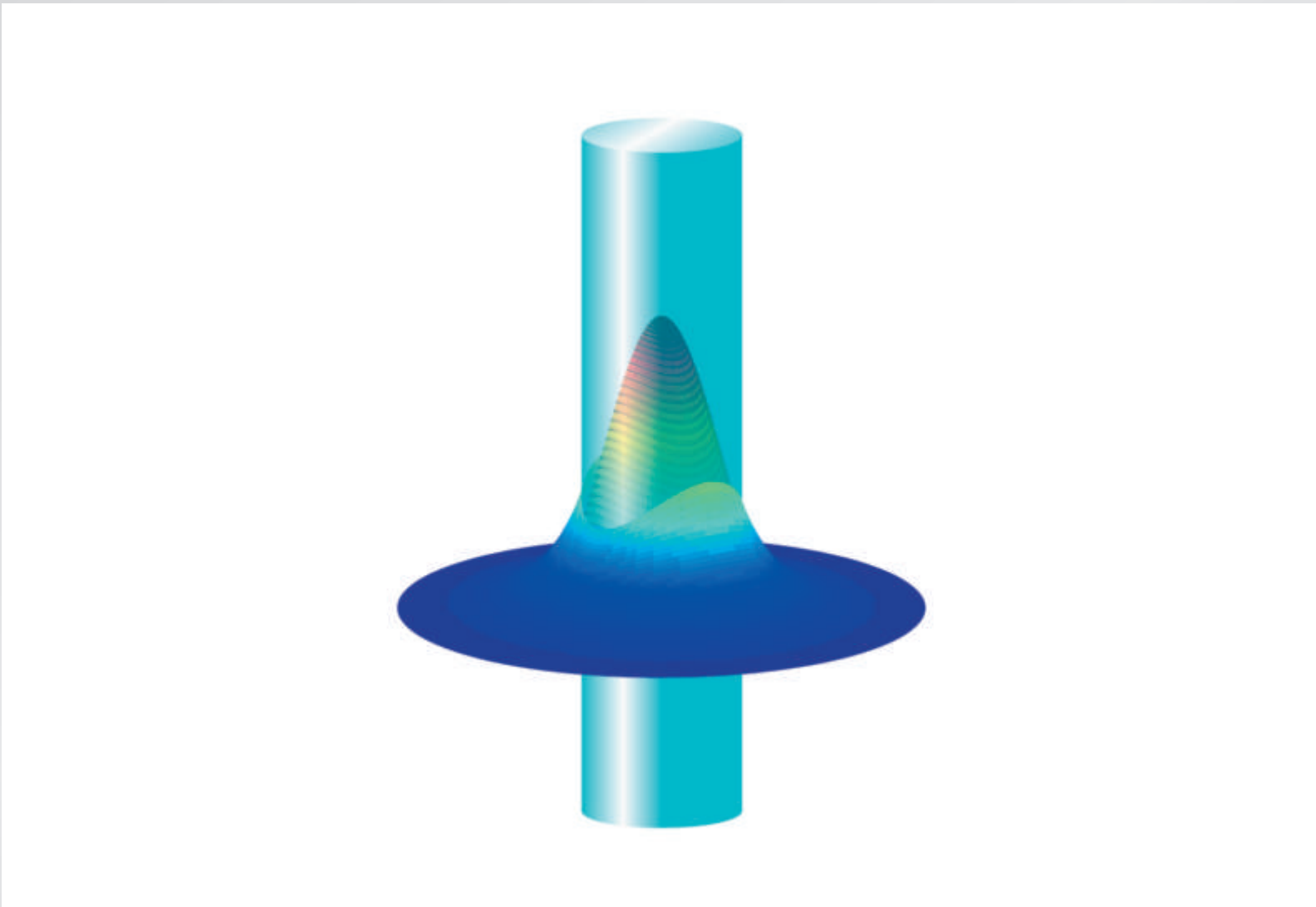
Optical properties

Poynting vector profile for 400-nm nanowire



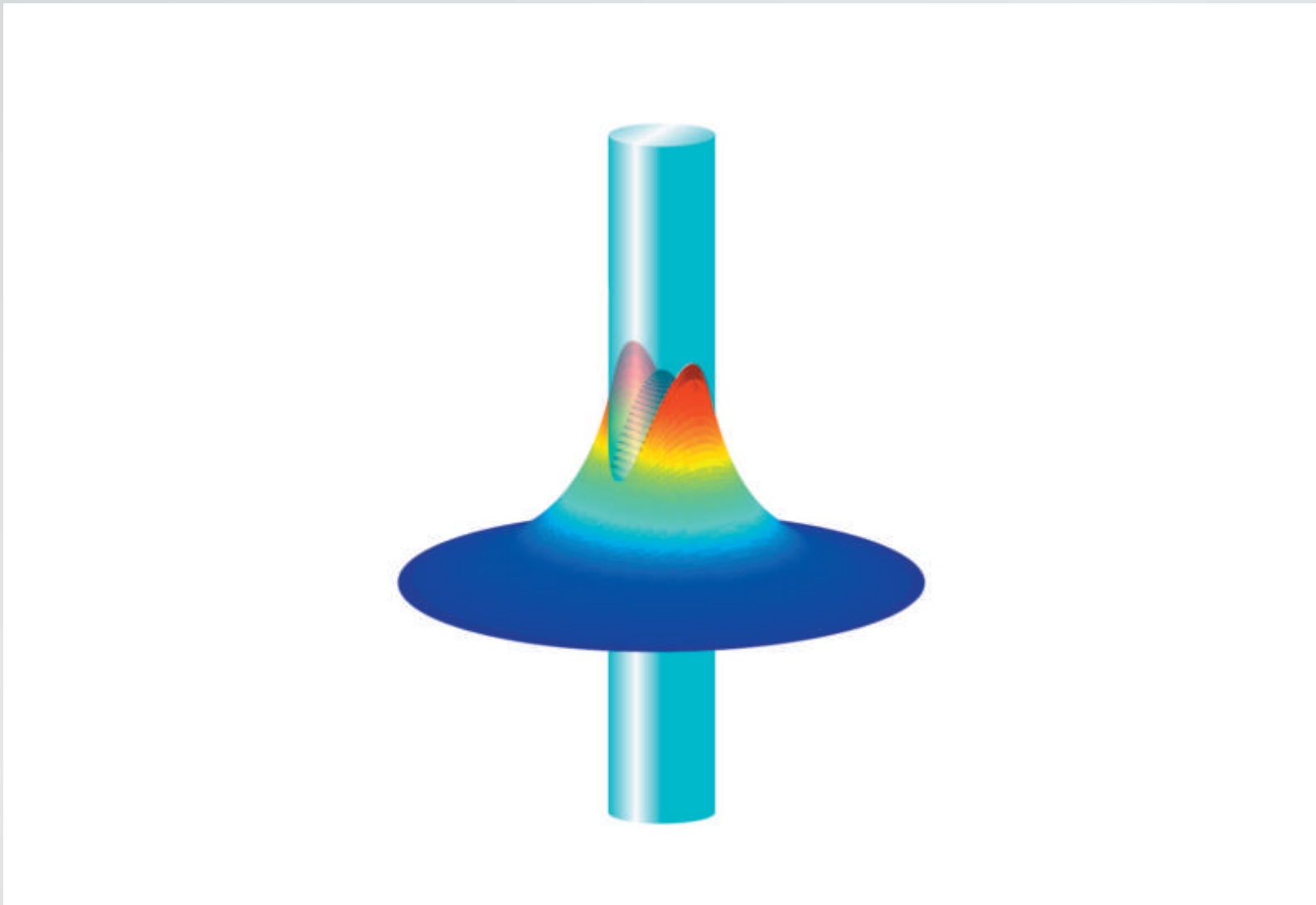
Optical properties

Poynting vector profile for 300-nm nanowire



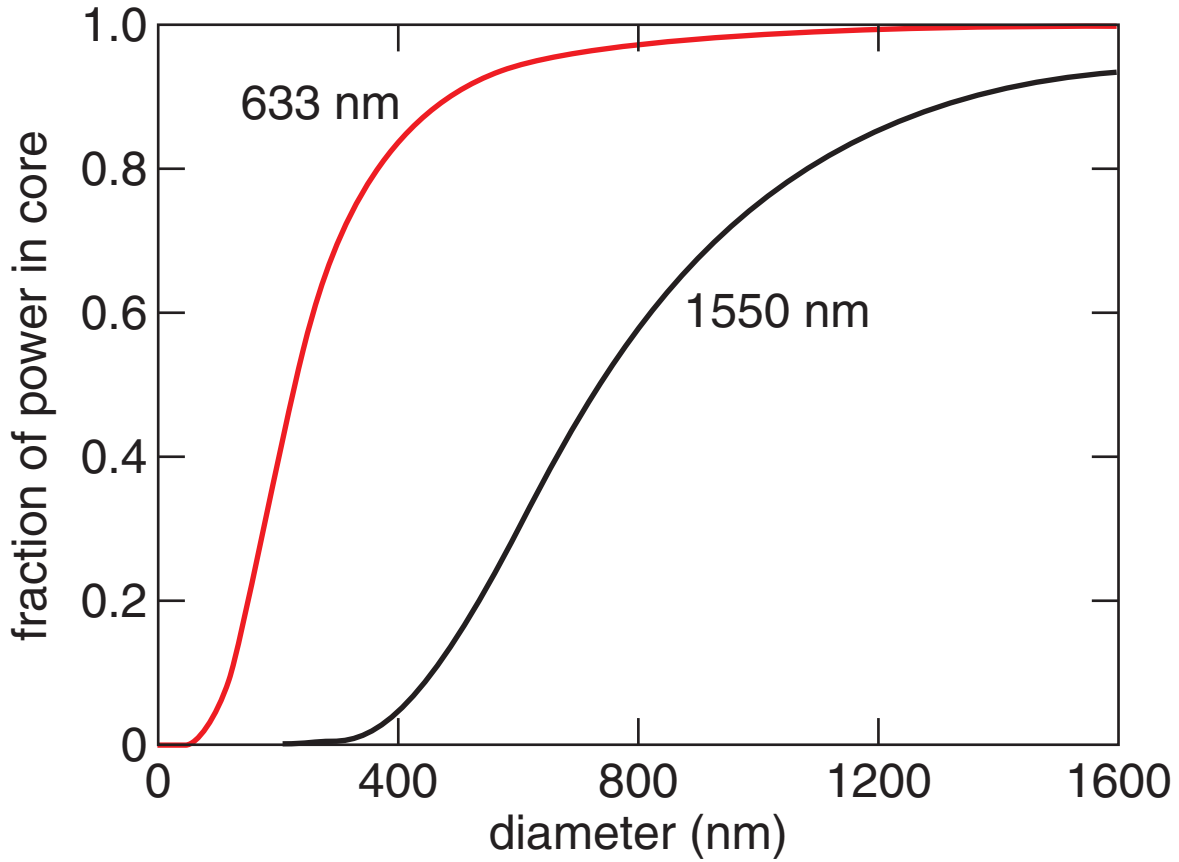
Optical properties

Poynting vector profile for 200-nm nanowire

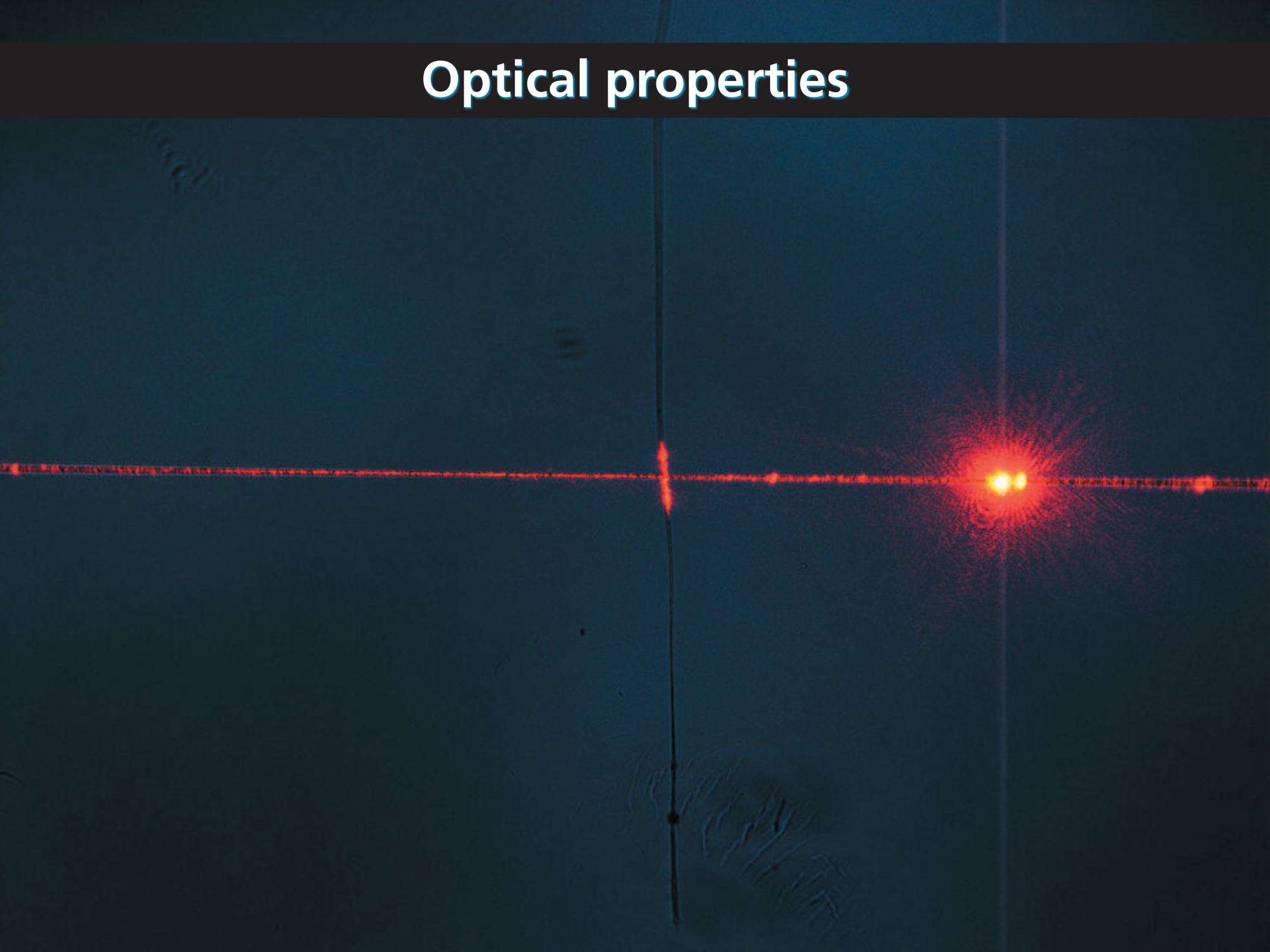


Waveguiding

fraction of power carried in core

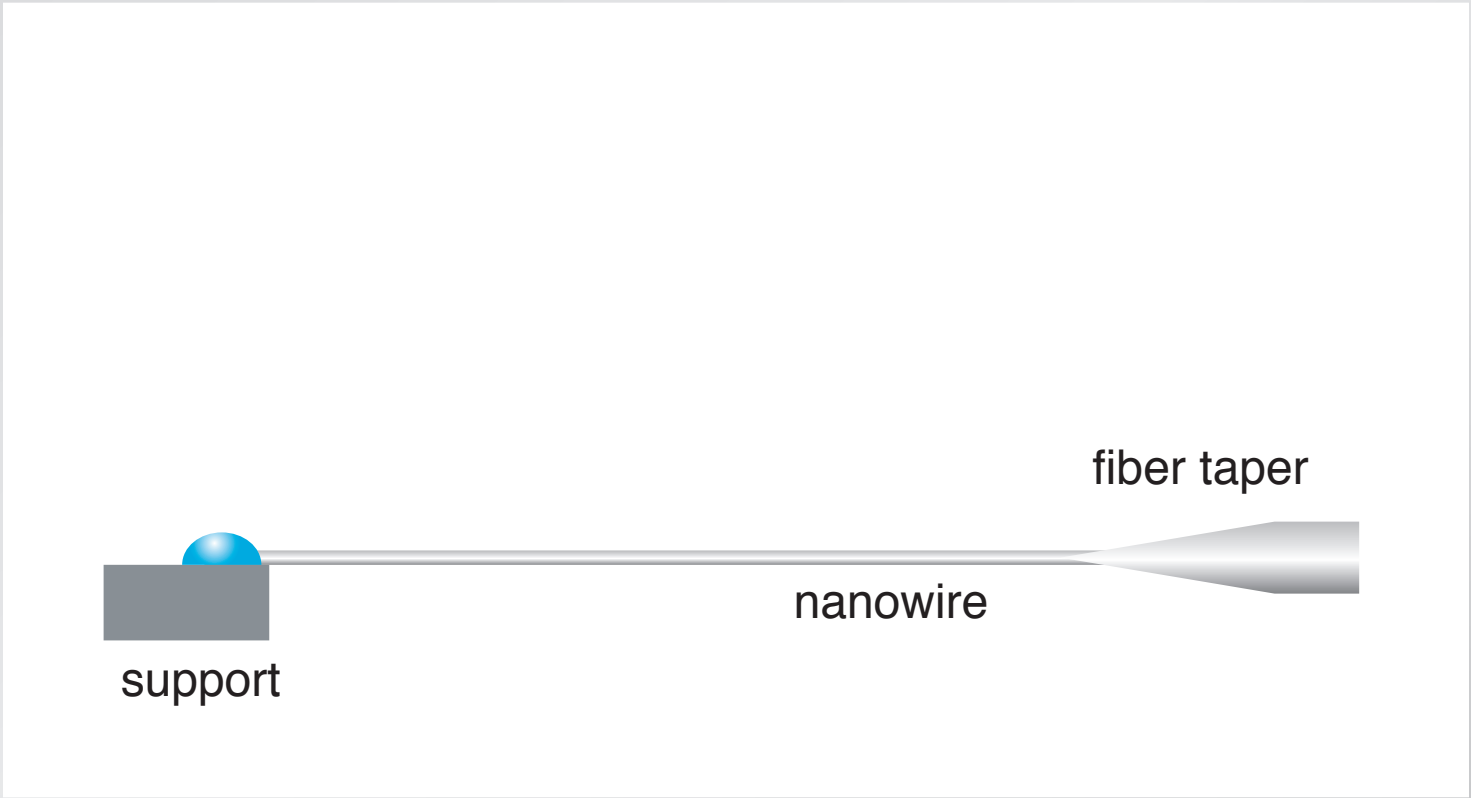


Optical properties



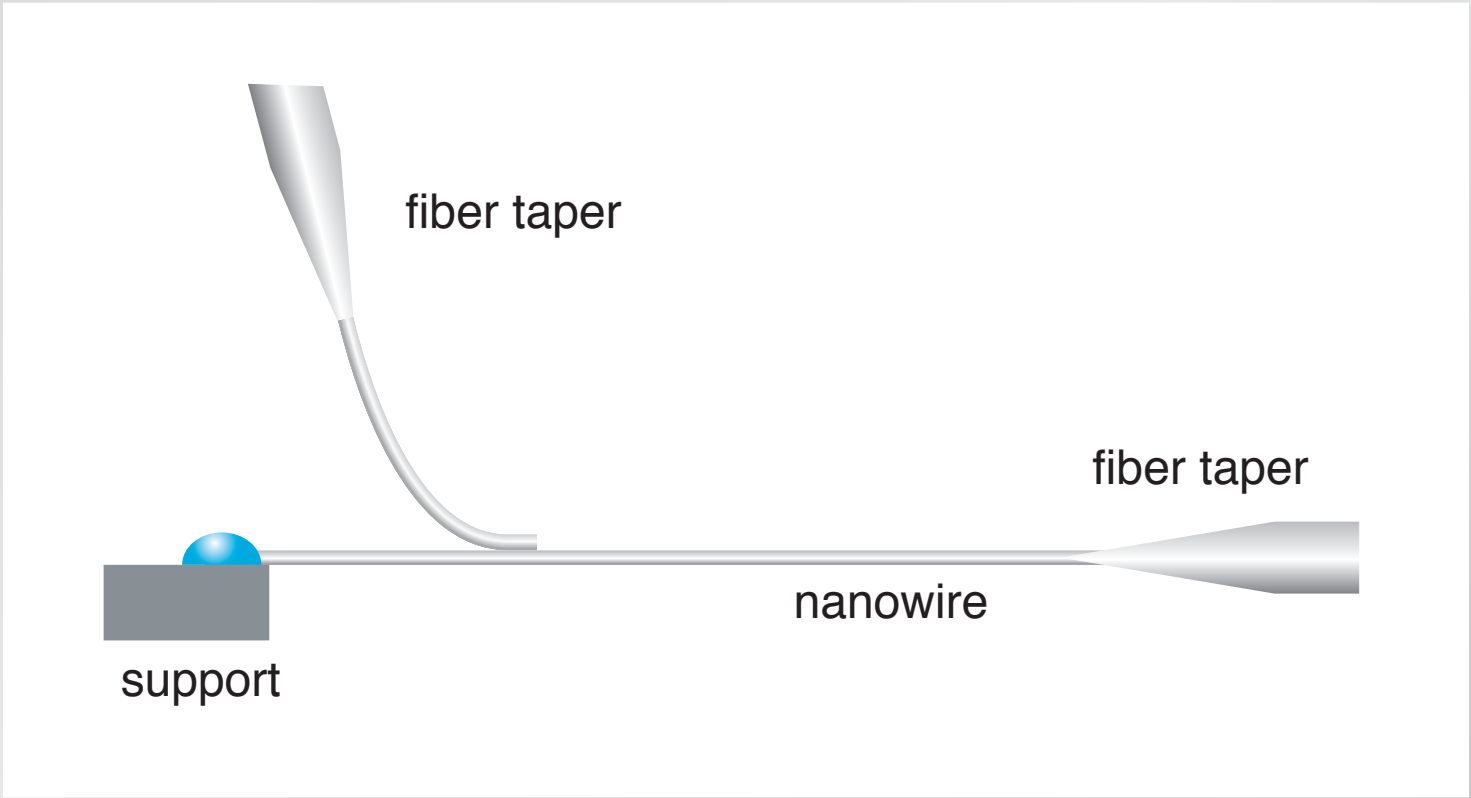
Optical properties

coupling light between nanowires



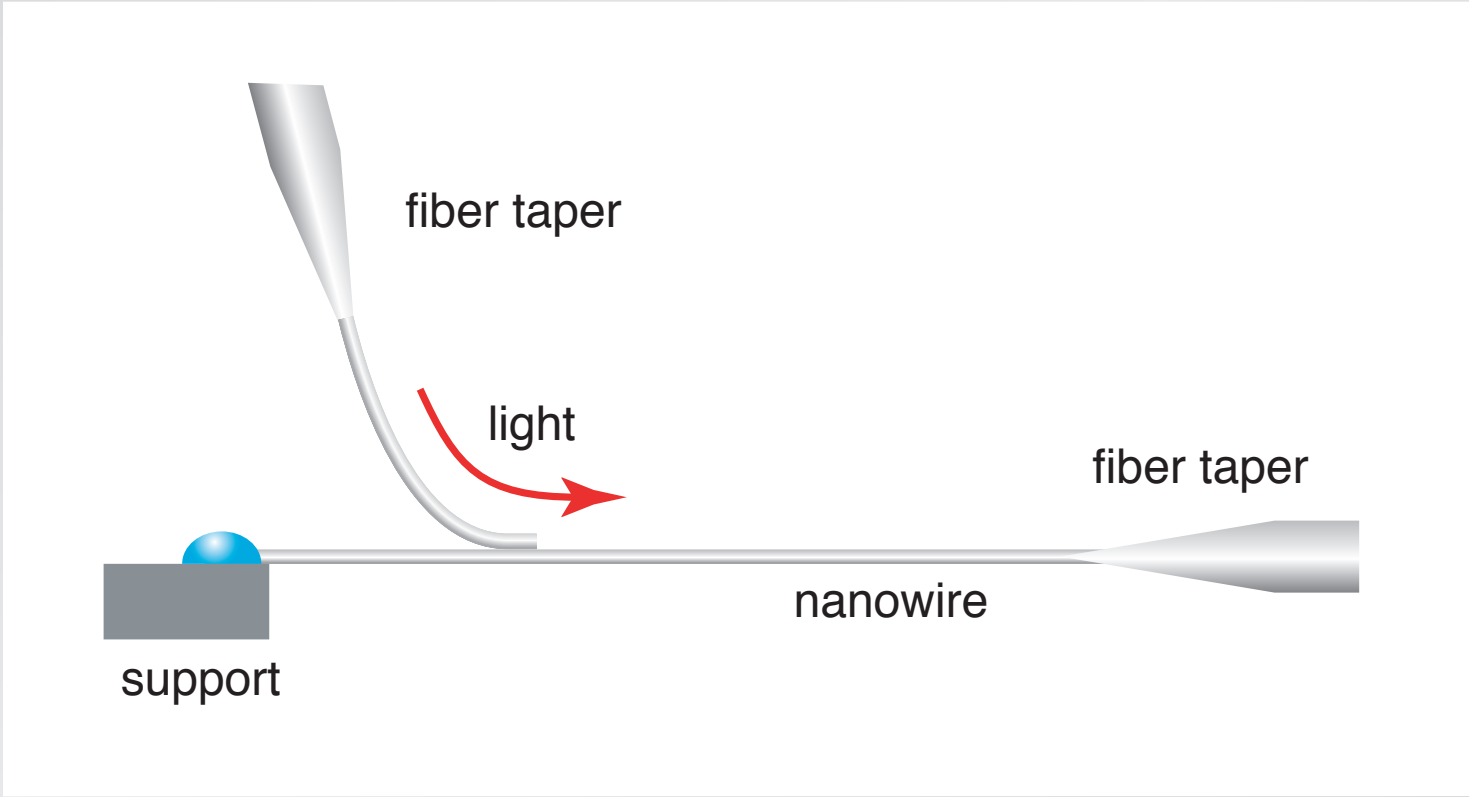
Optical properties

coupling light between nanowires



Optical properties

coupling light between nanowires



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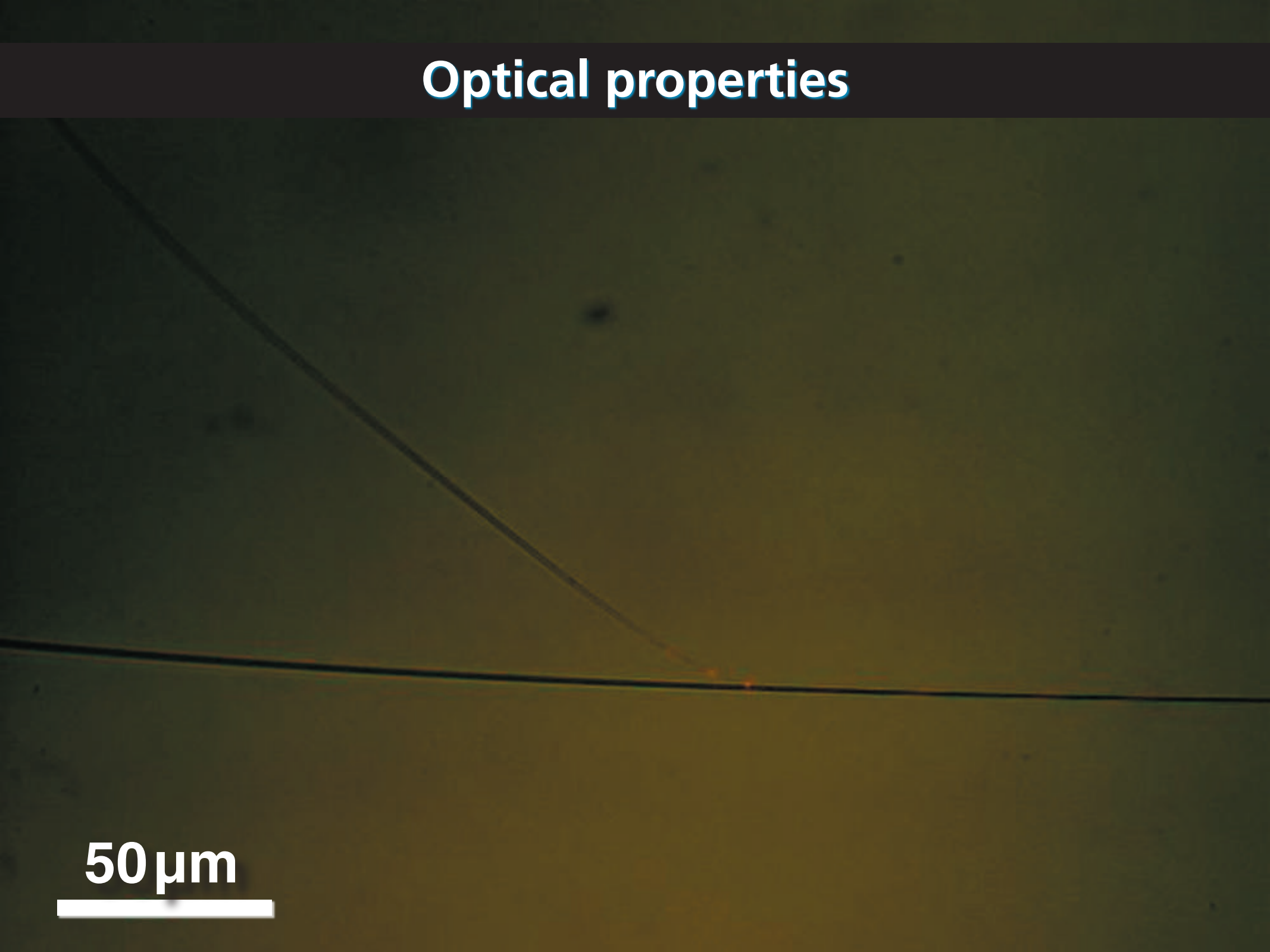
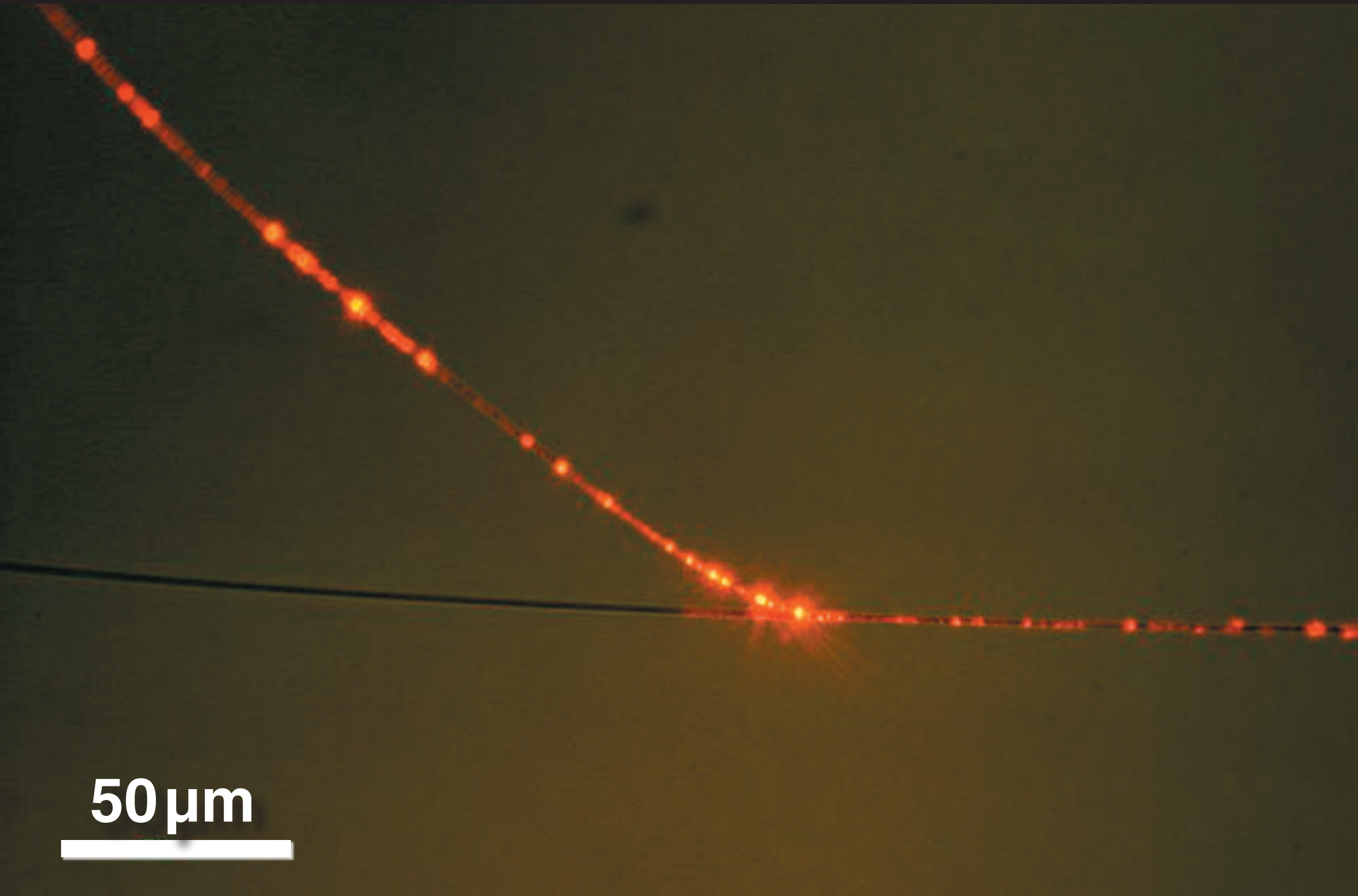
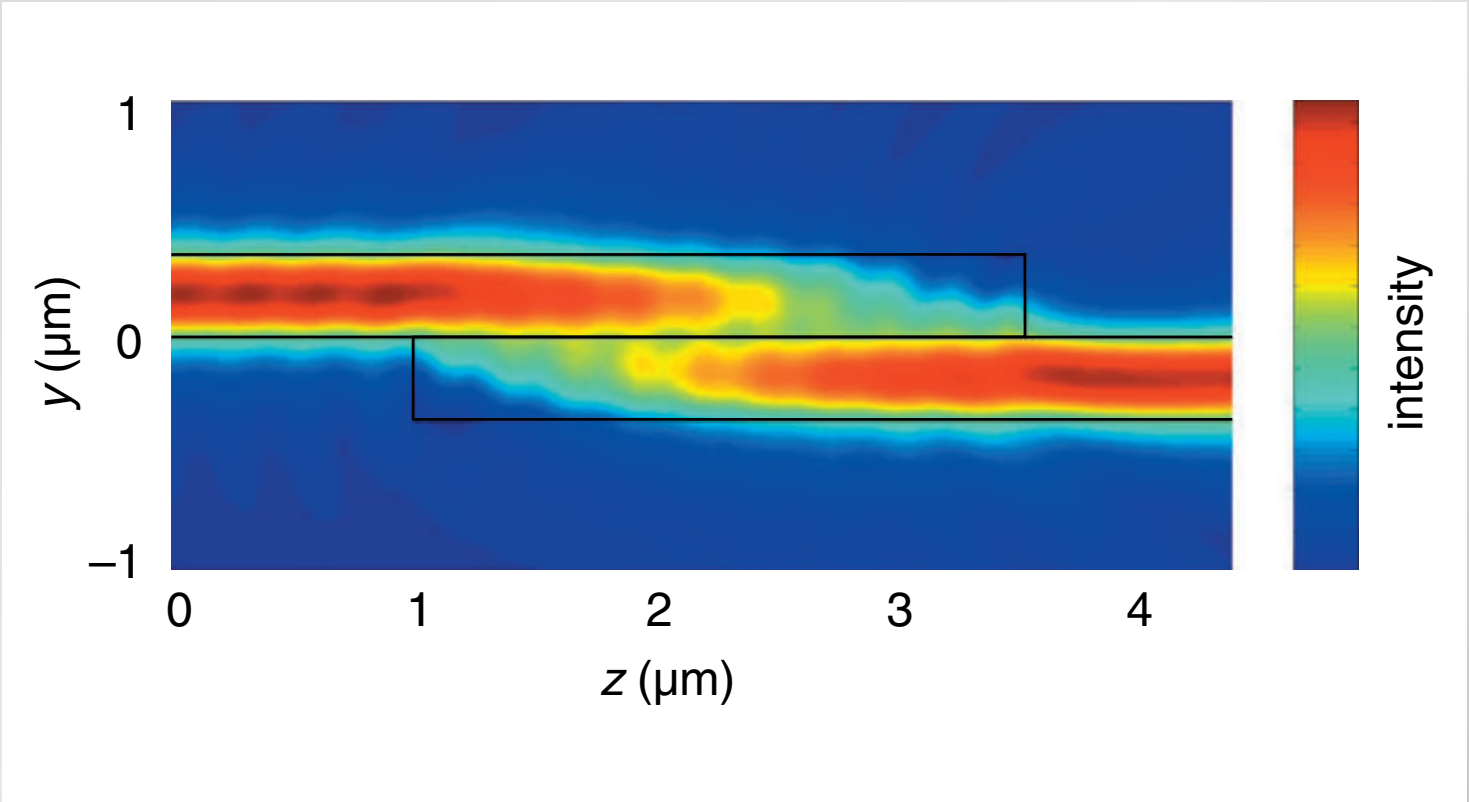


Optical properties



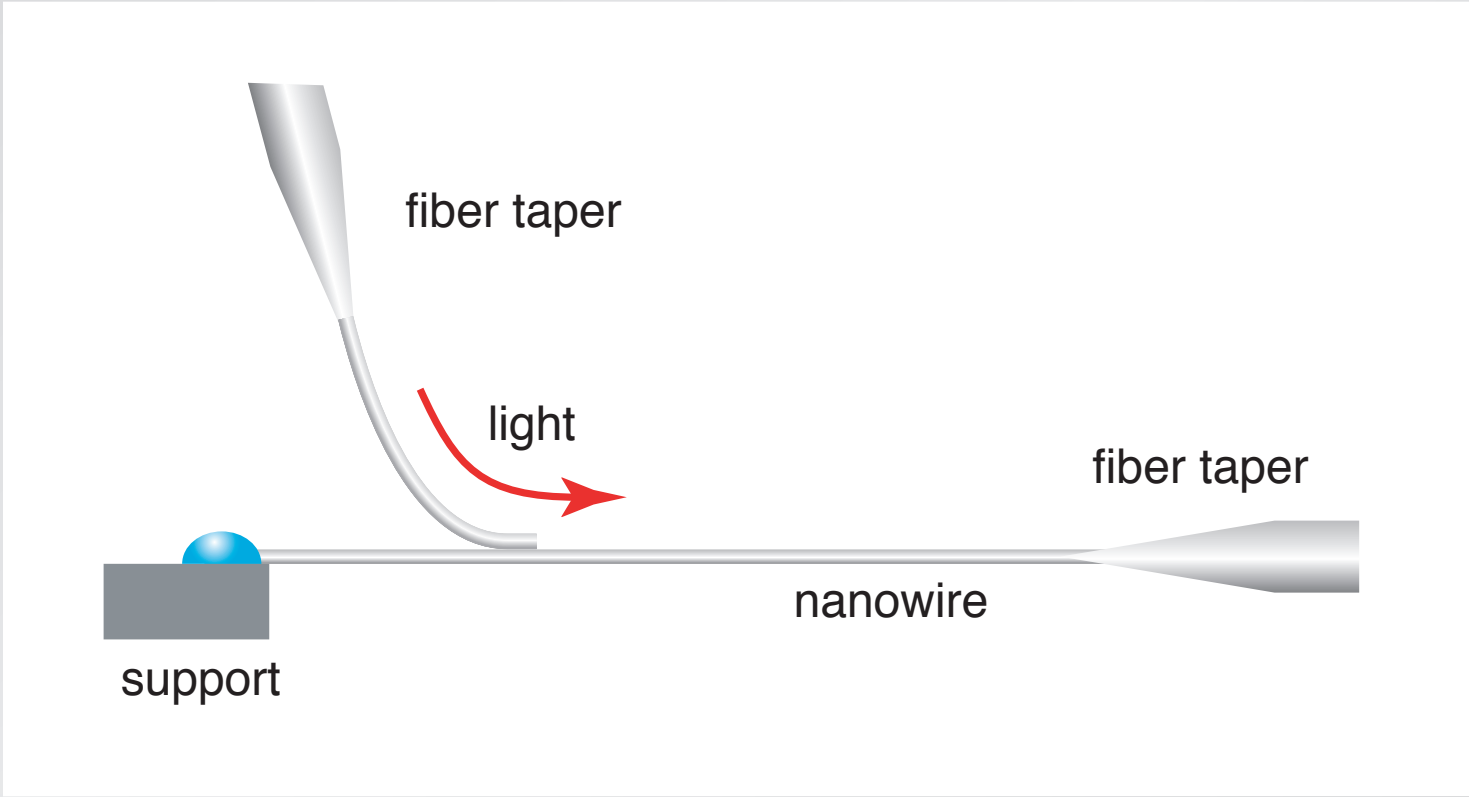
Optical properties

intensity distribution



Optical properties

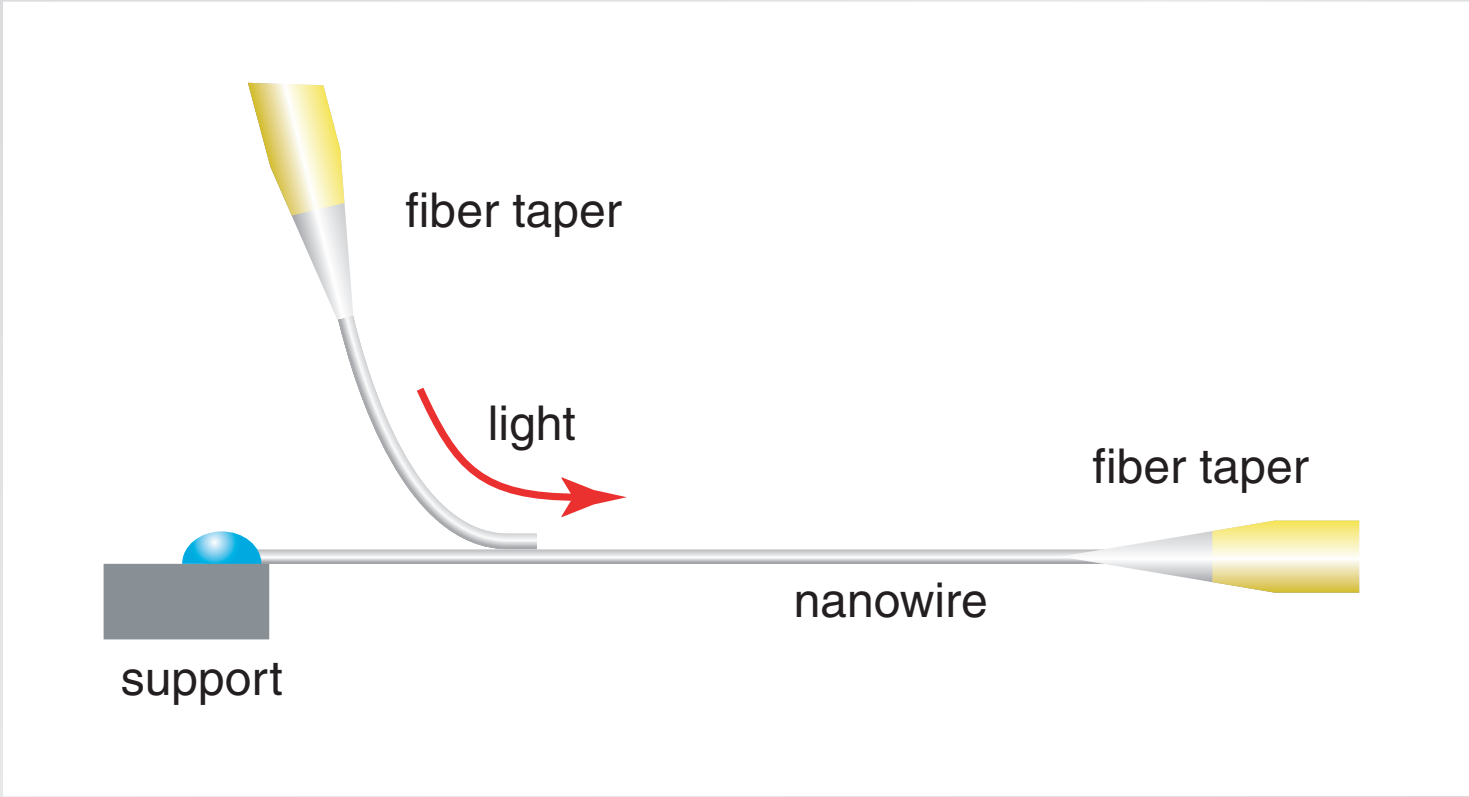
loss measurement



Nature, 426, 816 (2003)

Optical properties

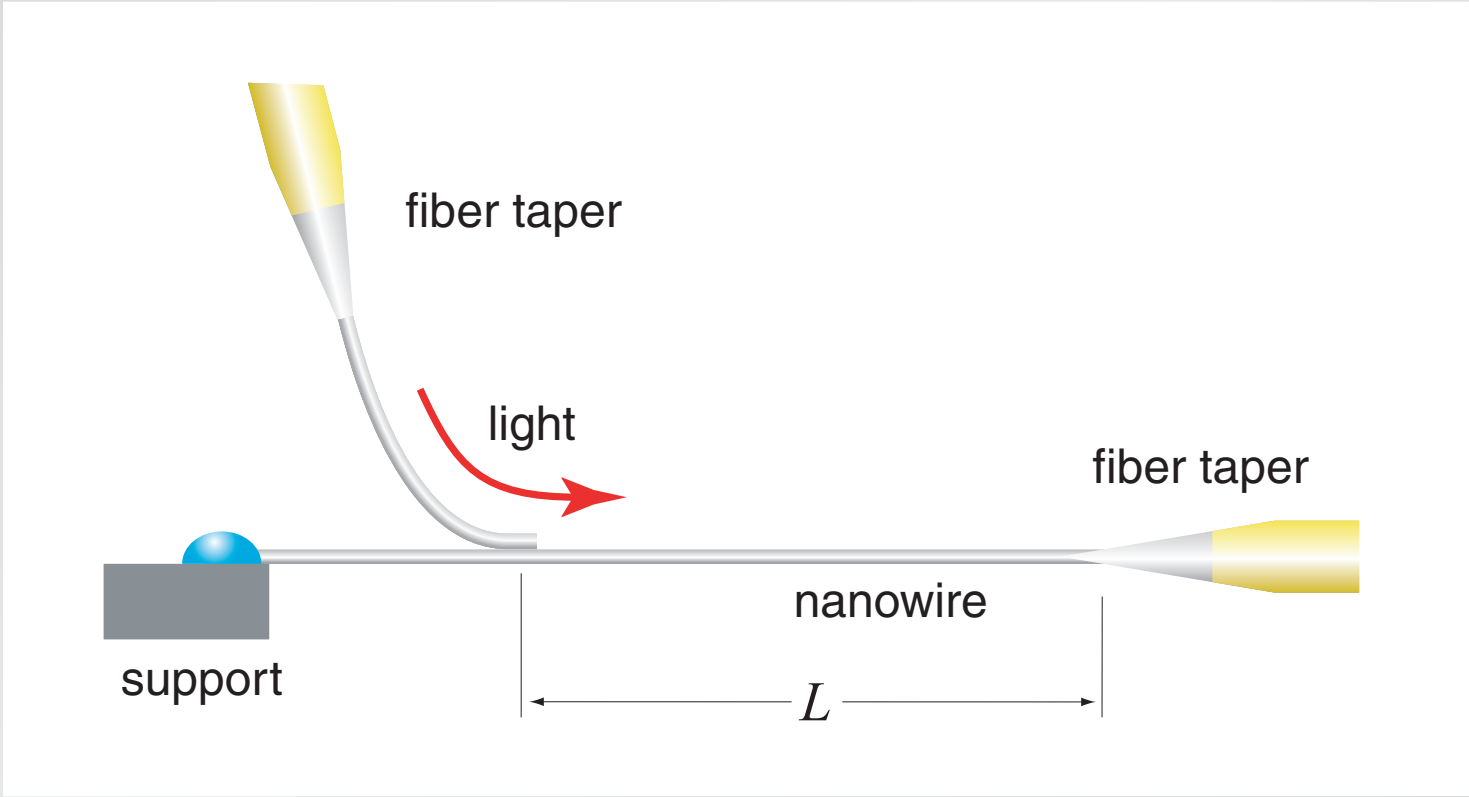
loss measurement



Nature, 426, 816 (2003)

Optical properties

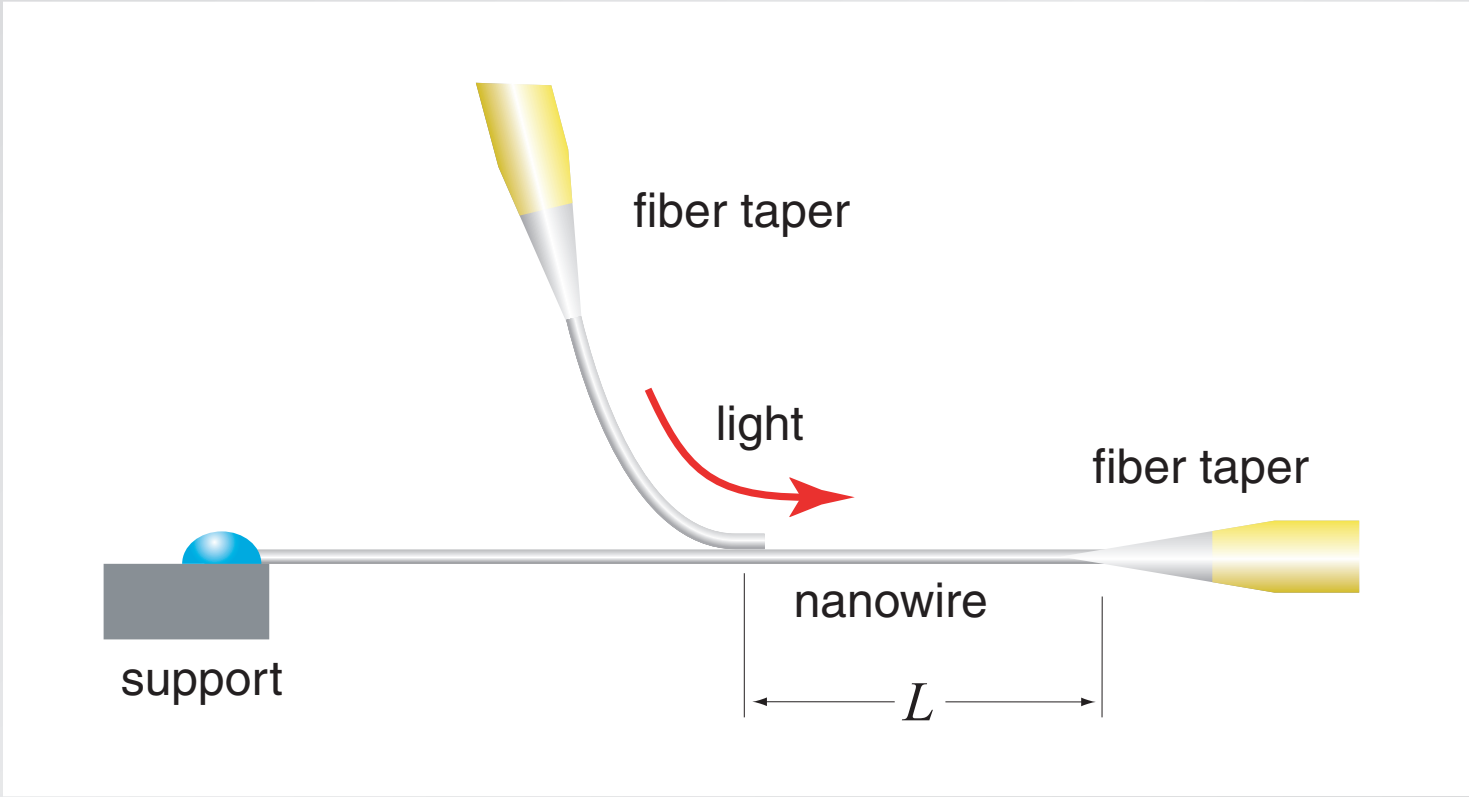
loss measurement



Nature, 426, 816 (2003)

Optical properties

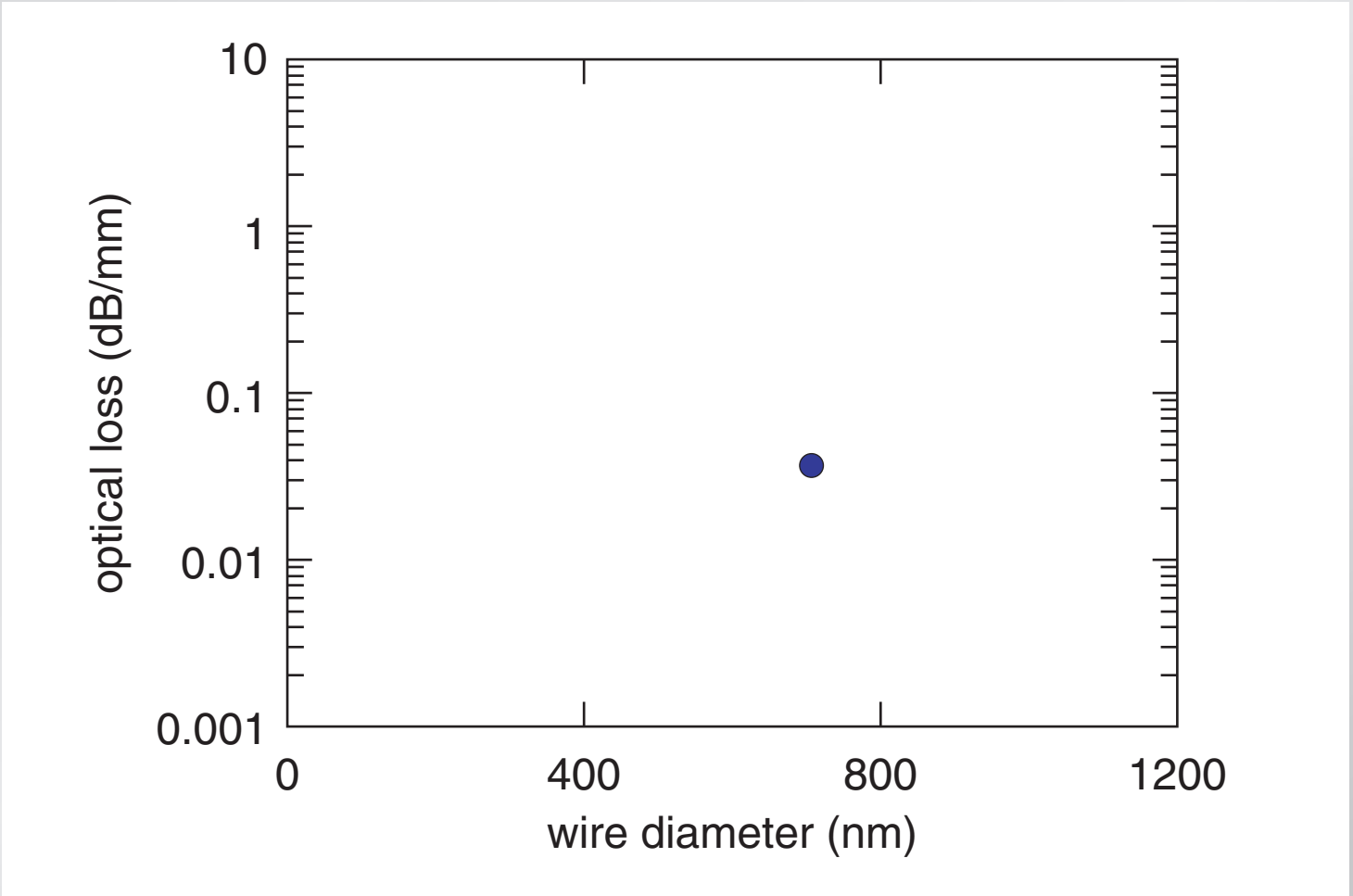
loss measurement



Nature, 426, 816 (2003)

Optical properties

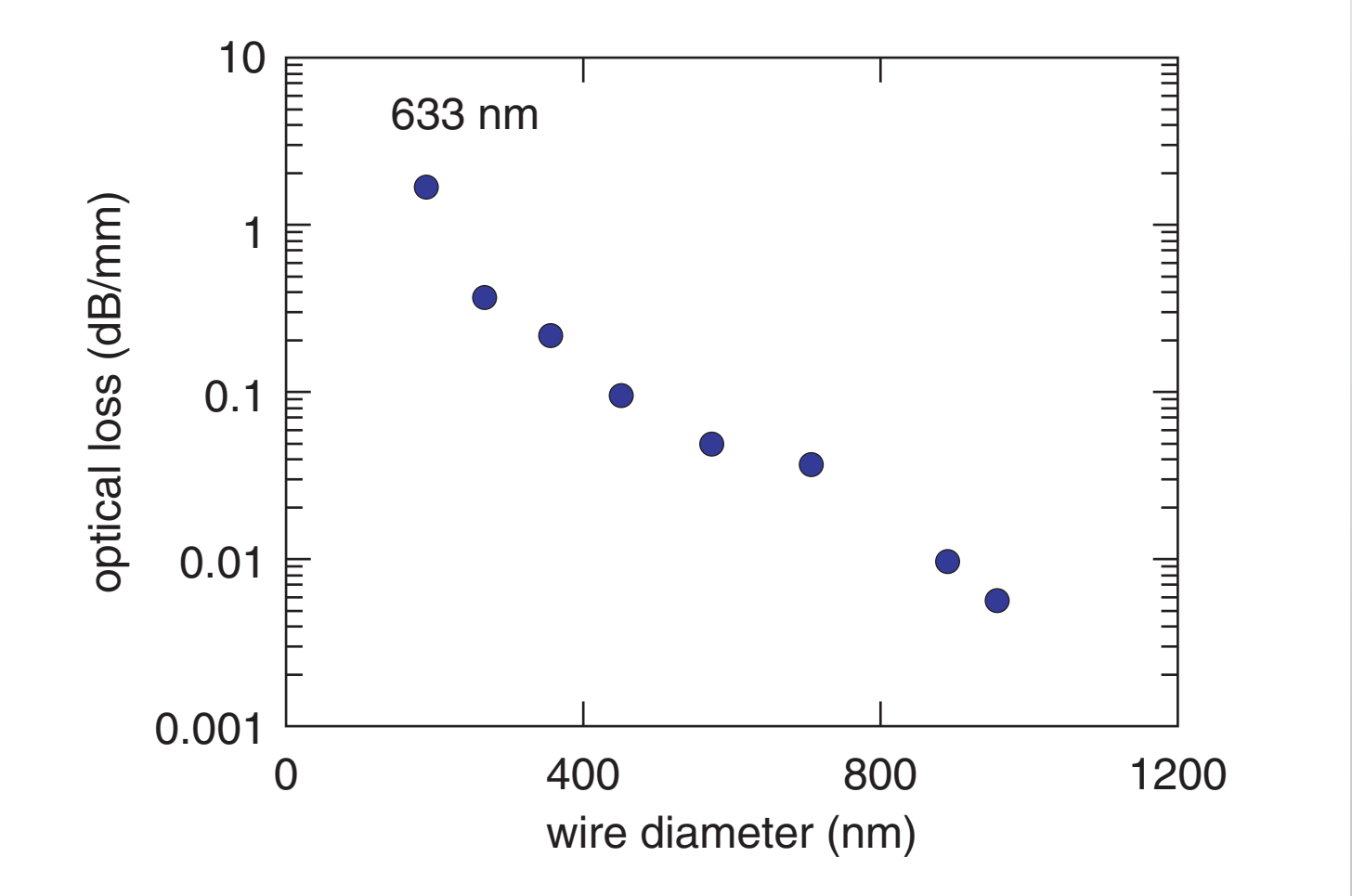
loss measurement



Nature, 426, 816 (2003)

Optical properties

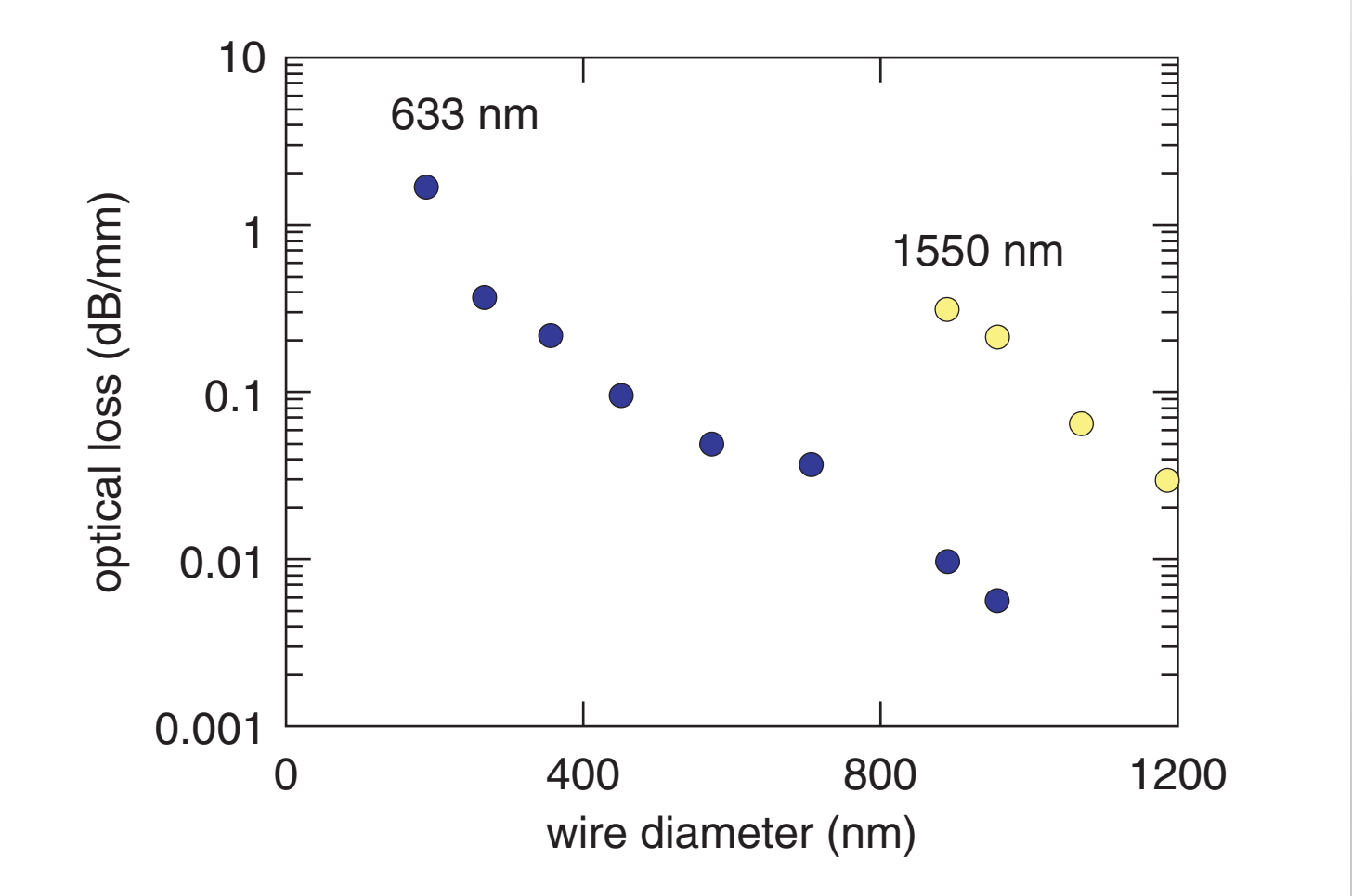
loss measurement



Nature, 426, 816 (2003)

Optical properties

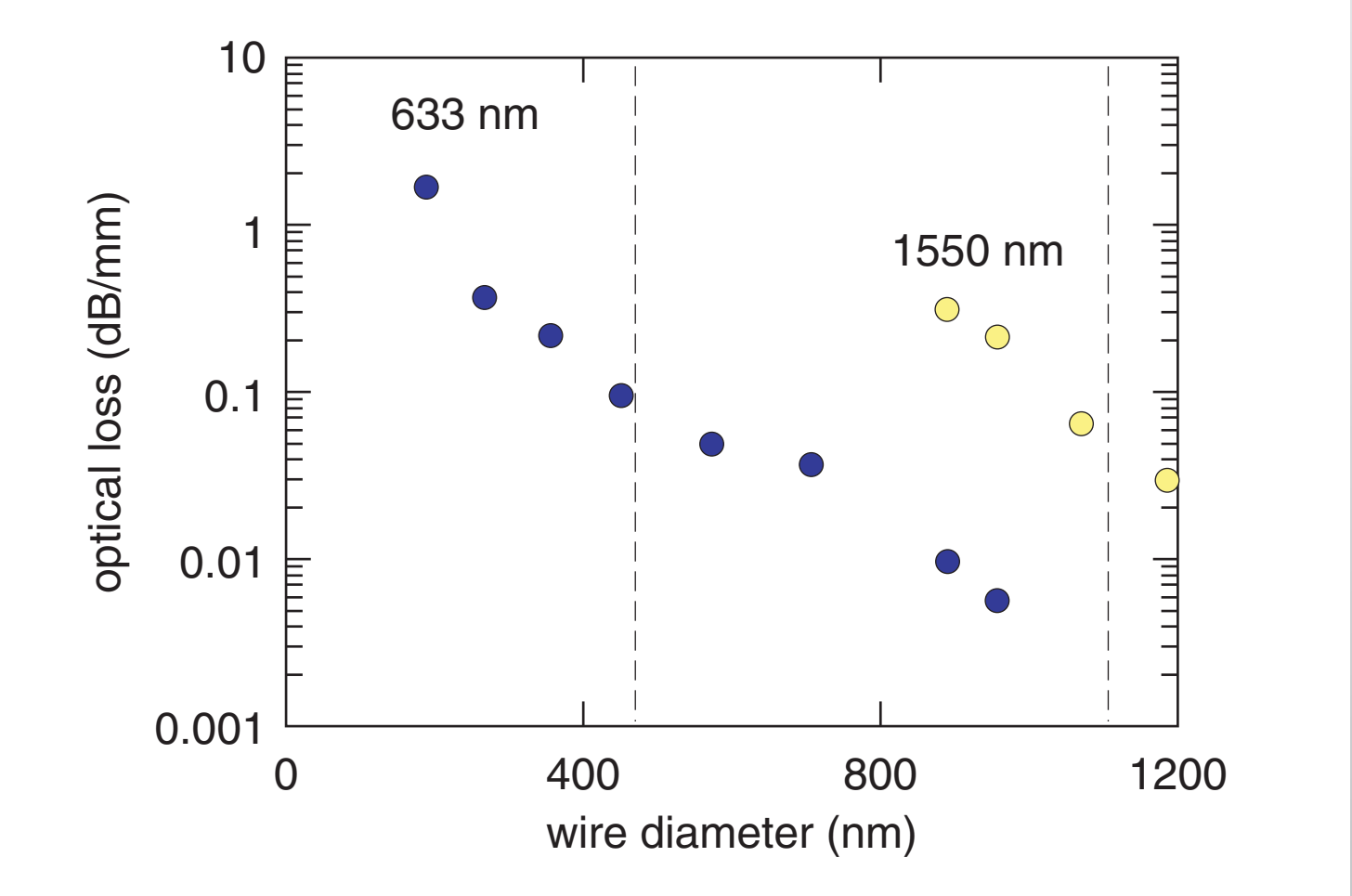
loss measurement



Nature, 426, 816 (2003)

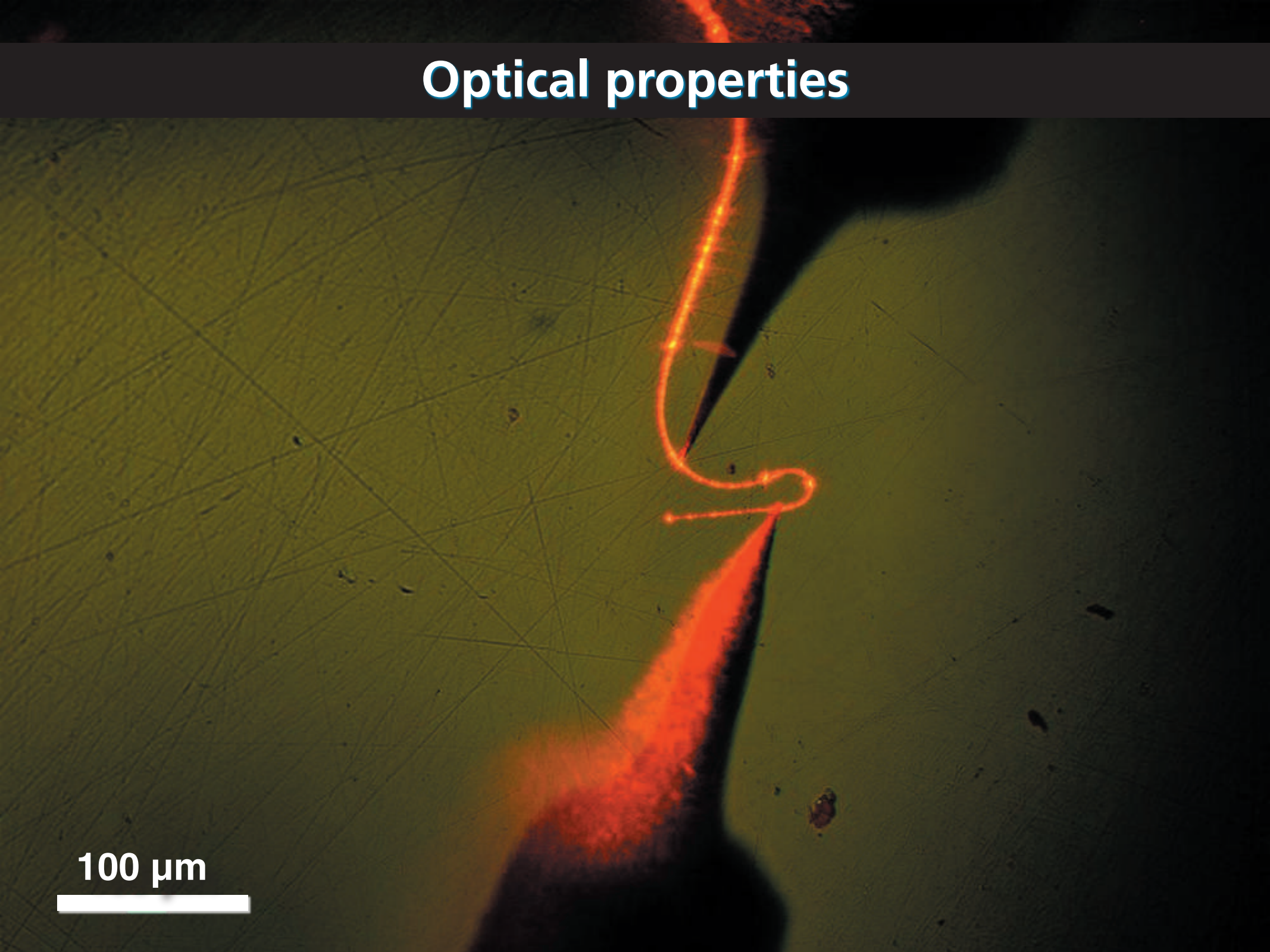
Optical properties

loss at single-mode diameter < 0.1 dB/mm



Nature, 426, 816 (2003)

Optical properties



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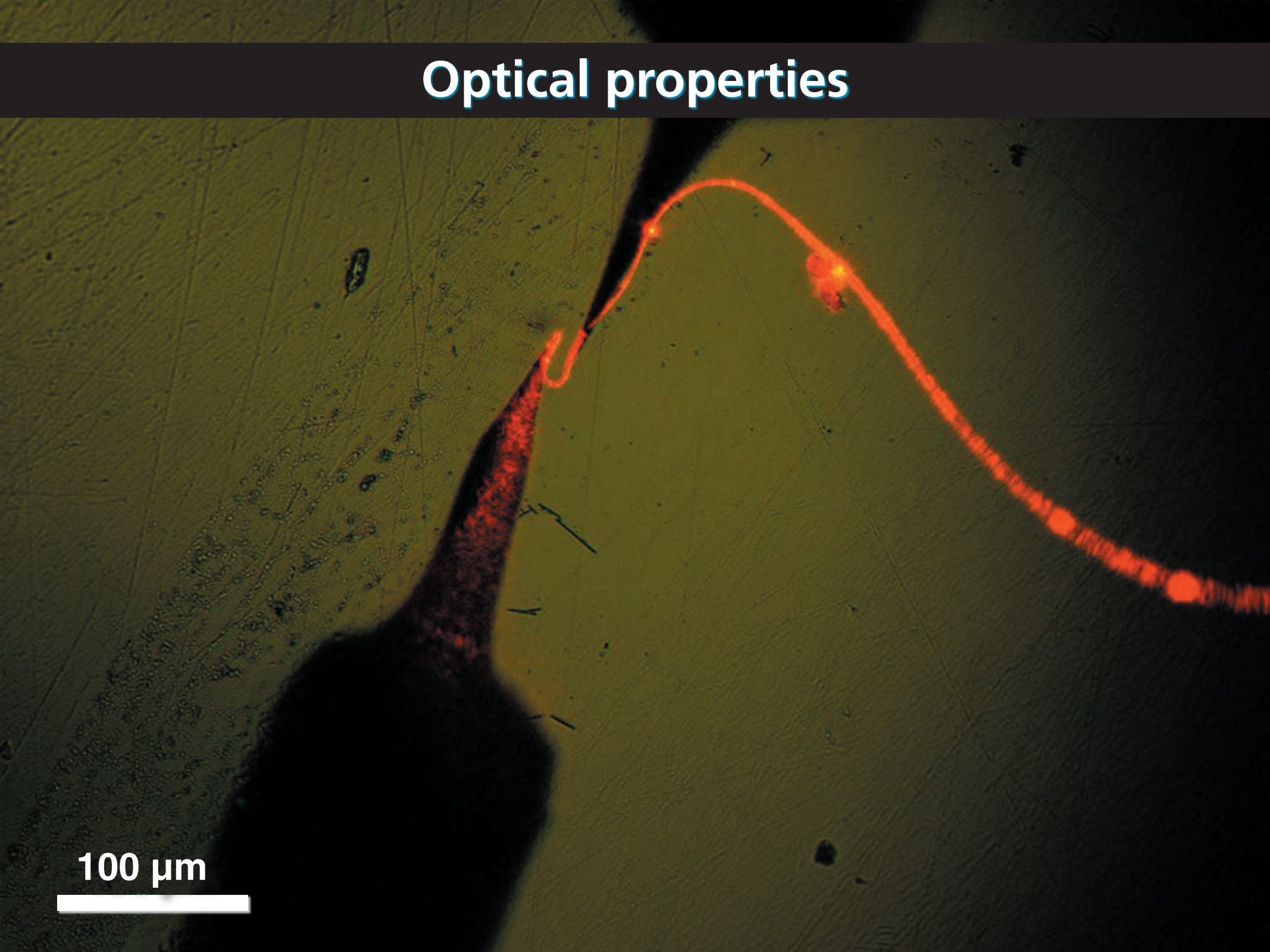

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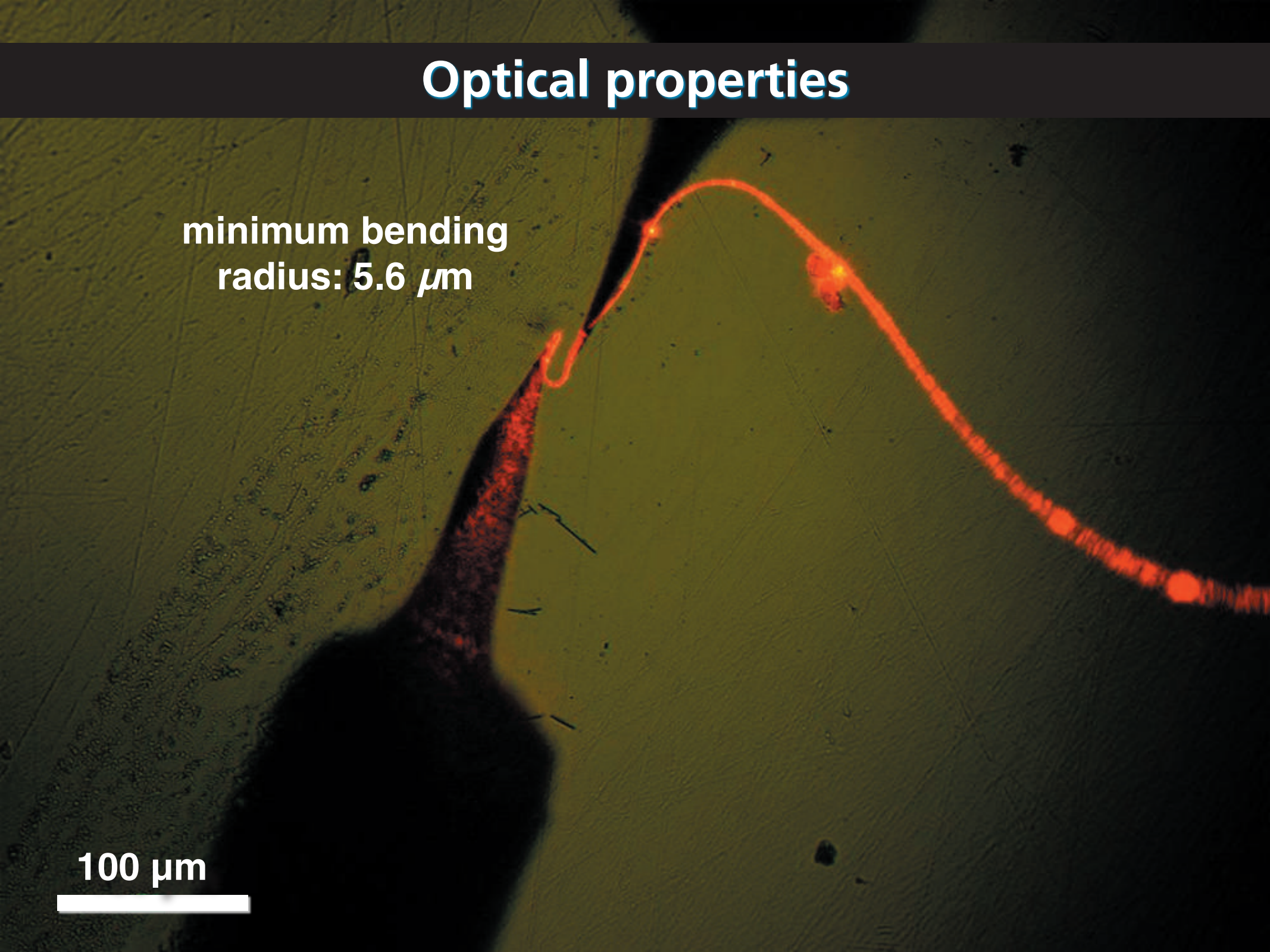
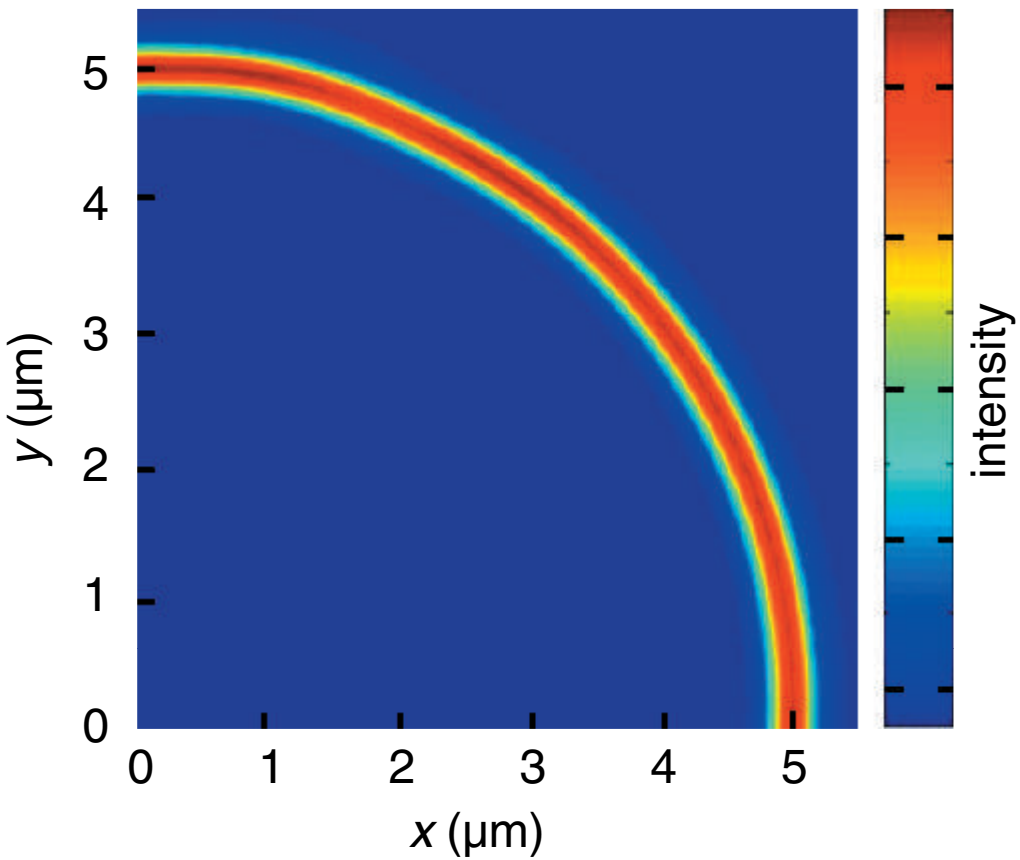
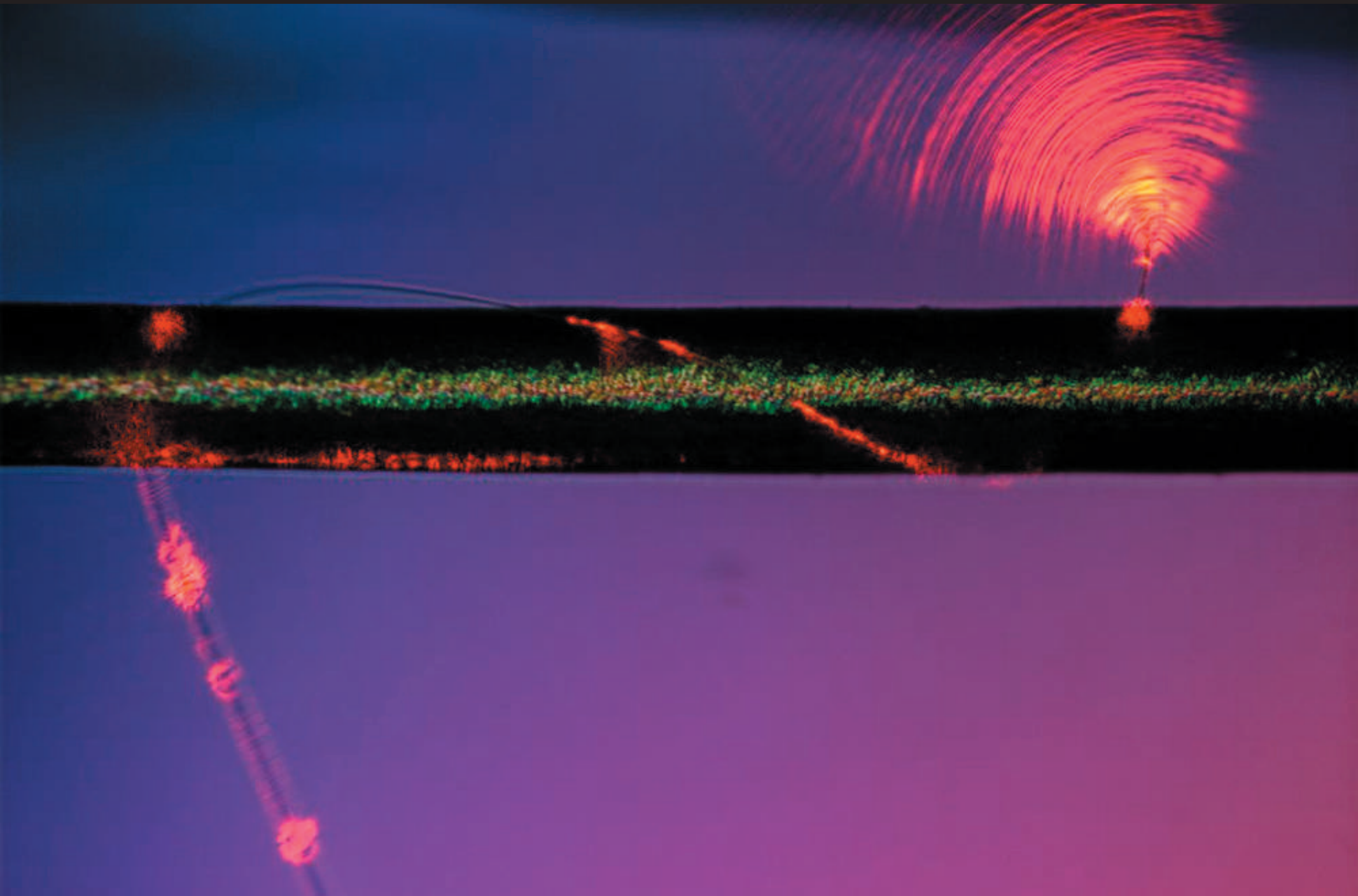


Optical properties

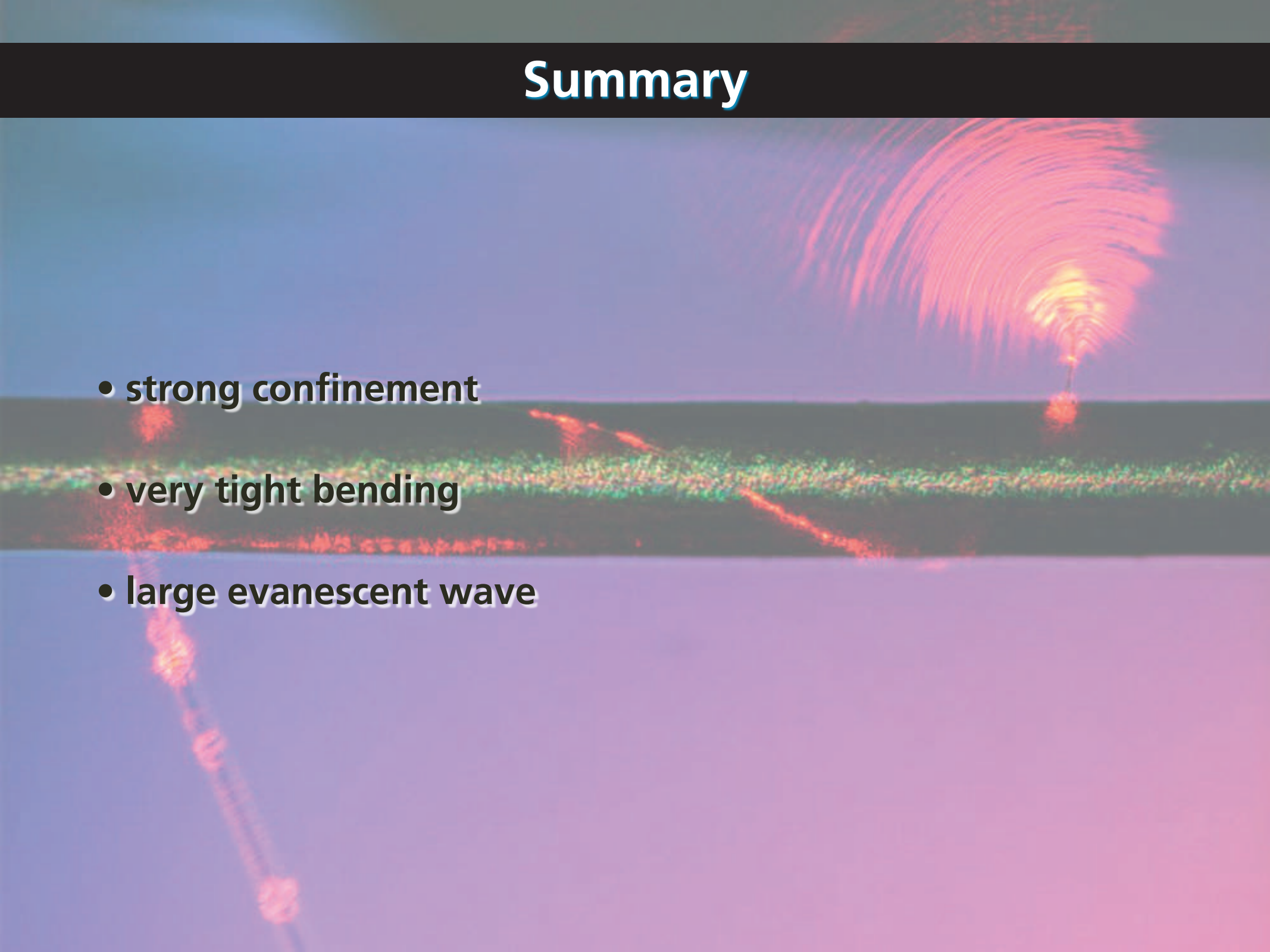
virtually no loss through 5 μm corner!



Summary



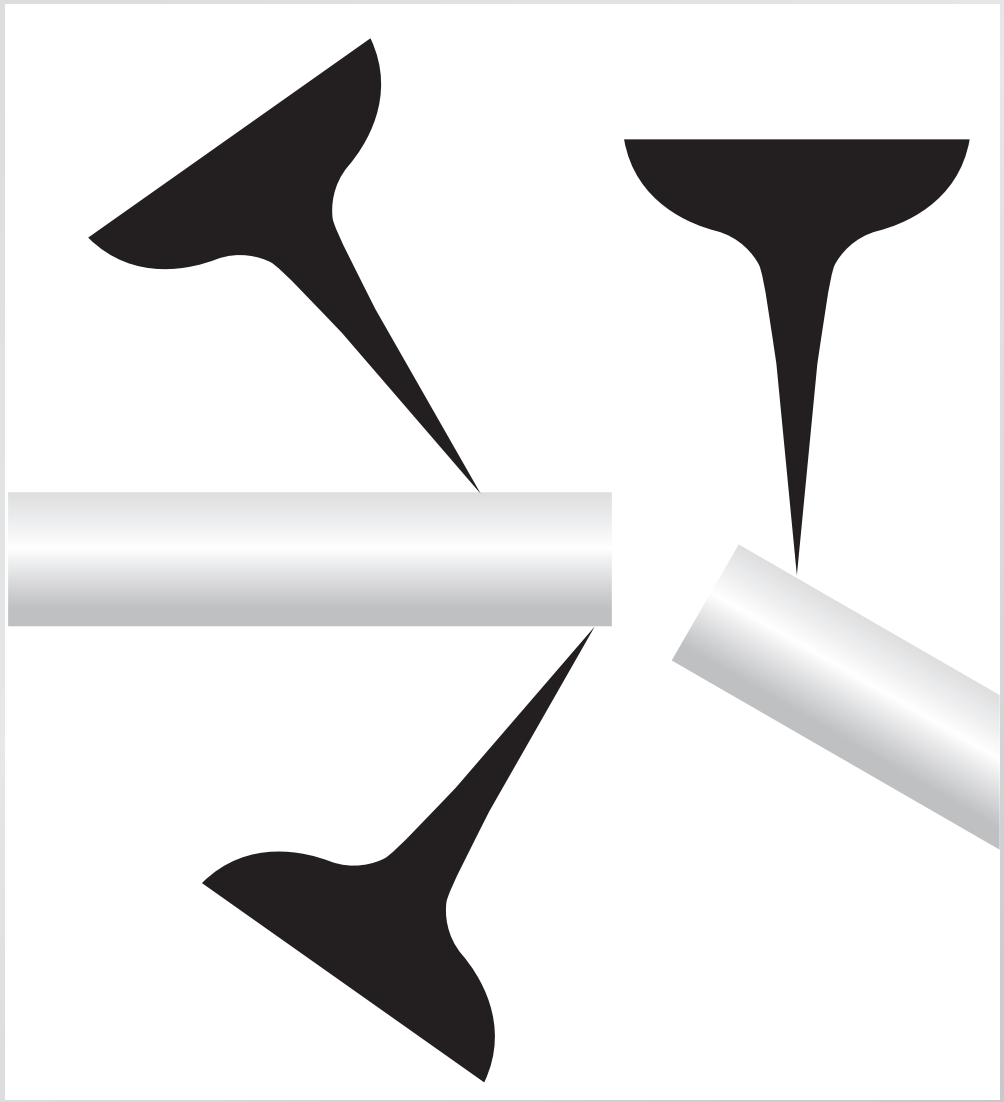
Summary



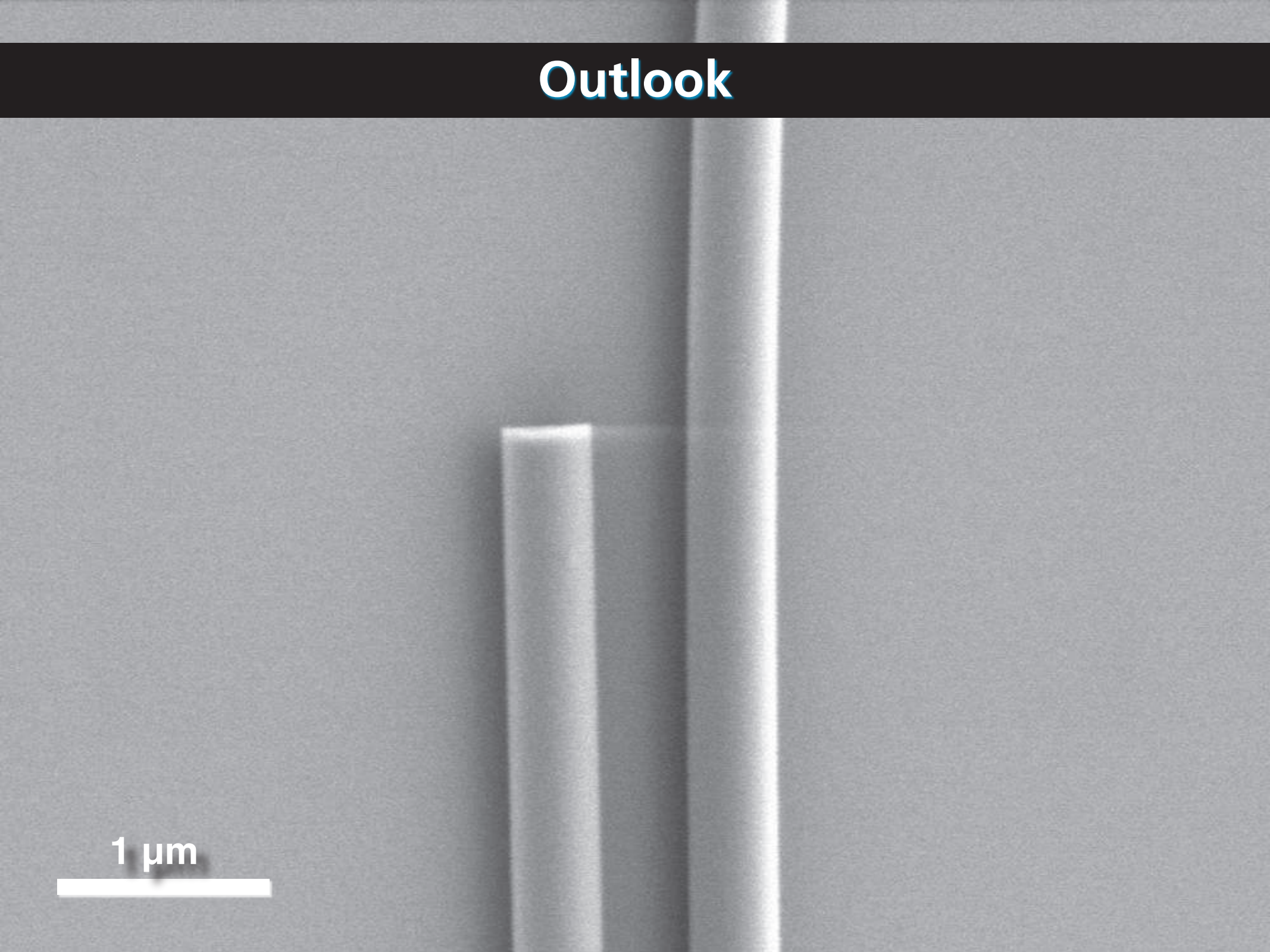
- strong confinement
- very tight bending
- large evanescent wave

Outlook

microphotonic components



Outlook



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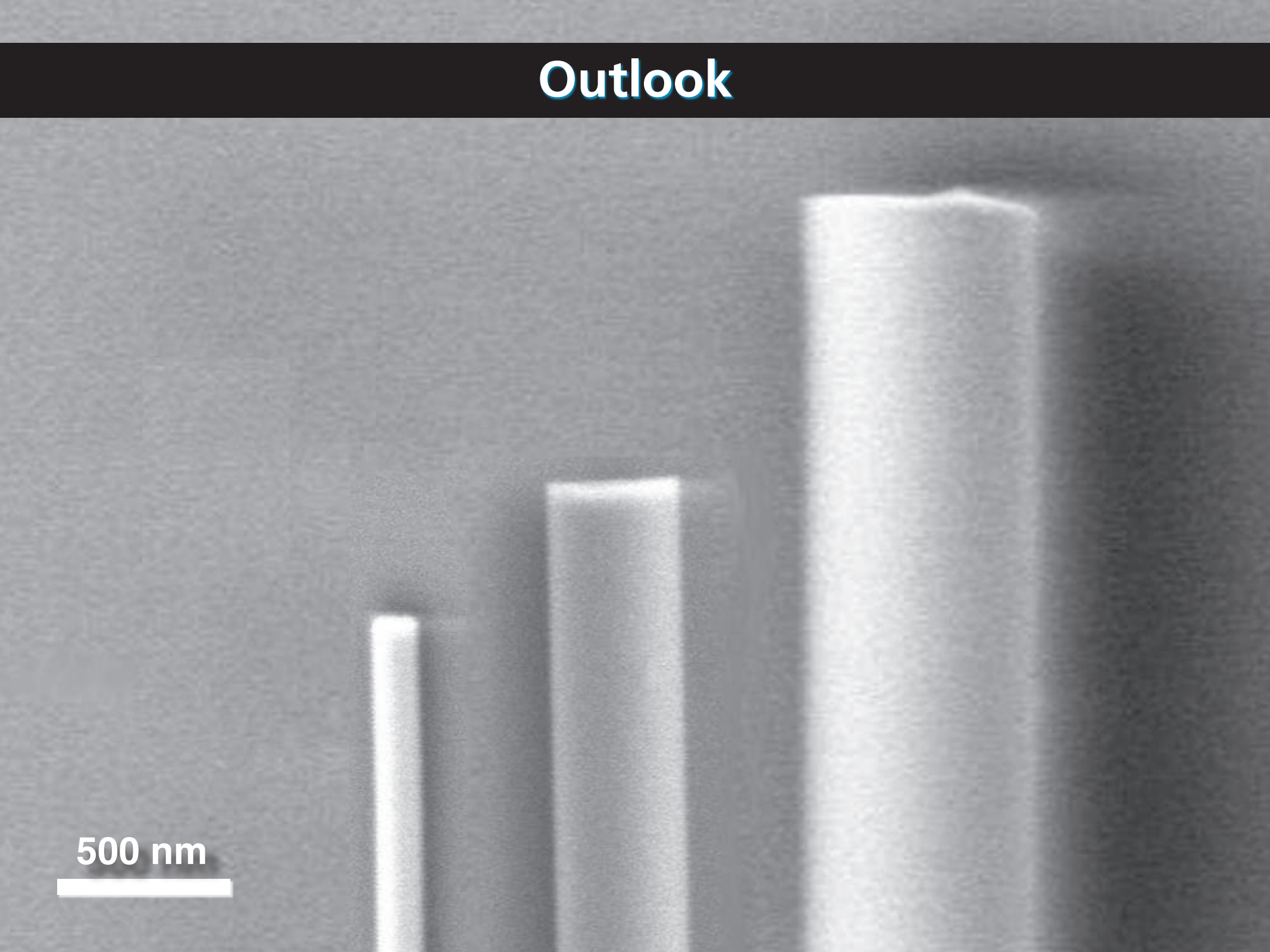

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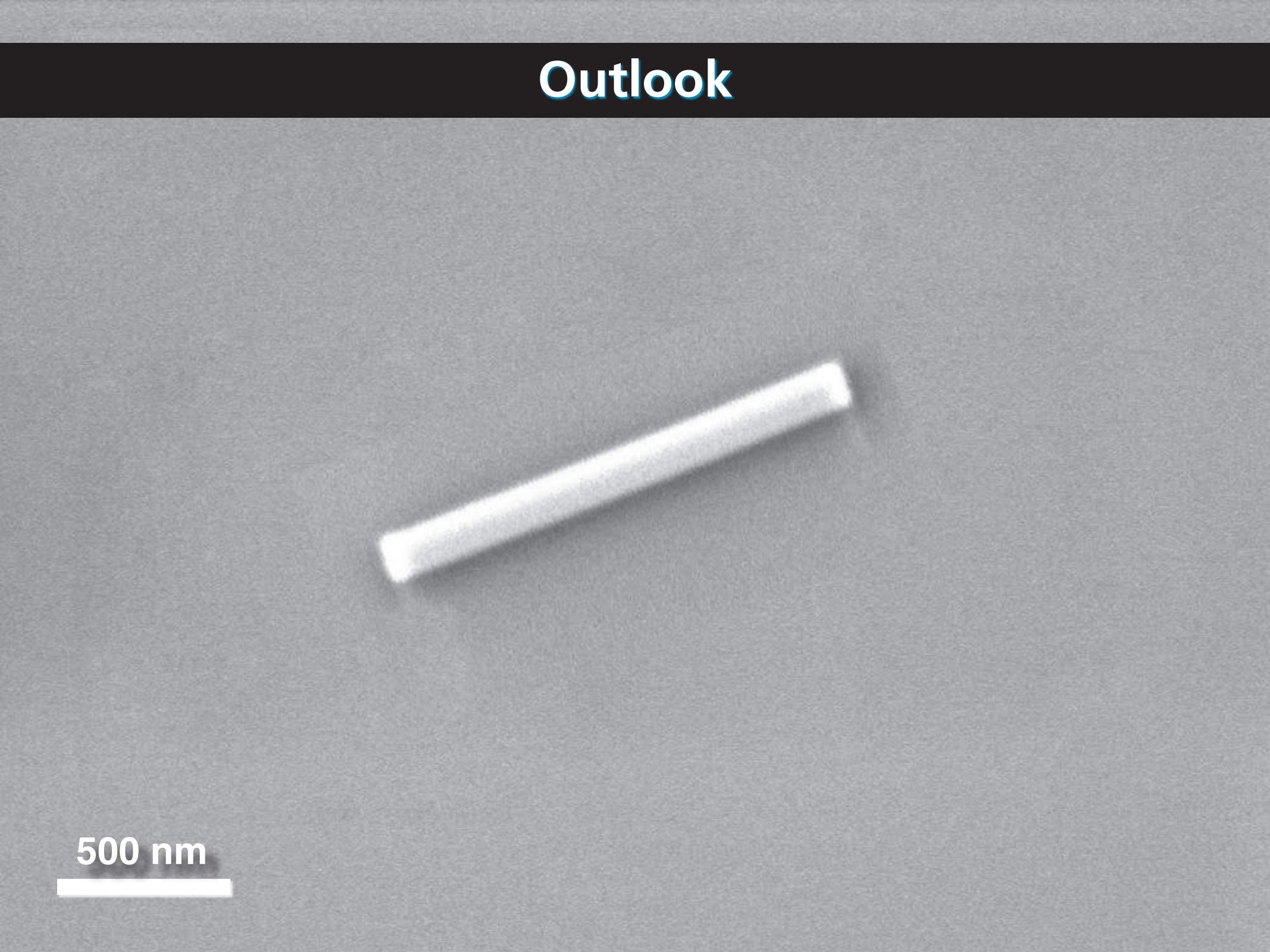

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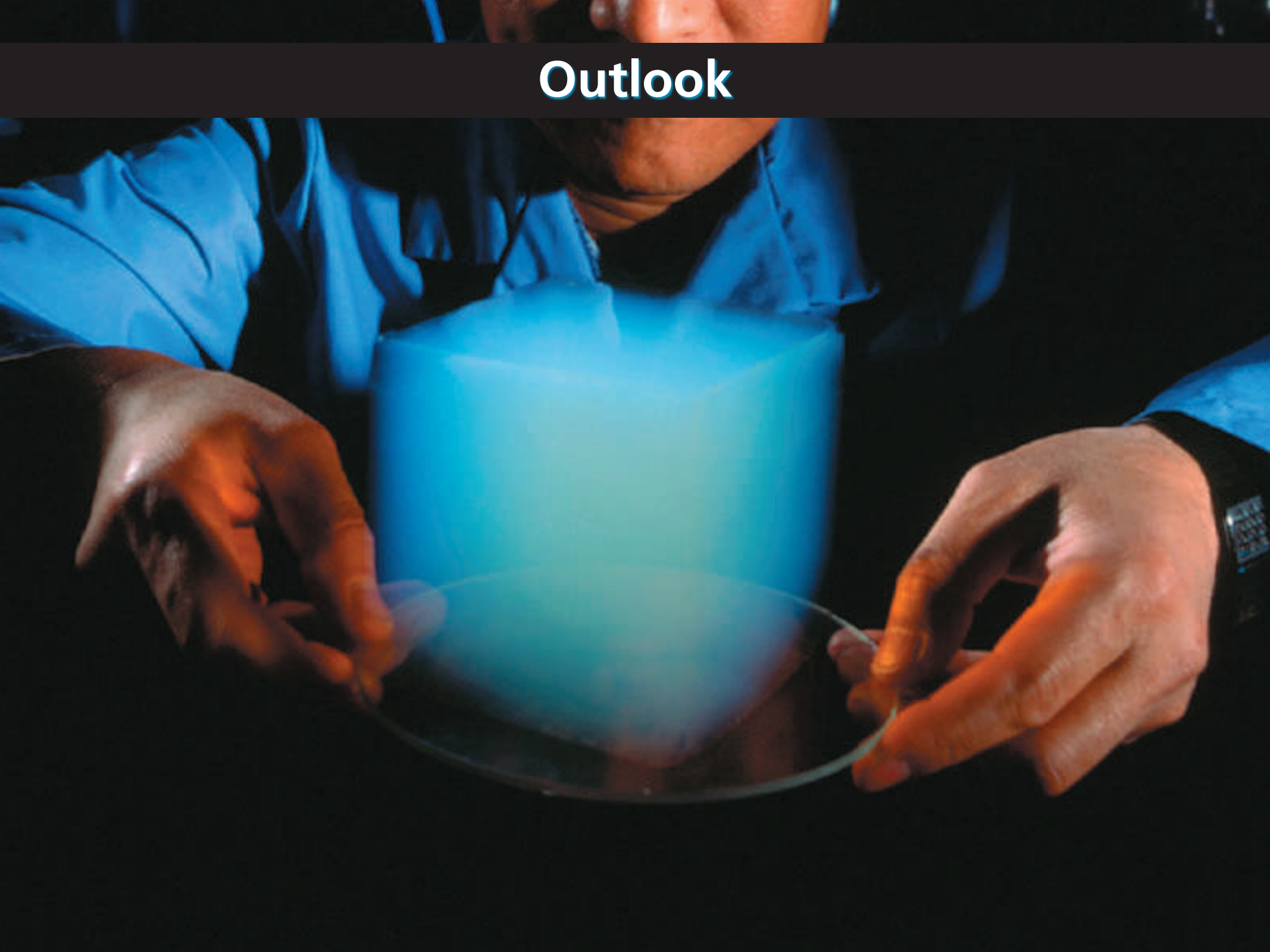
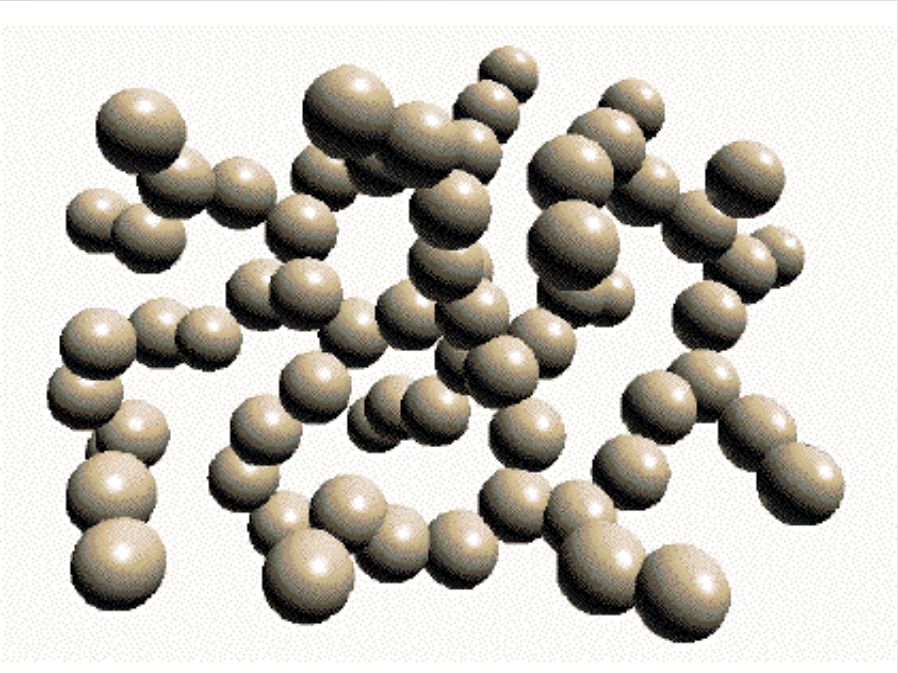
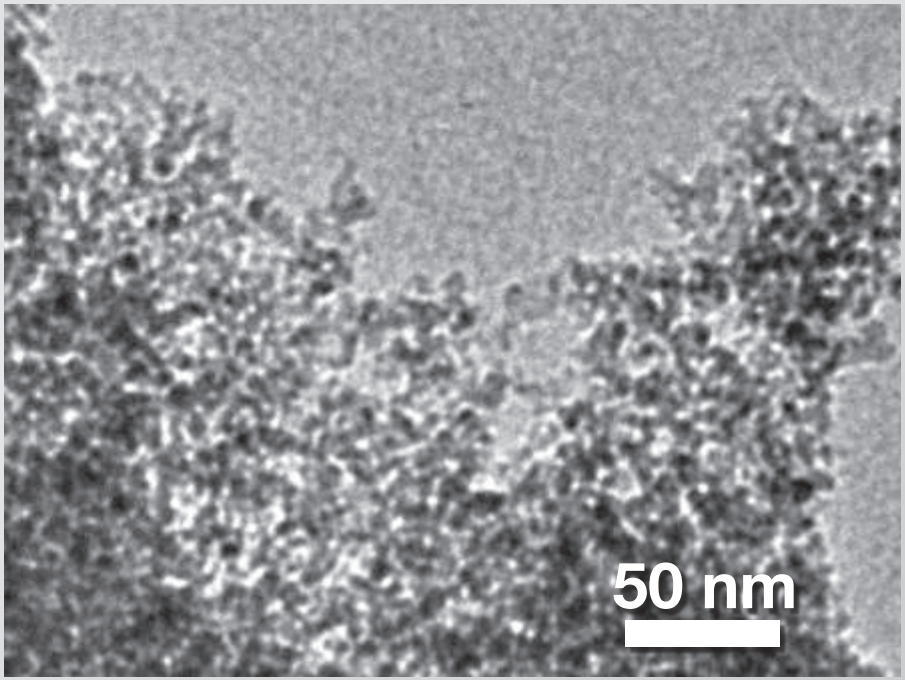


Outlook

Aerogel

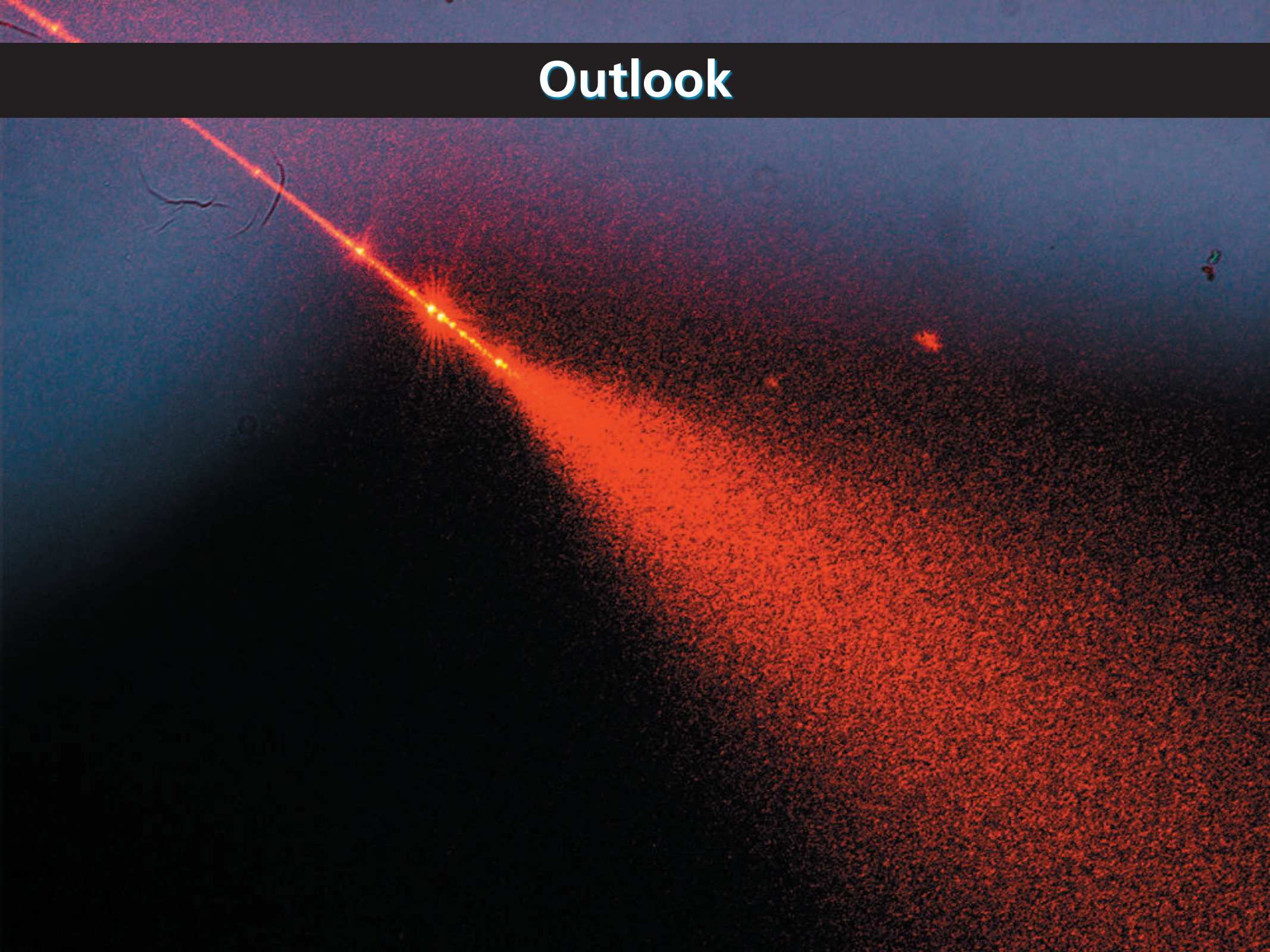




density: 1.9 kg/m^3

index of refraction: 1.03–1.08

Outlook



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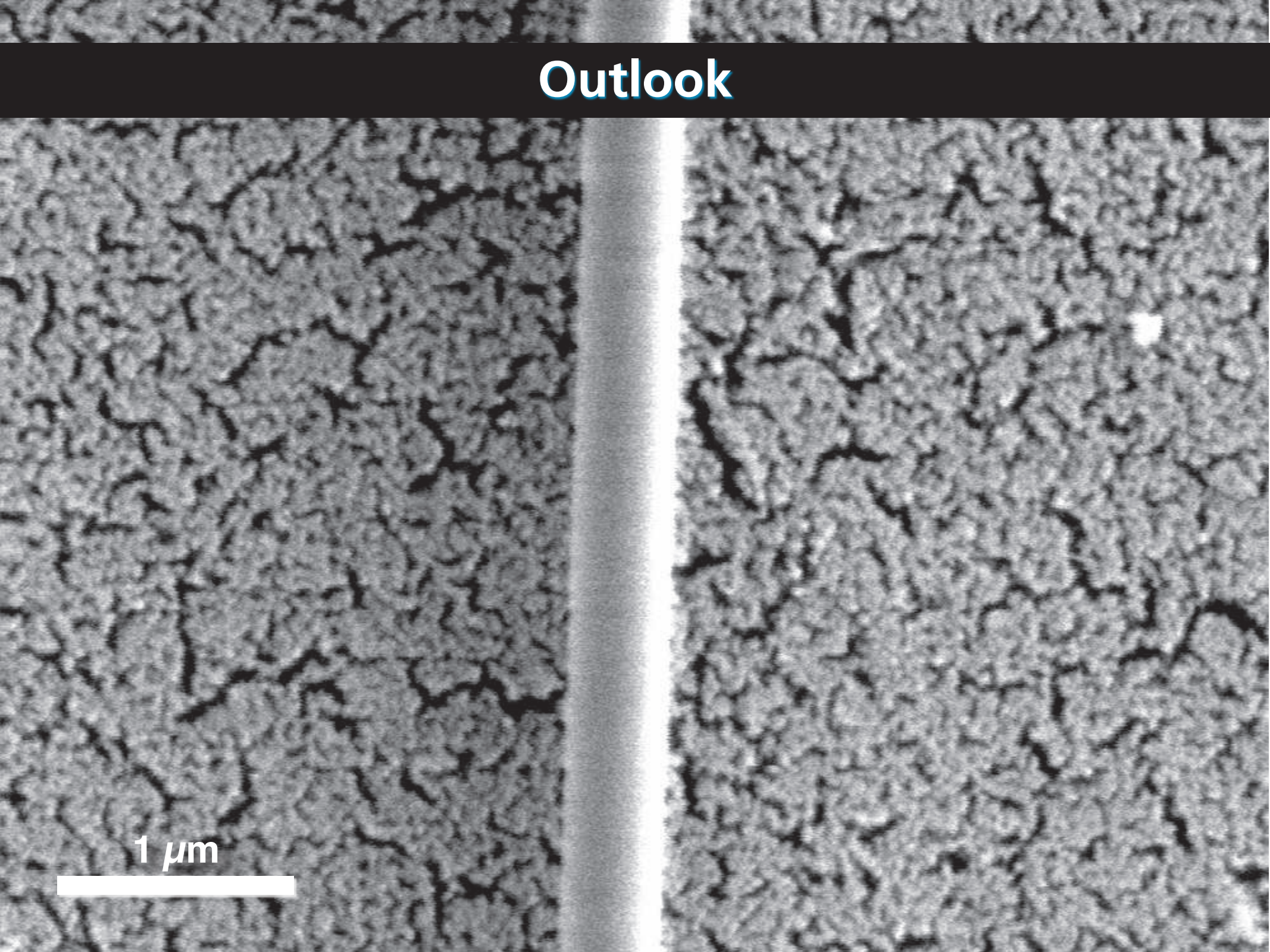
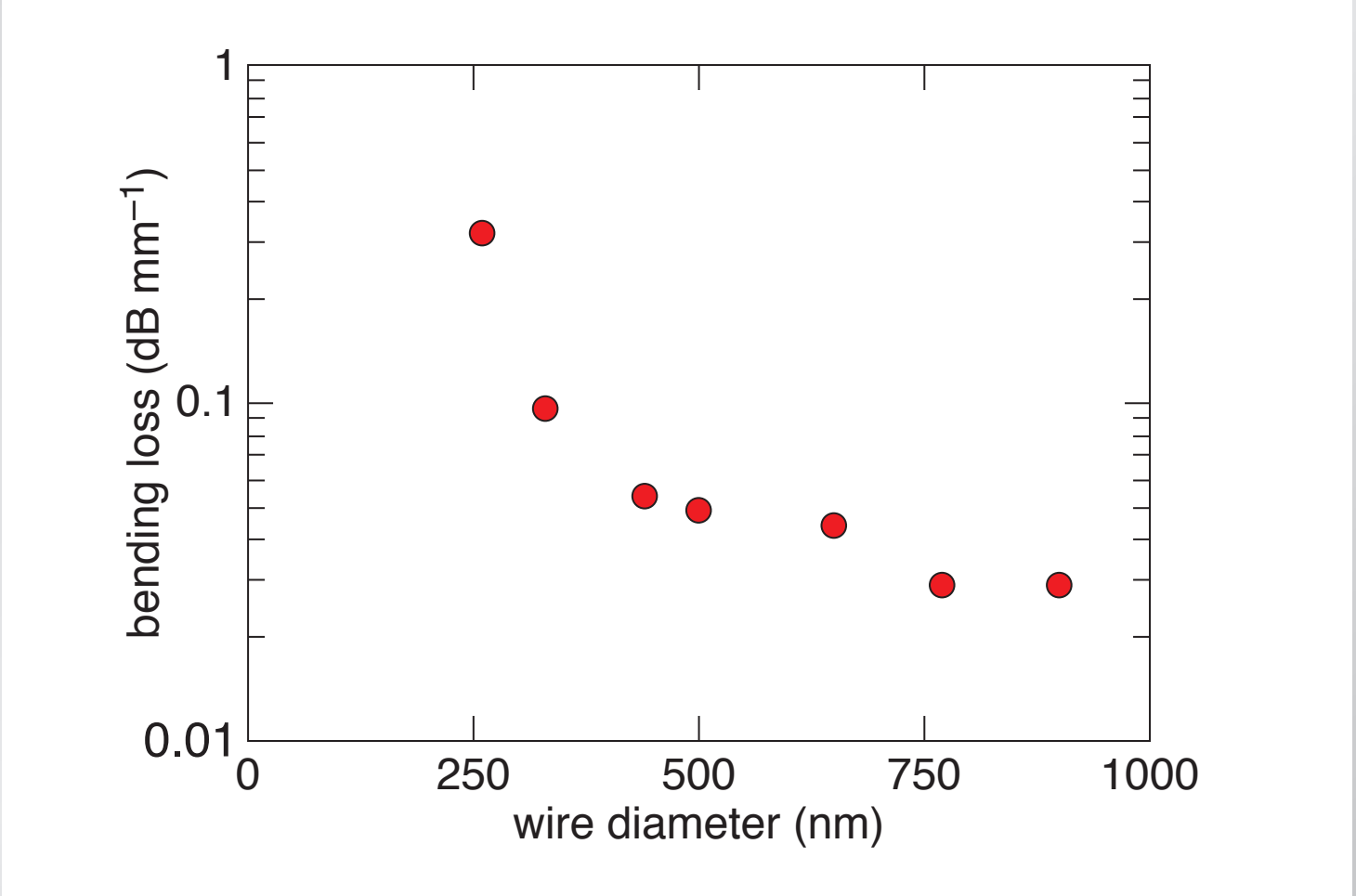


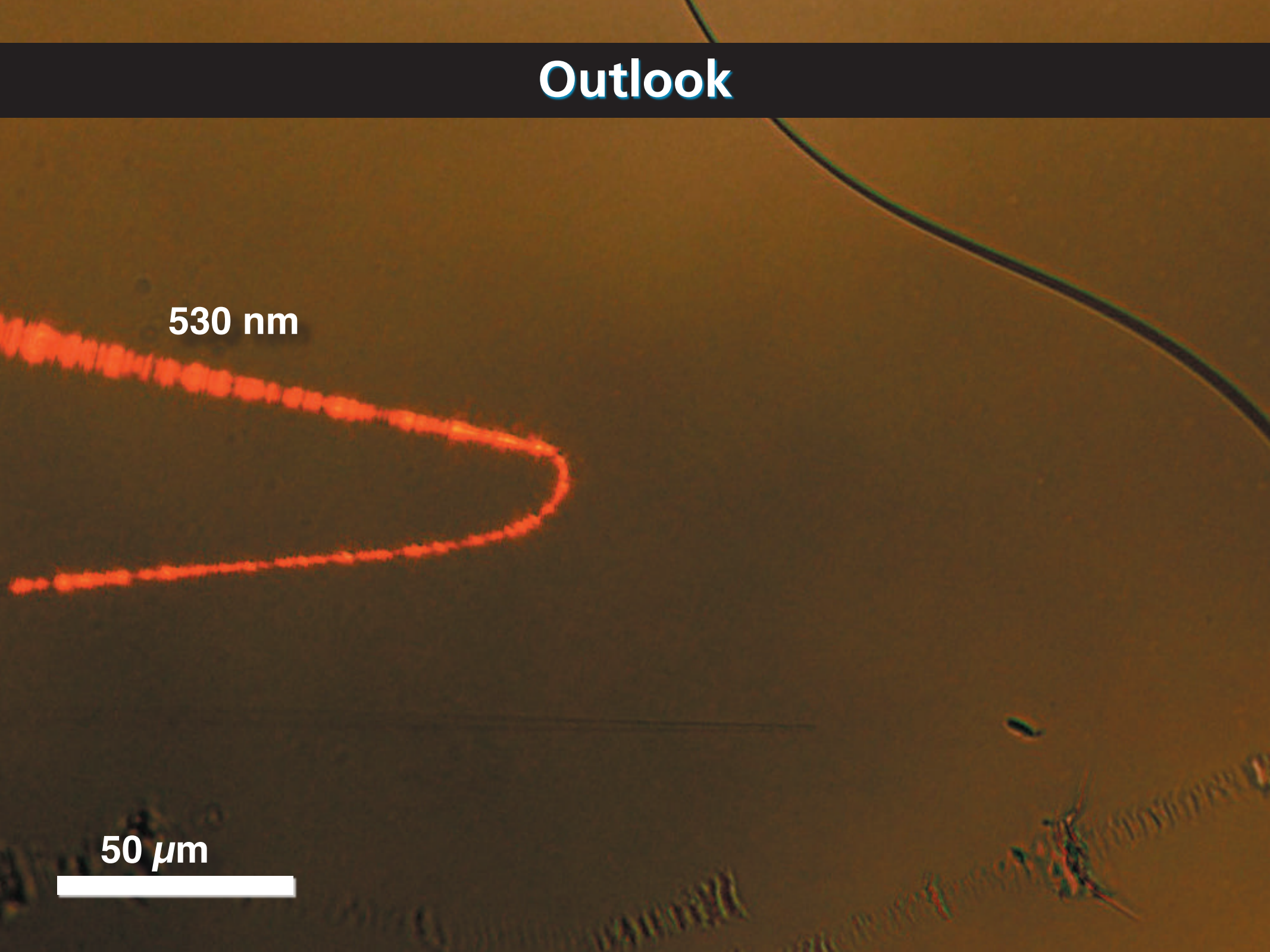
Outlook

loss measurement @ 633 nm

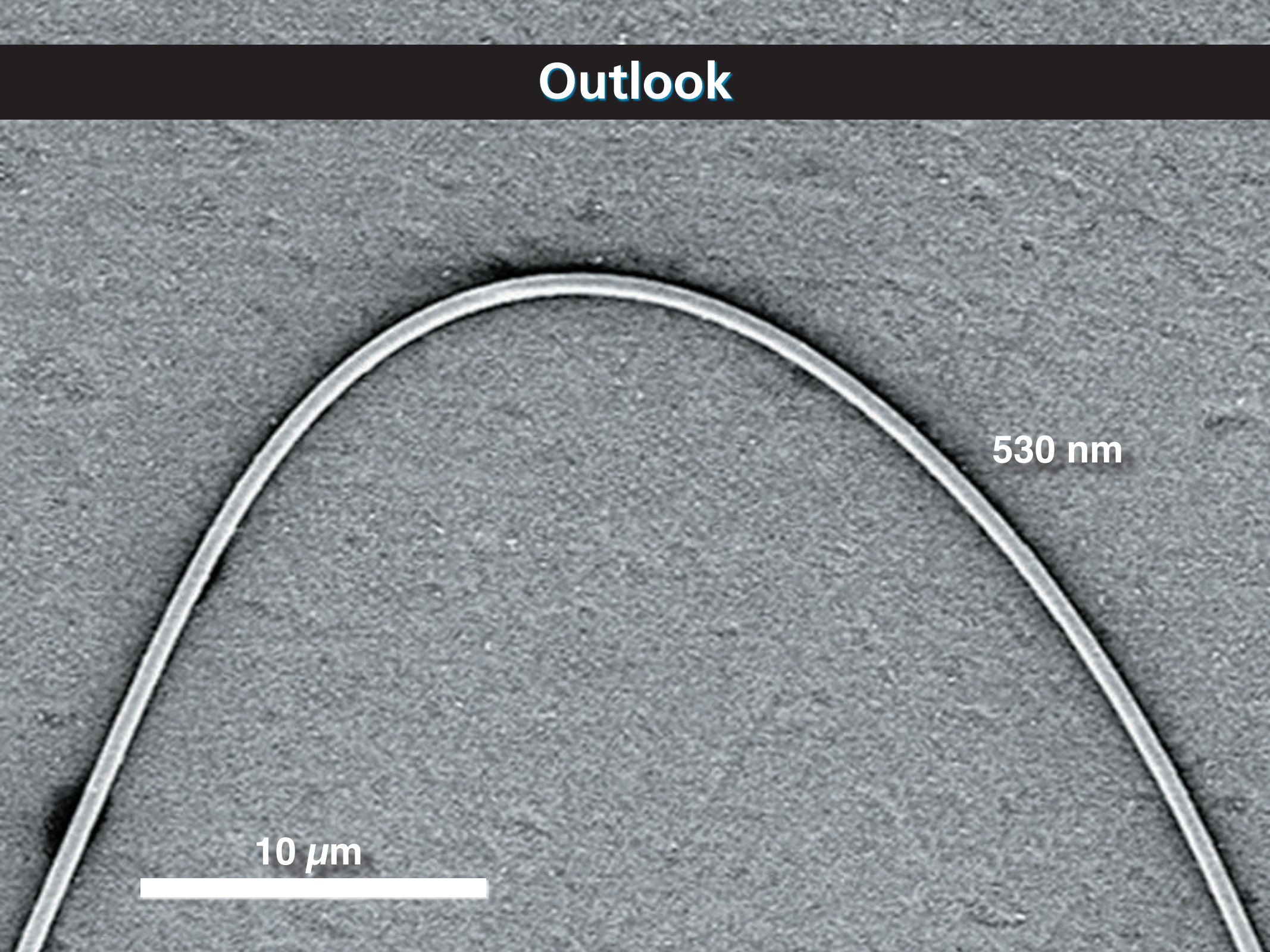


Nanoletters, in press (2005)

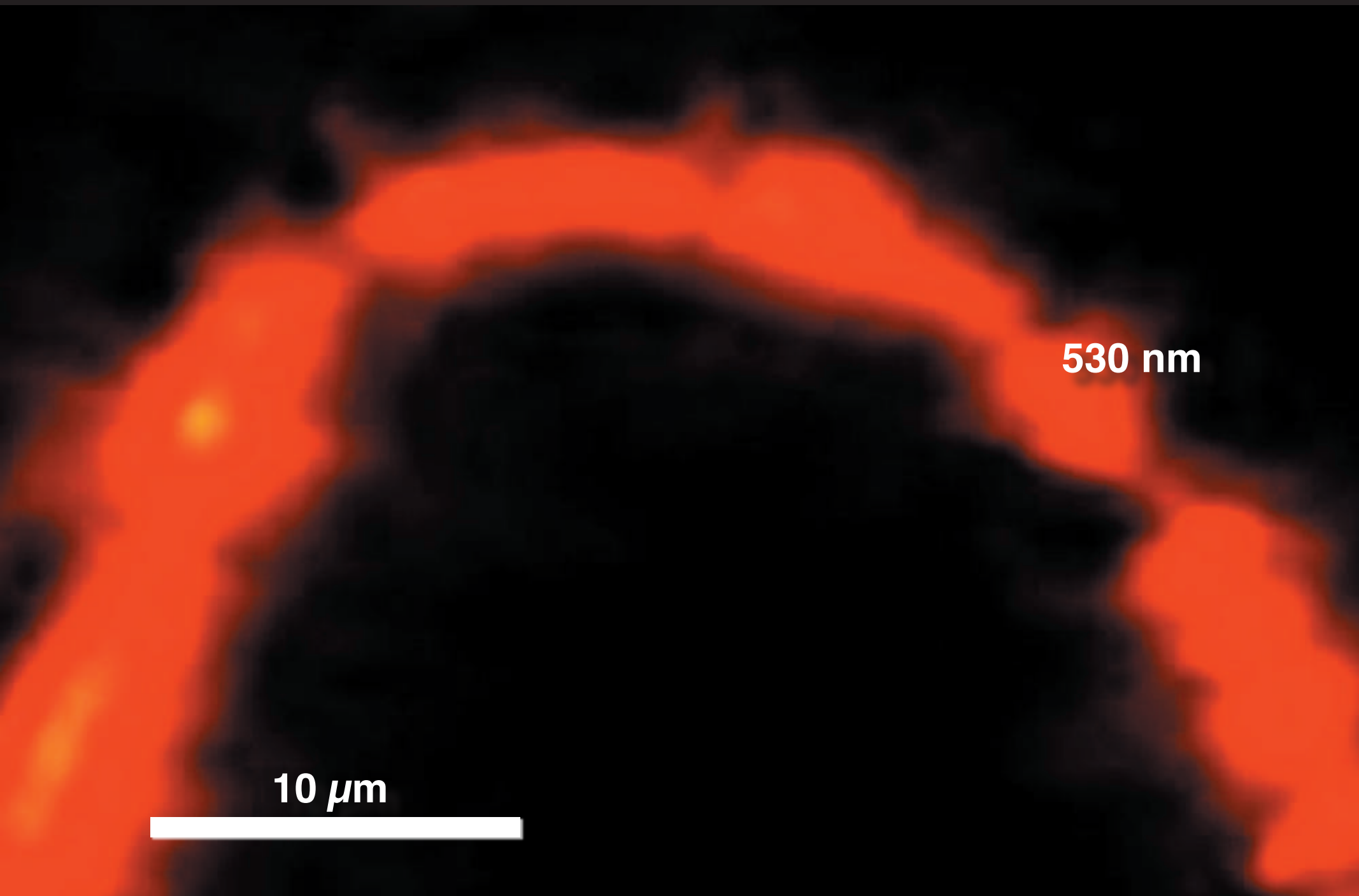
Outlook



Outlook

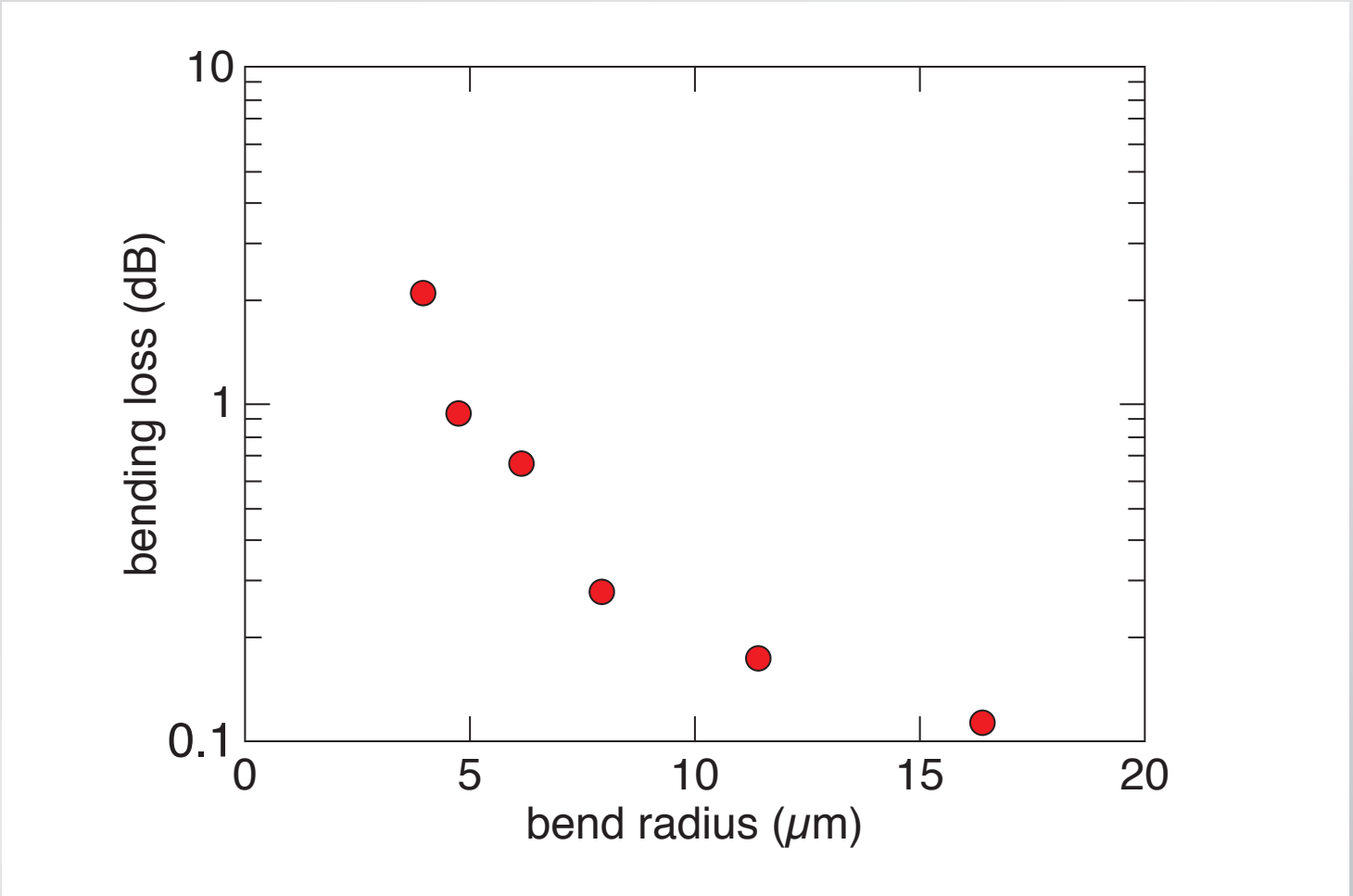


Outlook



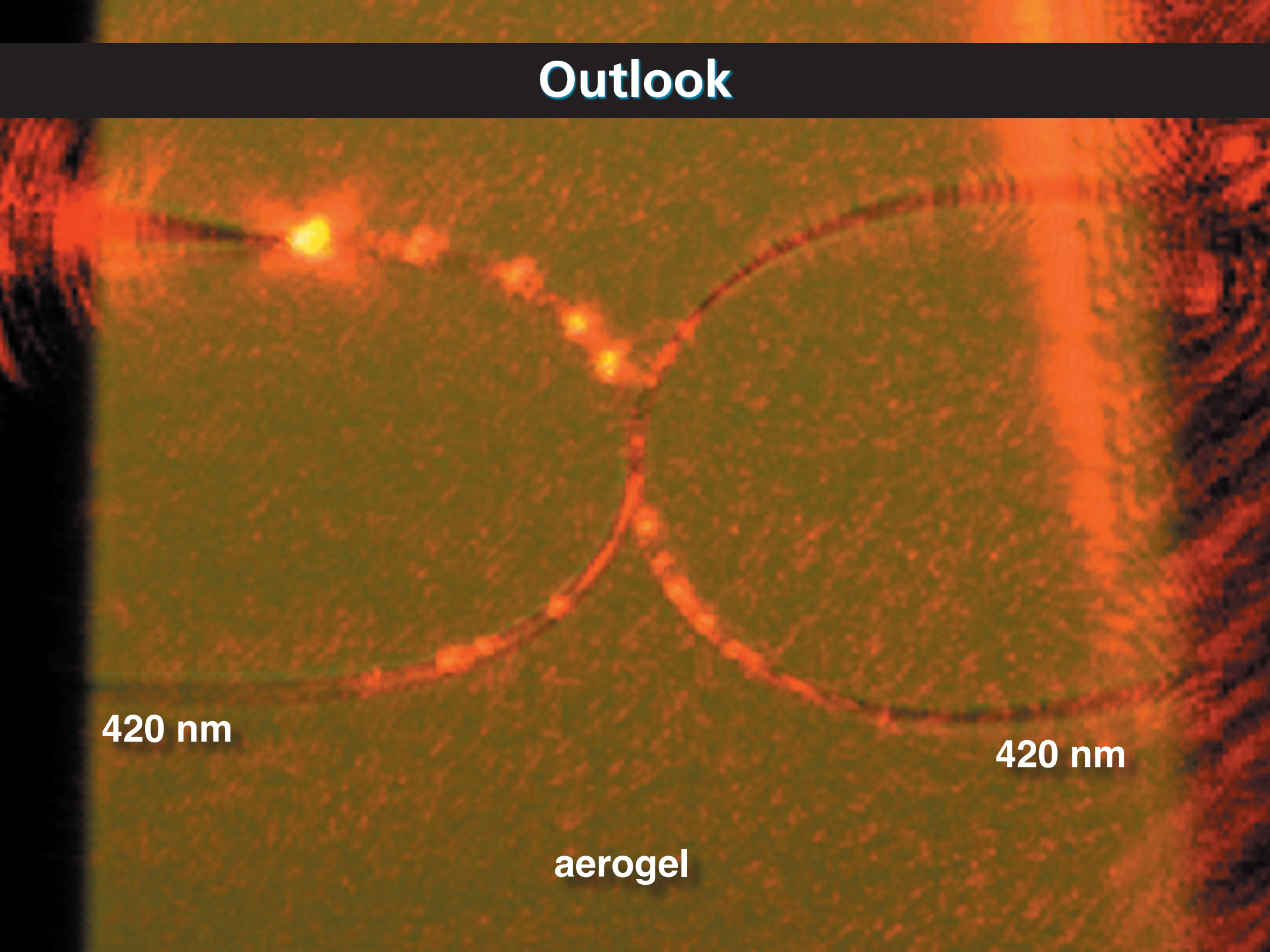
Outlook

bending loss @ 633 nm



Nanoletters, in press (2005)

Outlook



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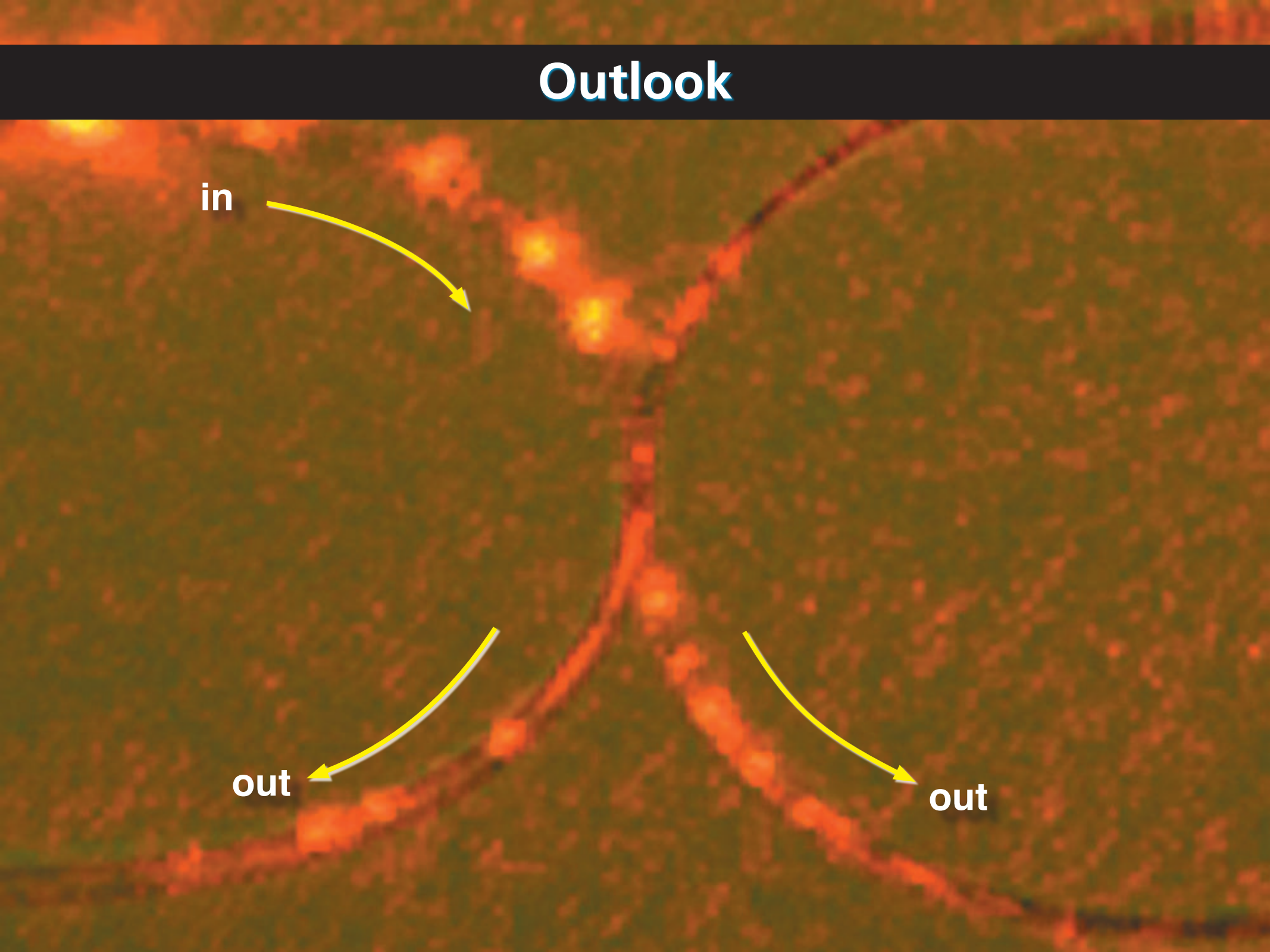

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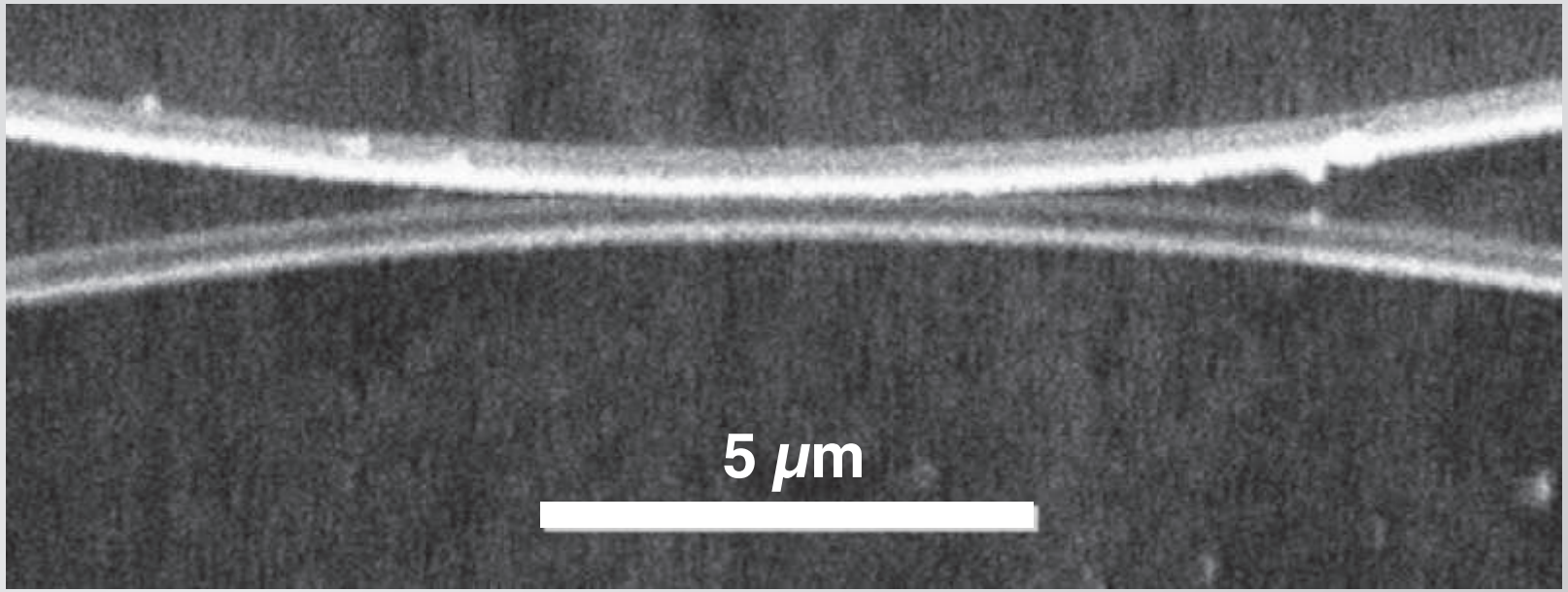

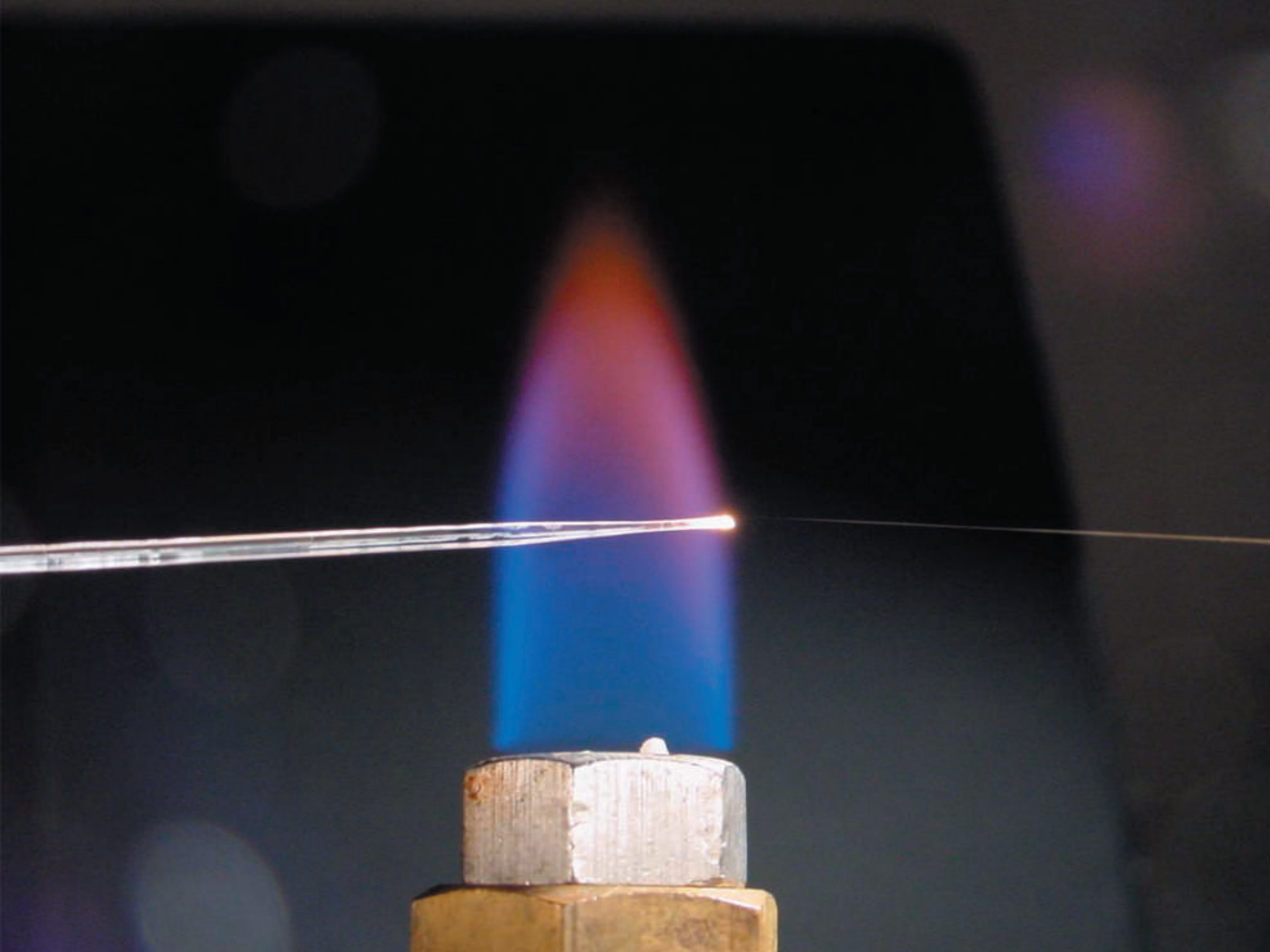

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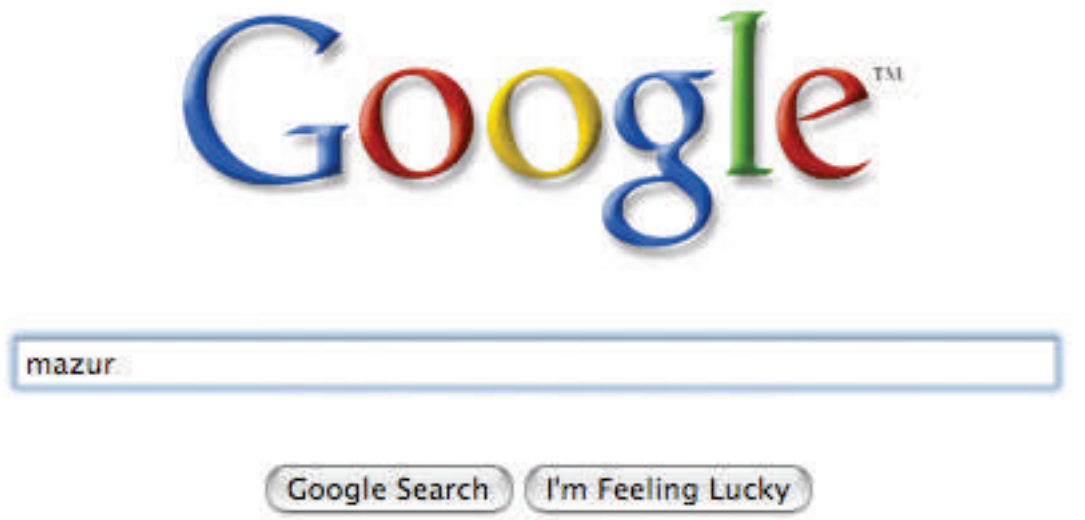
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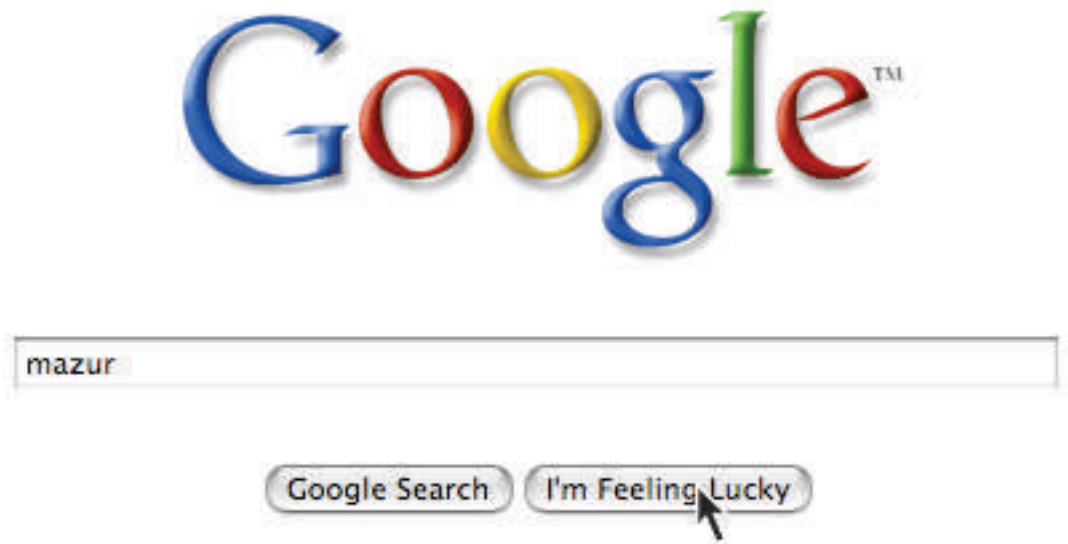
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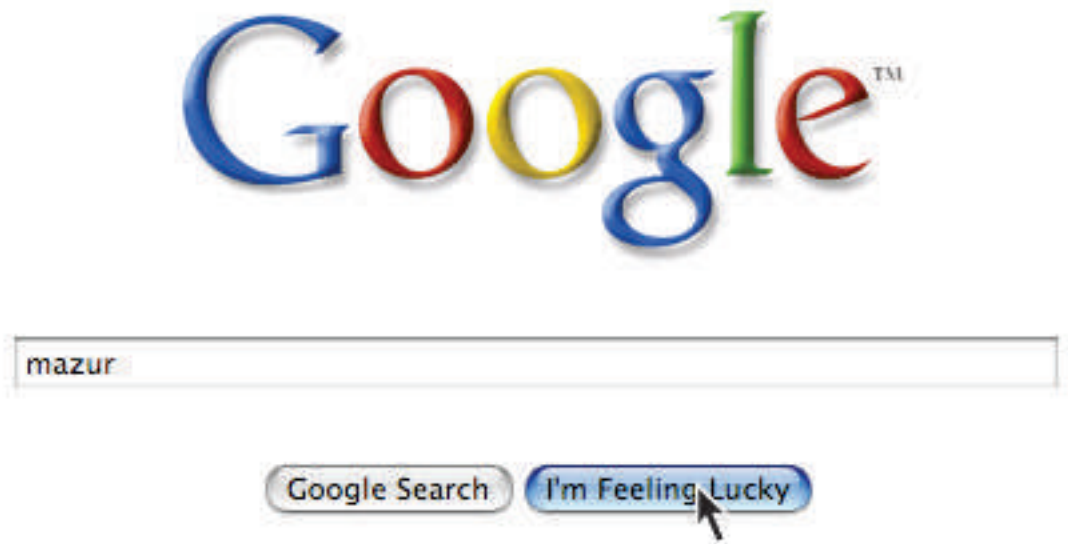
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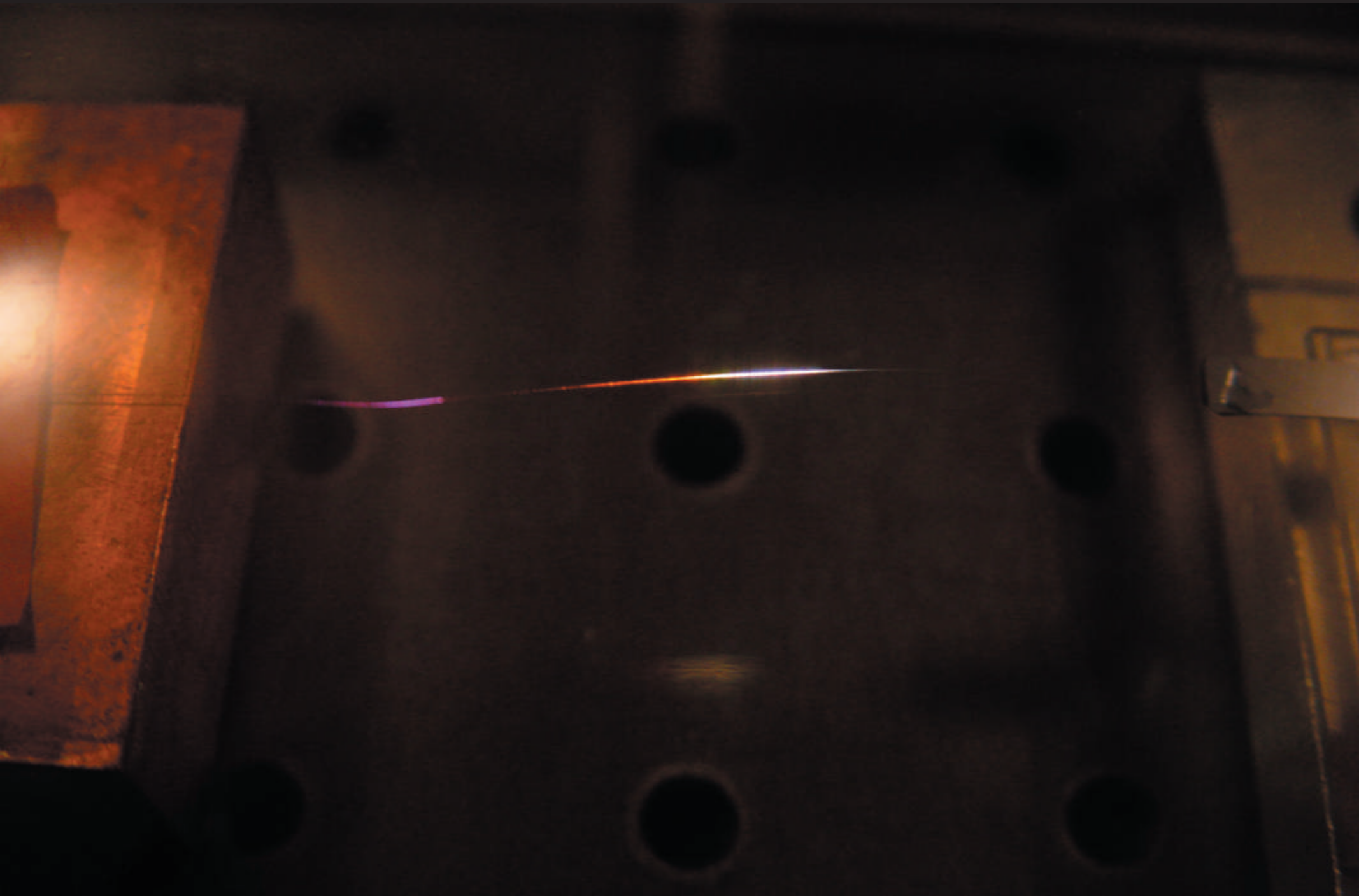
Optical properties



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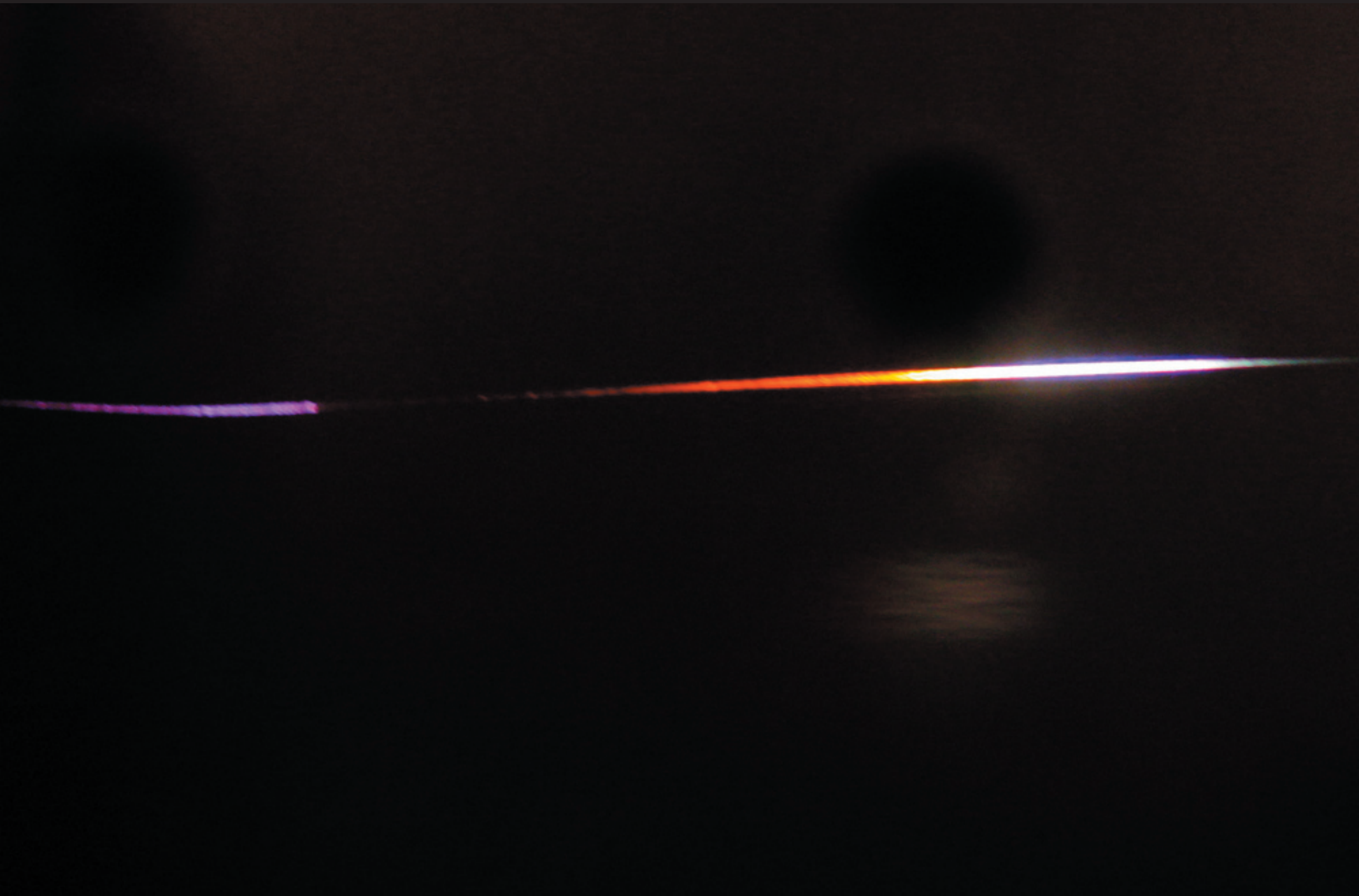
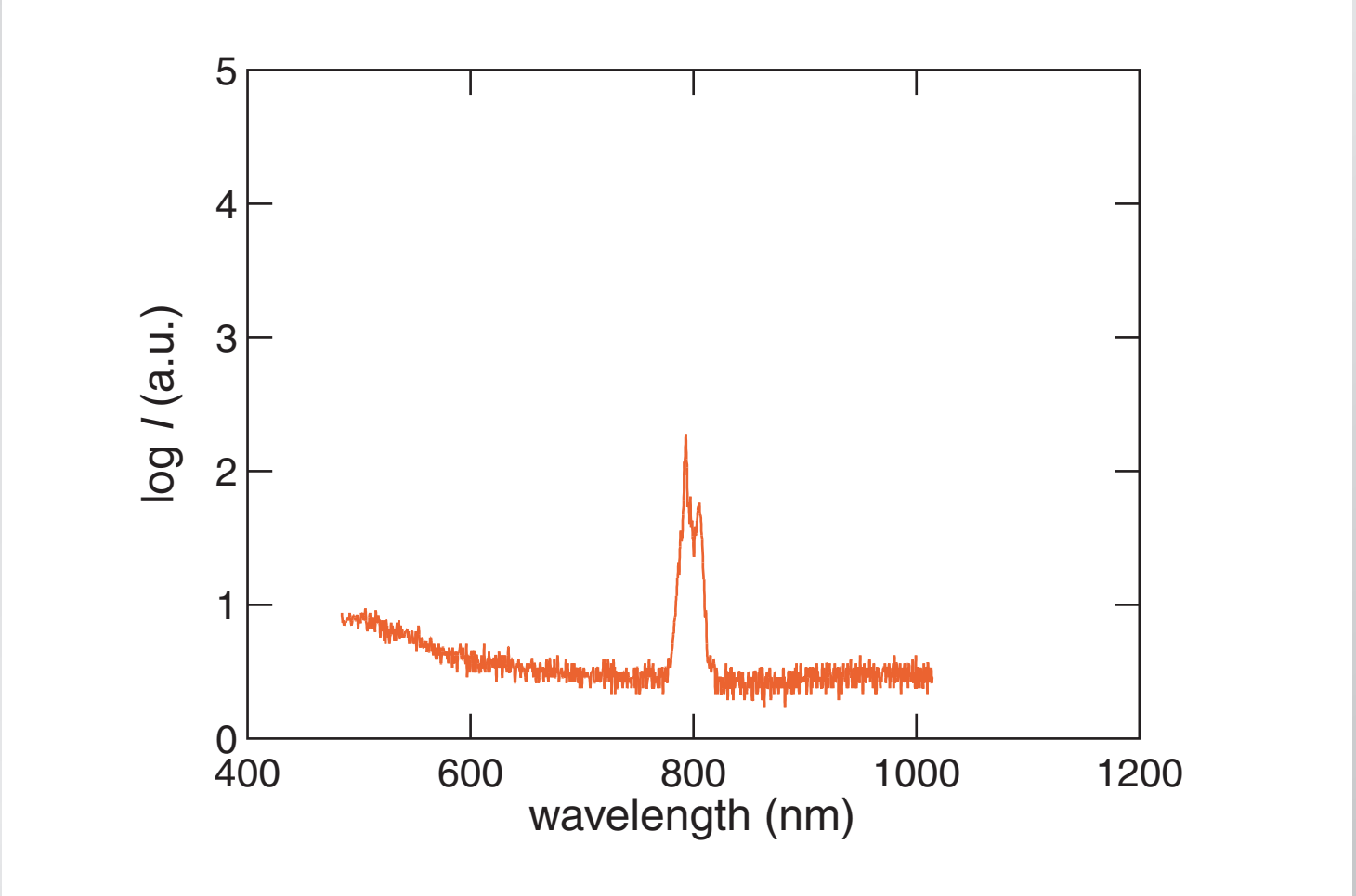


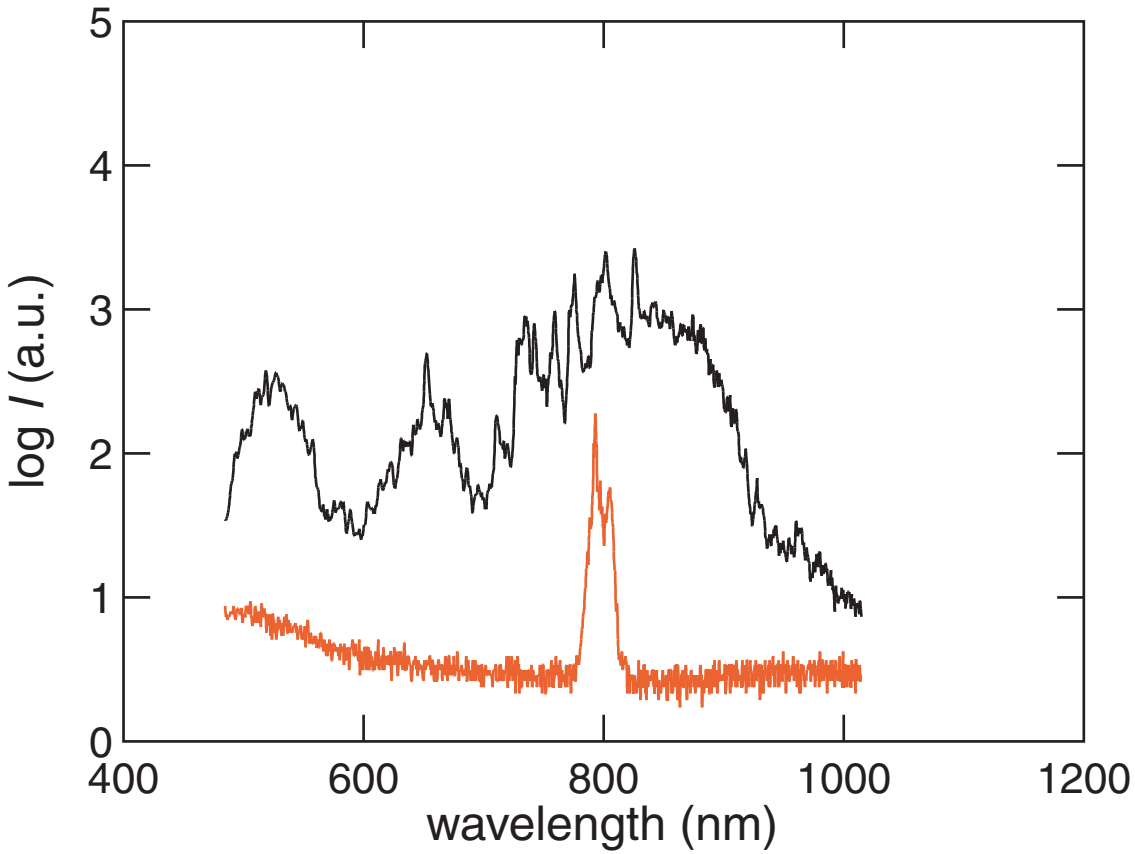
Optical properties

self-phase modulation



Optical properties

self-phase modulation



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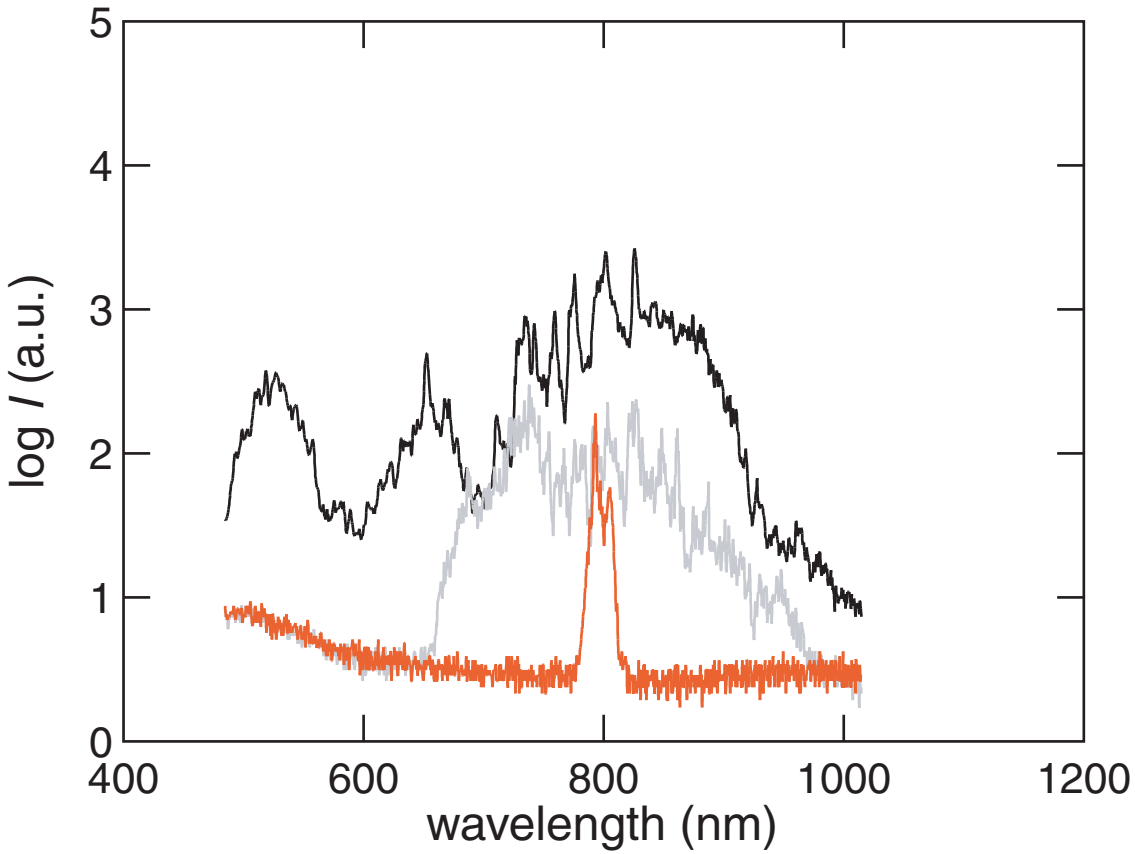
self-phase modulation