# Wrapping light around a hair


ISTA Annual Conference 2016
Limerick, Ireland, 9 April 2016

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**ISTA Annual Conference 2016**
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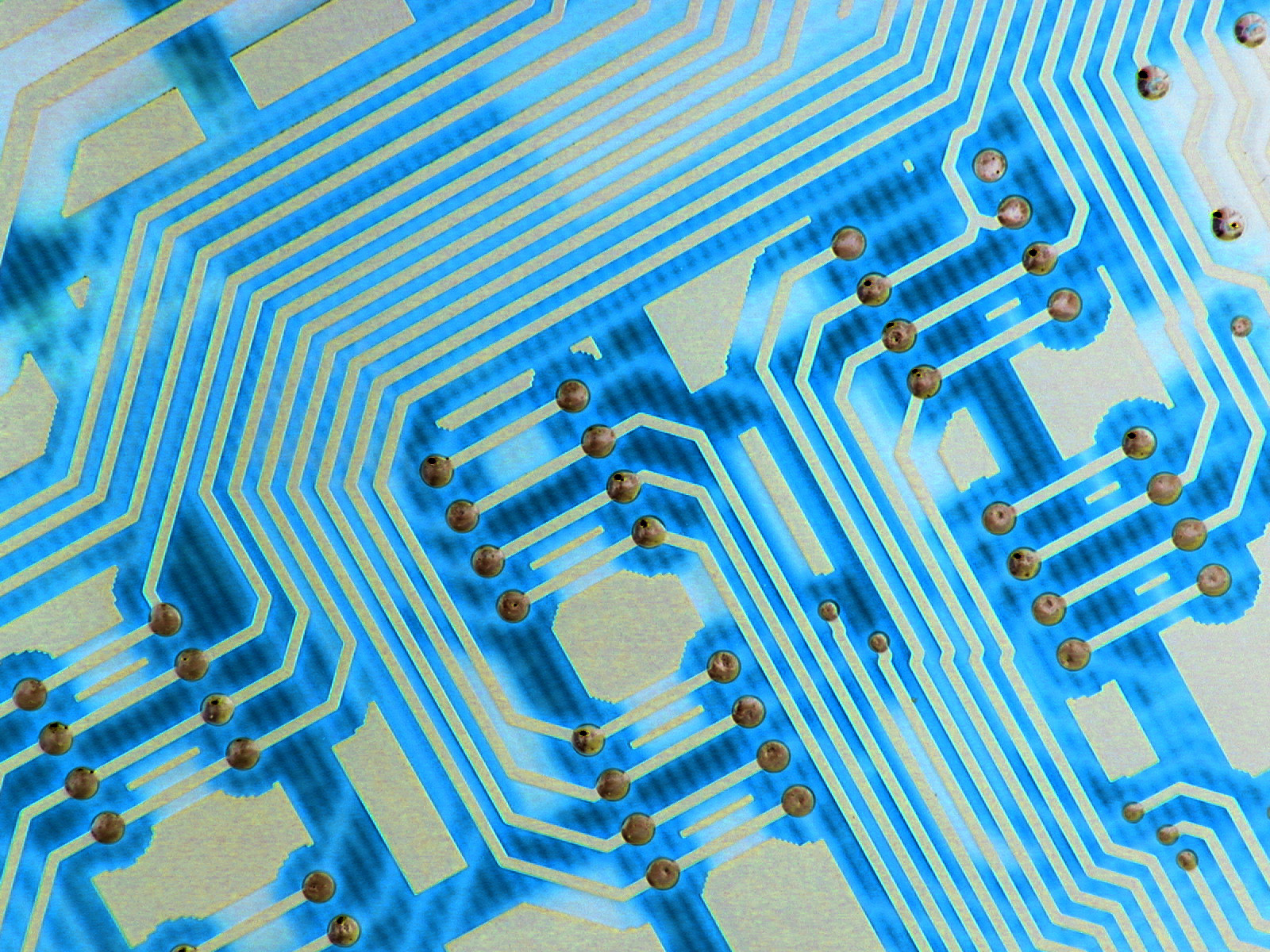
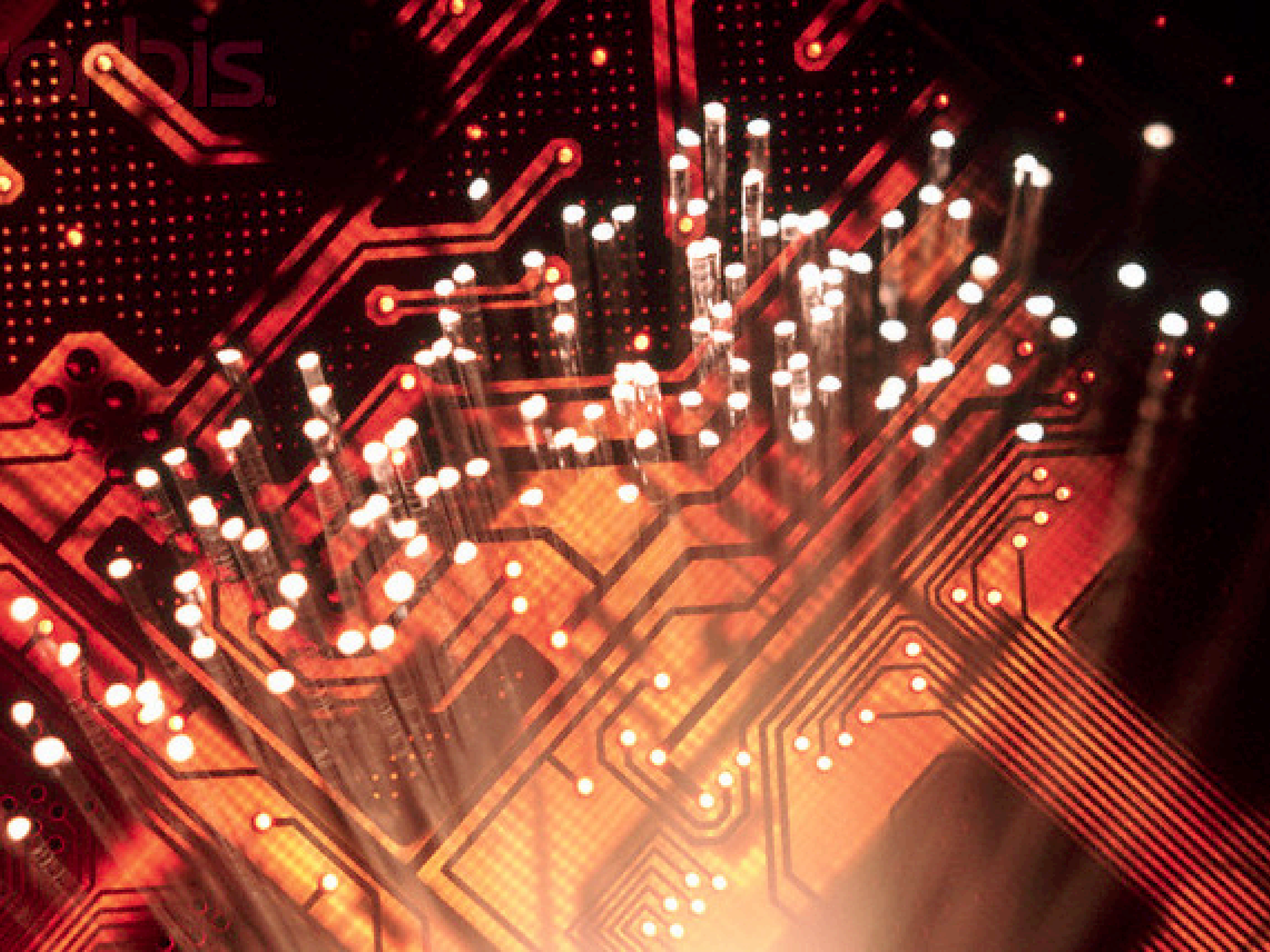
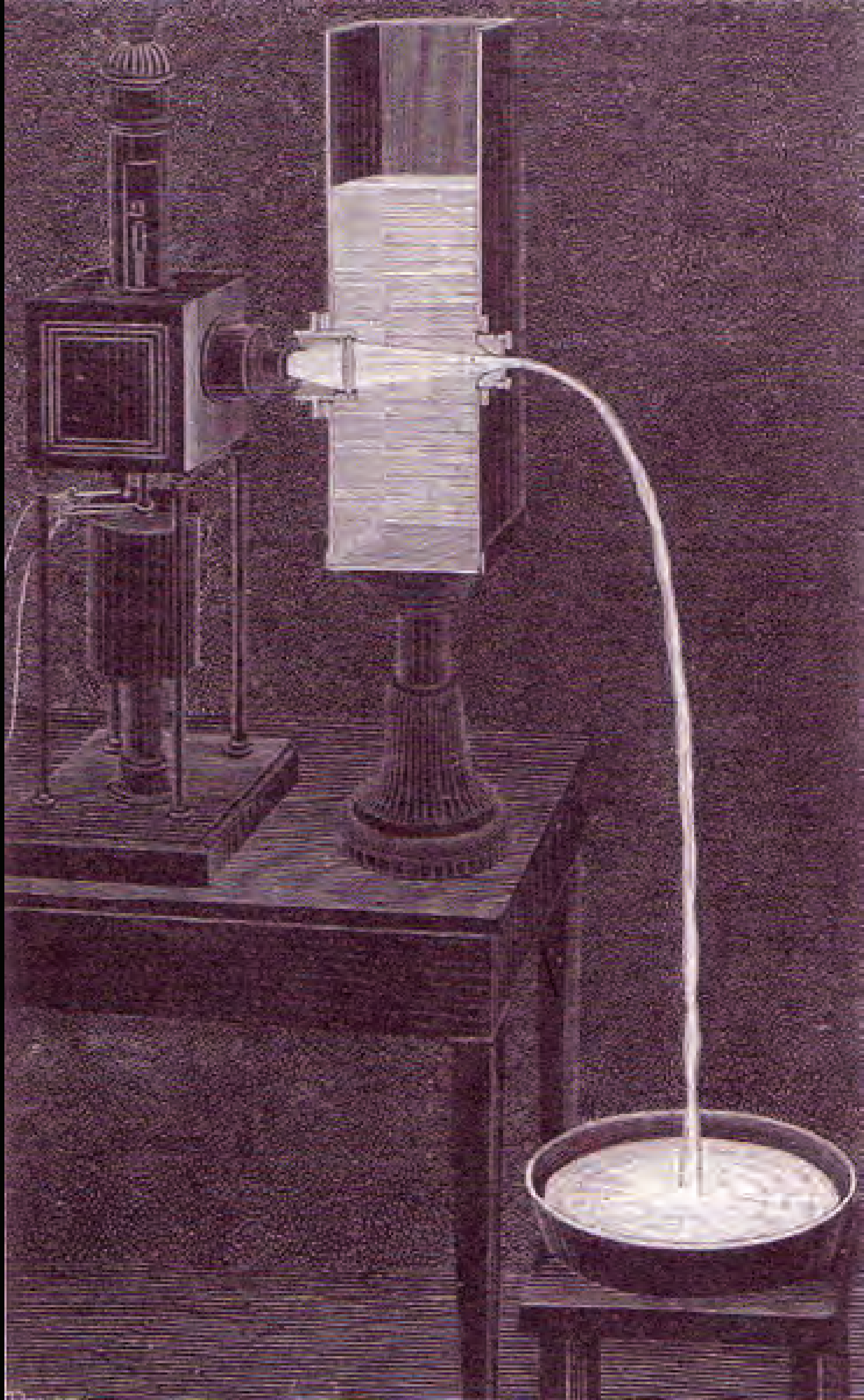


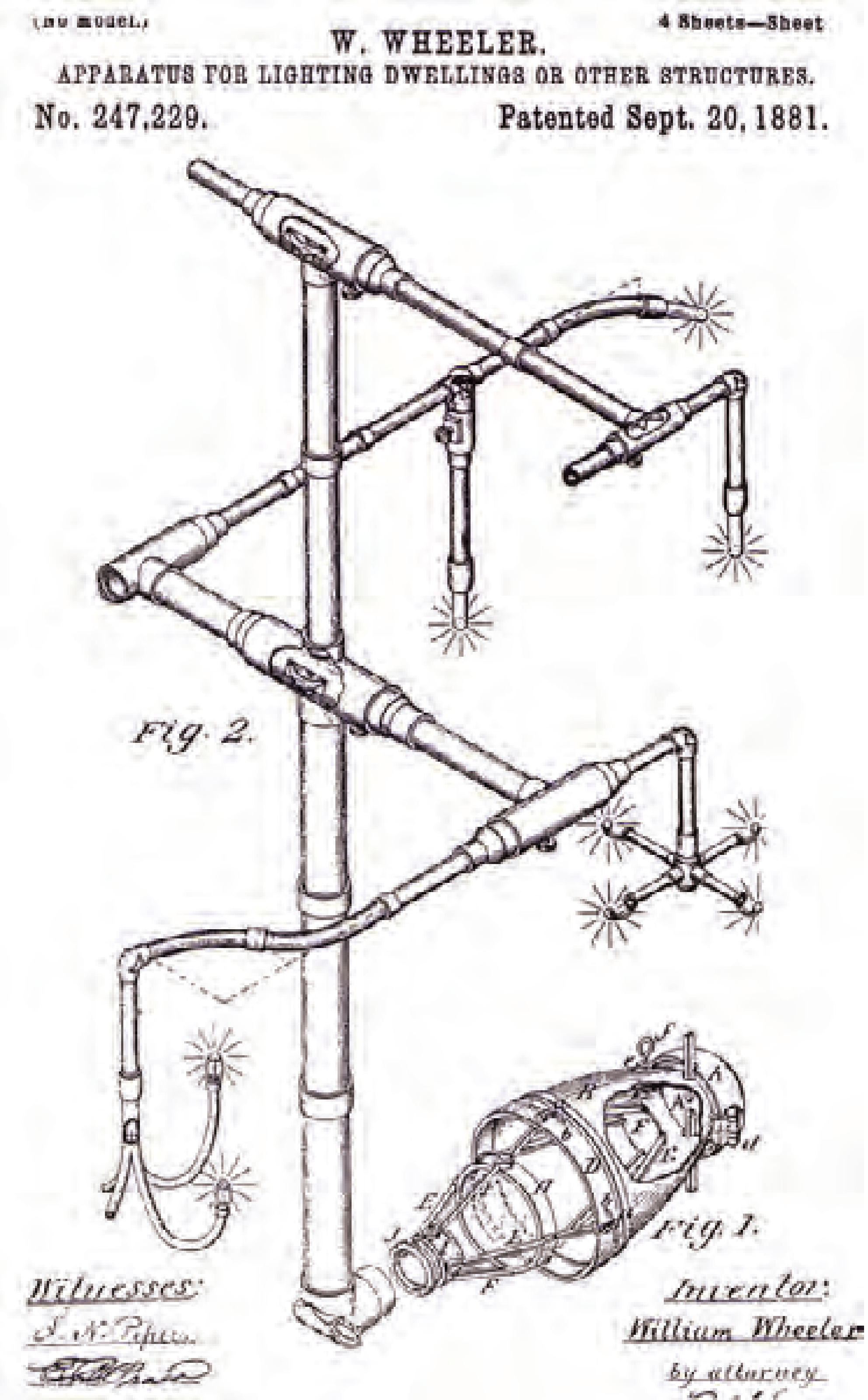


*“I managed to illuminate the interior of a stream in a dark space. I have discovered that this strange arrangement offers one of the most beautiful, and most curious experiments that one can perform in a course on Optics.“*

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



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



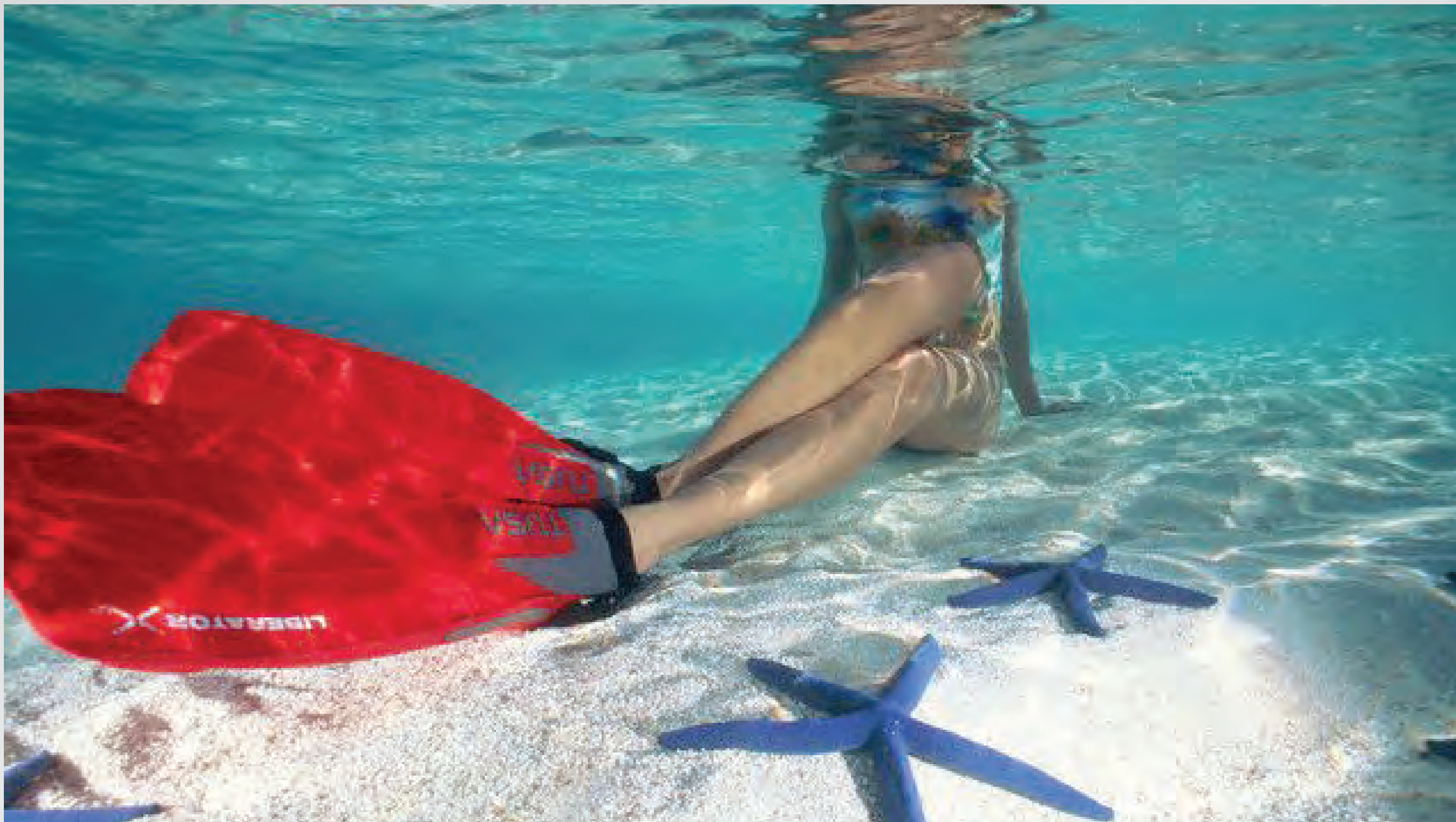

**US Patent 247, 229 (1881)**

# Outline

- waveguiding
- nanowire fabrication
- optical properties

# Waveguiding

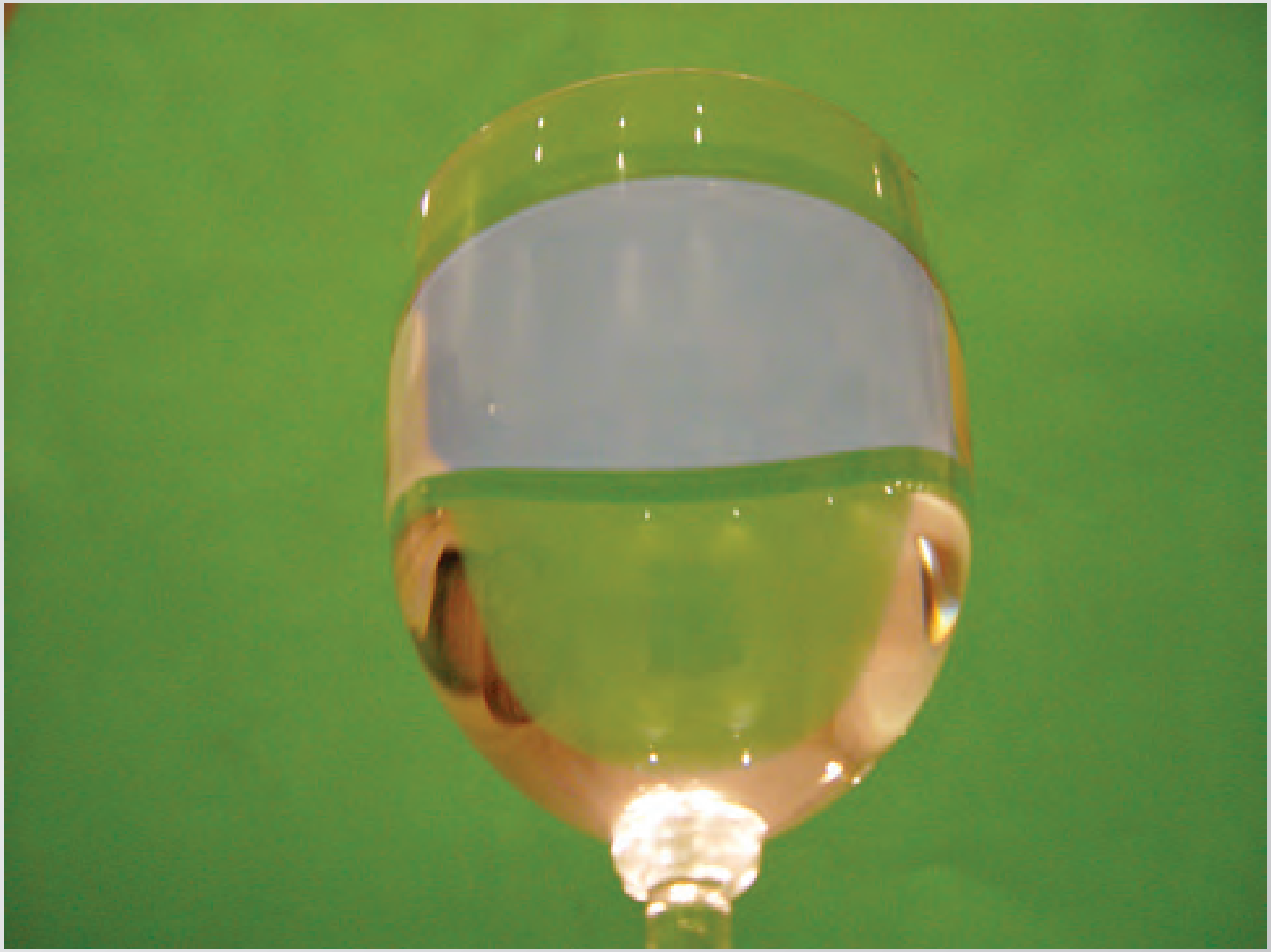
## how does water surface look from bottom?



# Waveguiding

**from top partially transmitting!**

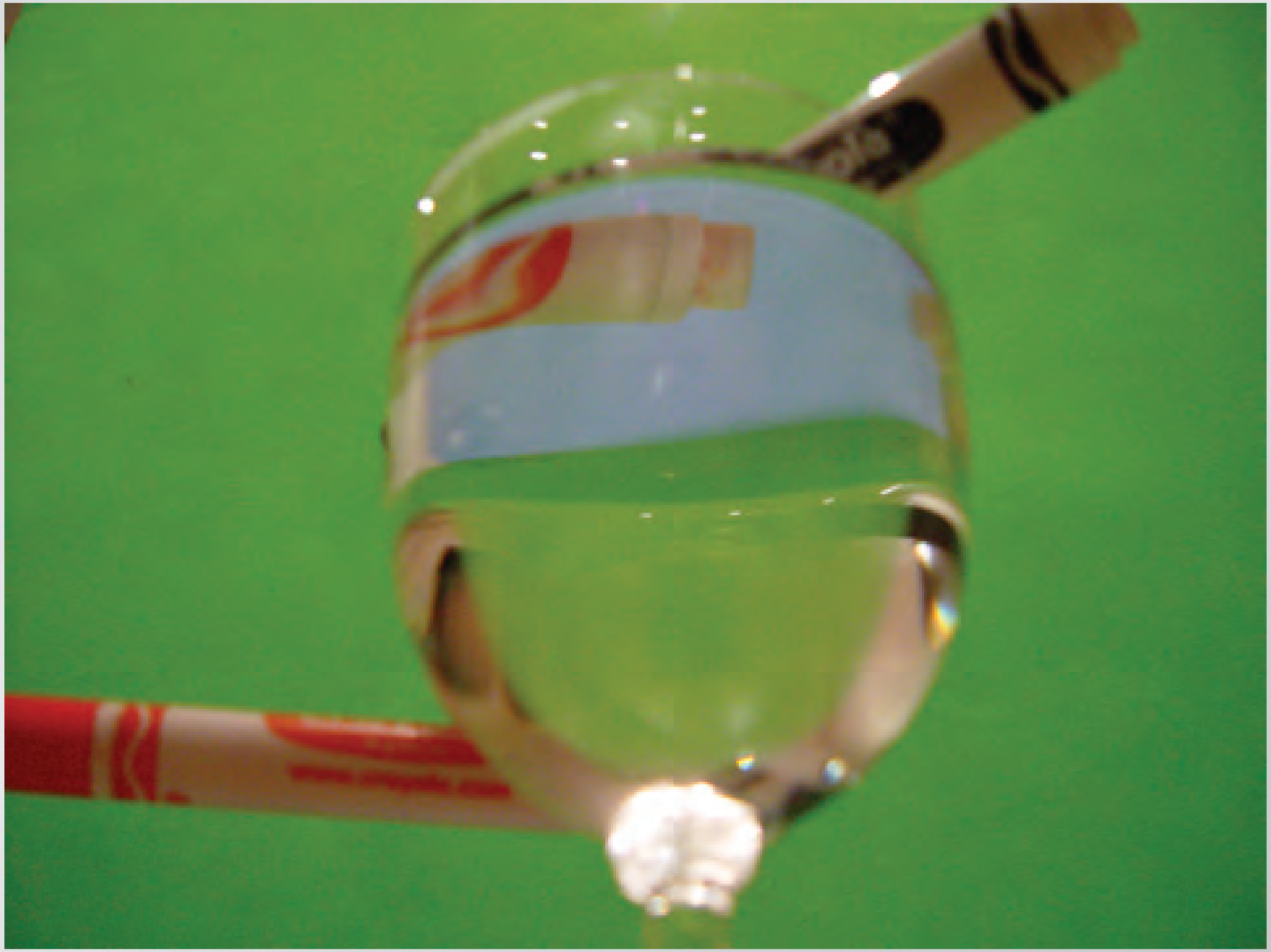
# Waveguiding



# Waveguiding

# Waveguiding

**water surface is perfect one-way mirror!**

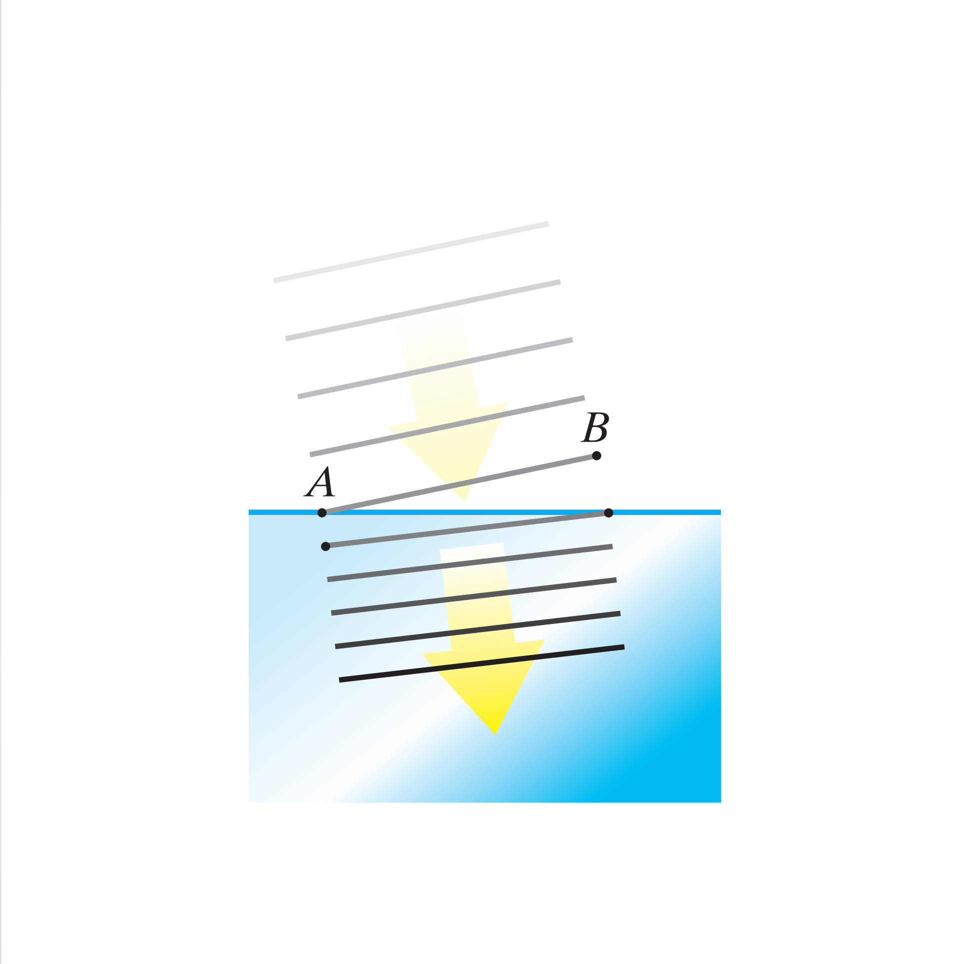


# Waveguiding

**Why? Because light travels more slowly in water…**

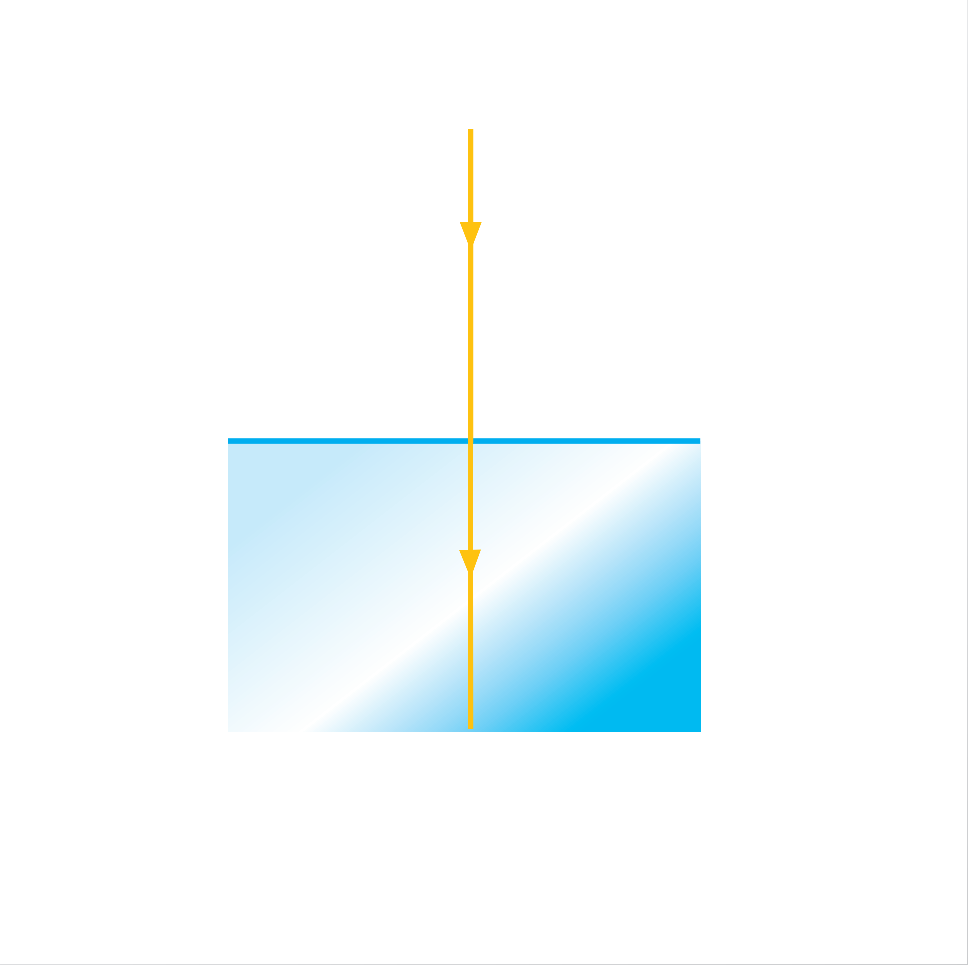
# Waveguiding

…making it bend as it crosses surface



# Waveguiding

The more angled the incident ray, the stronger the bending



# Waveguiding

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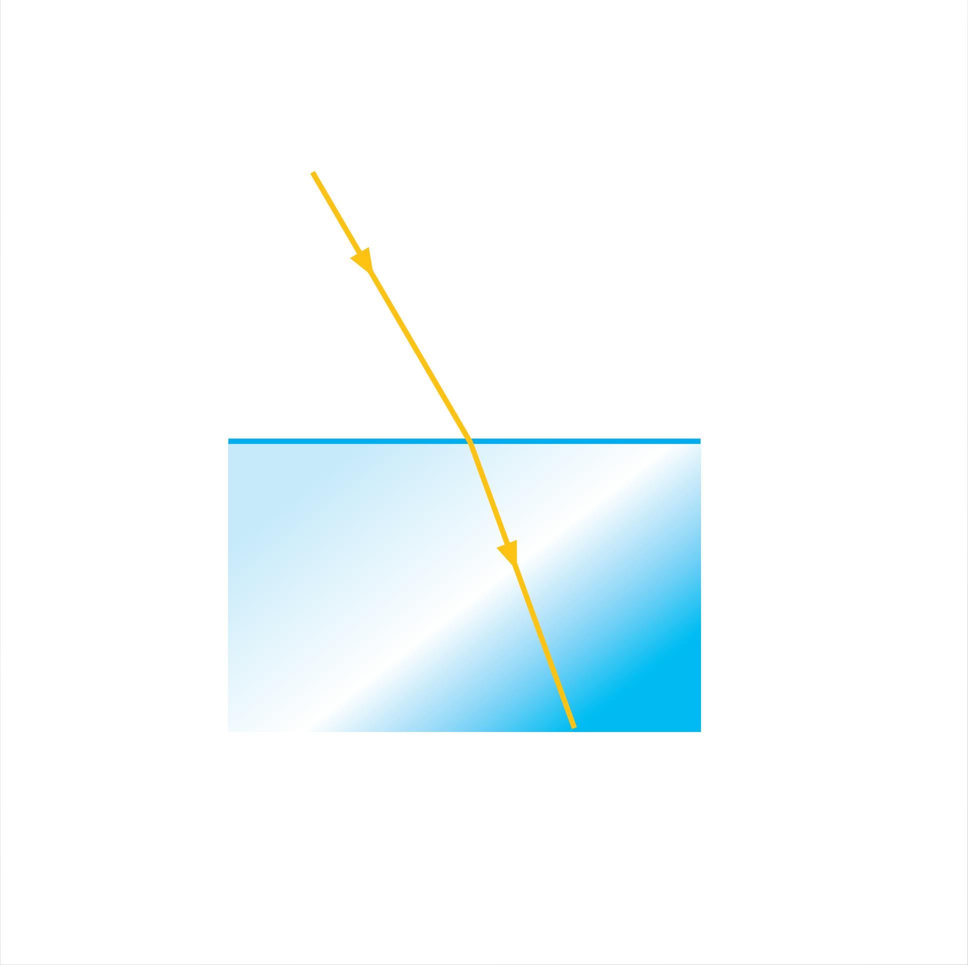
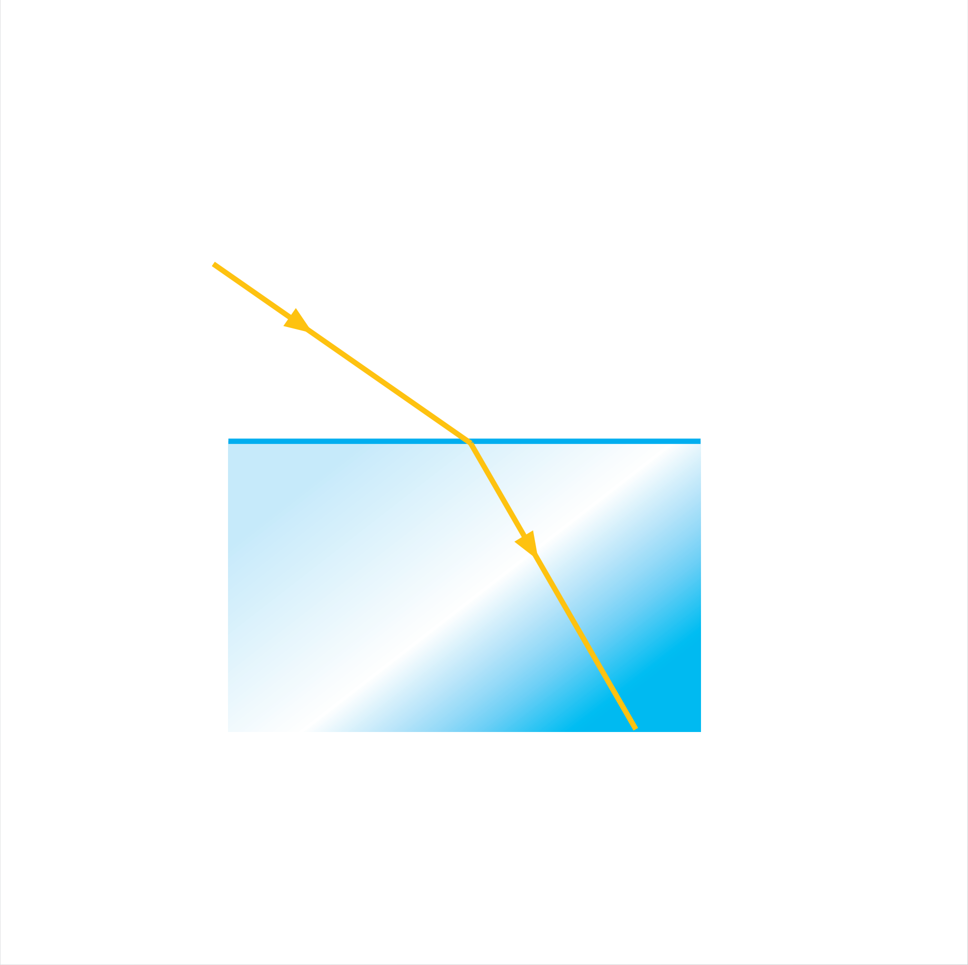


# Waveguiding

**The more angled the incident ray, the stronger the bending**



# Waveguiding

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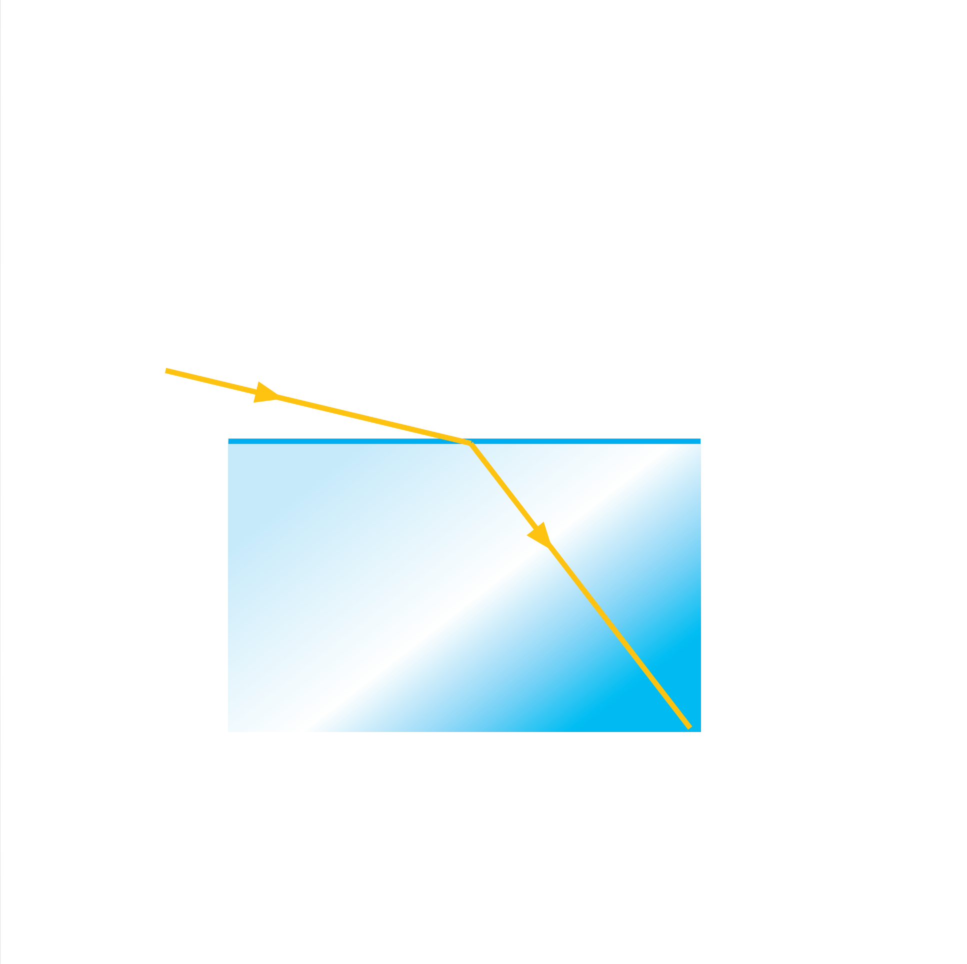
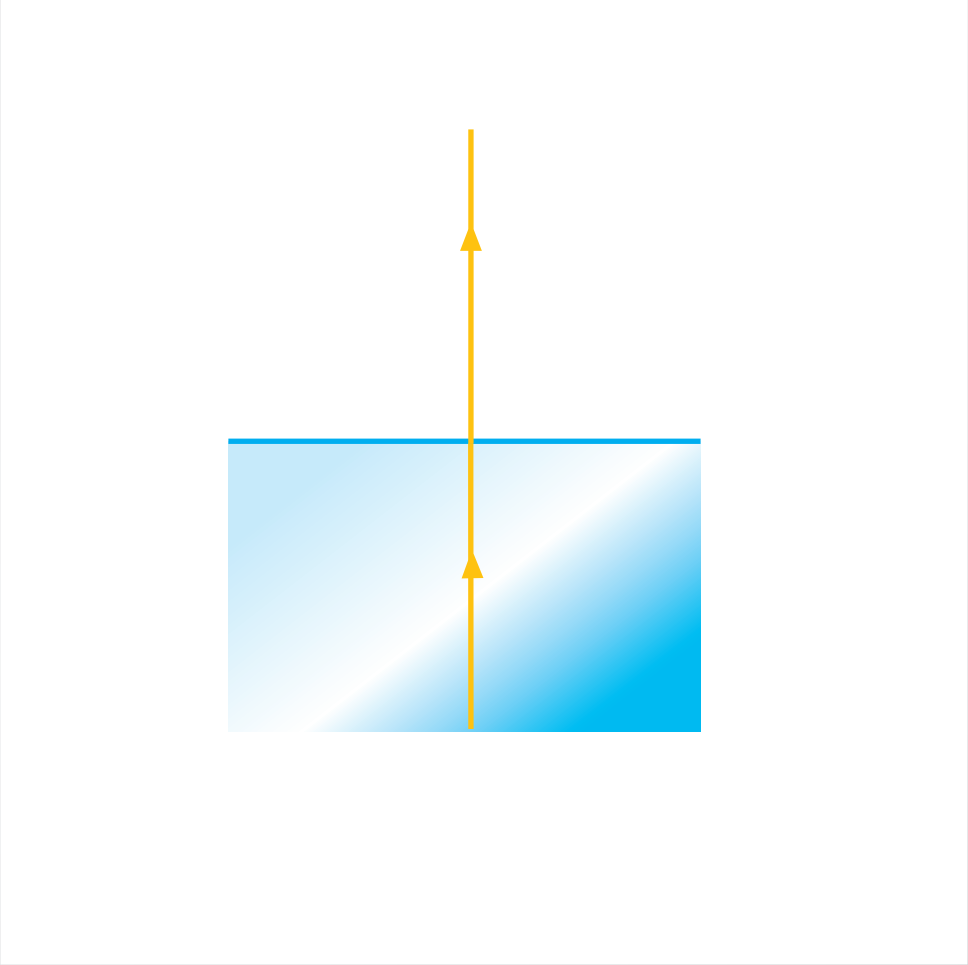


# Waveguiding

## The amount of bending is the same in reverse



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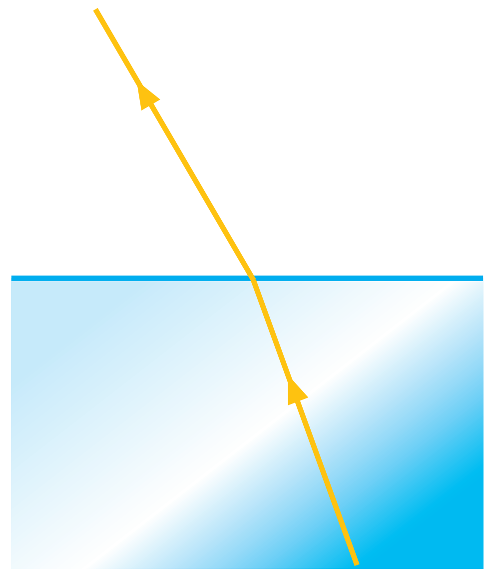

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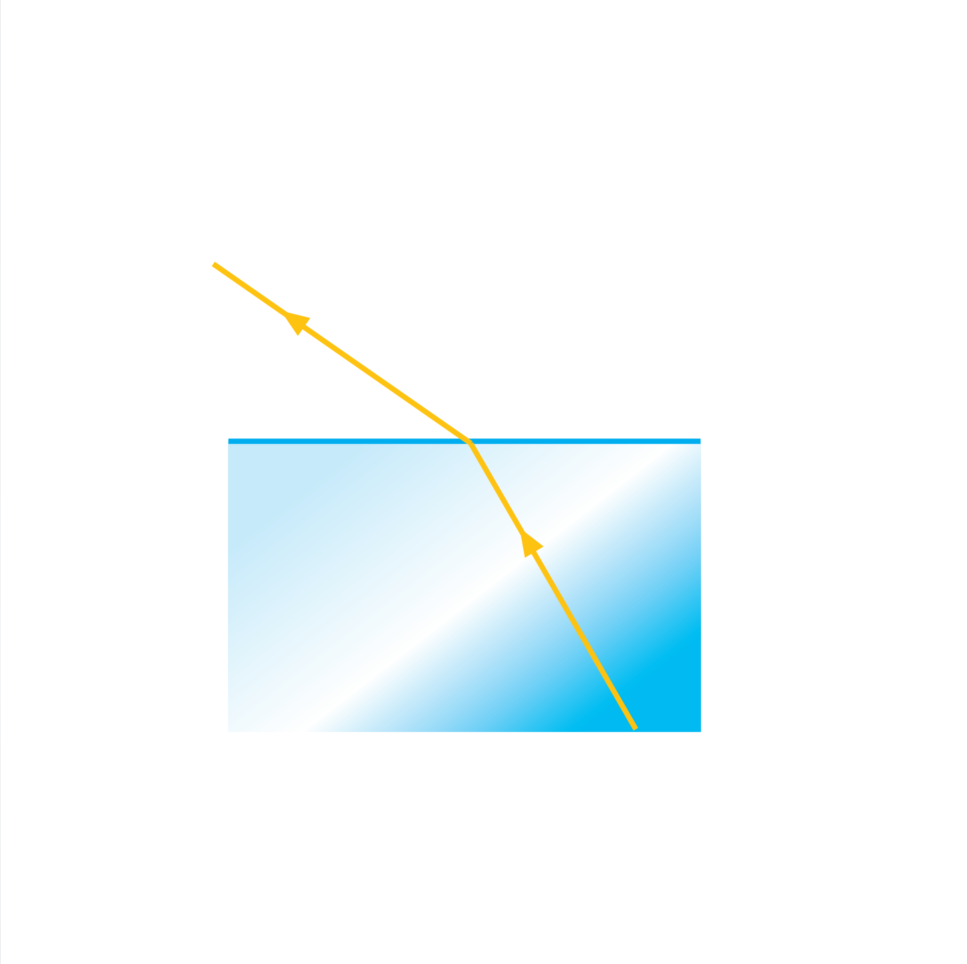

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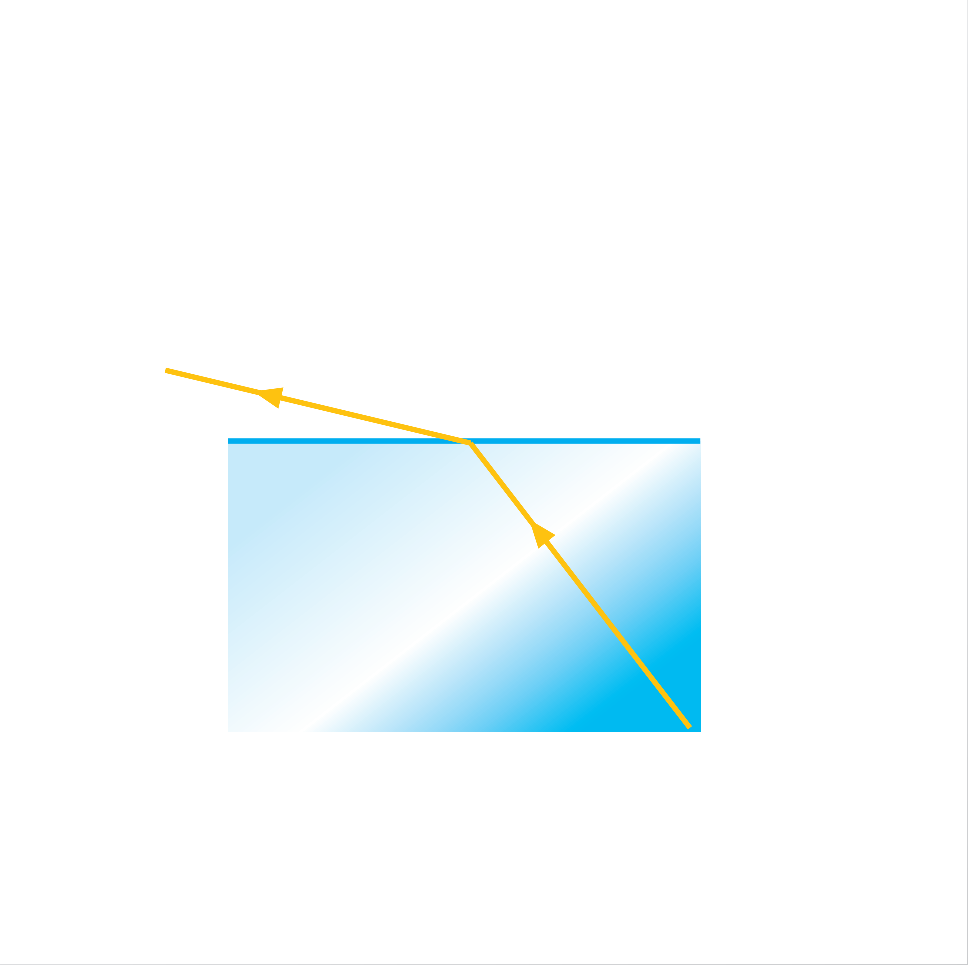
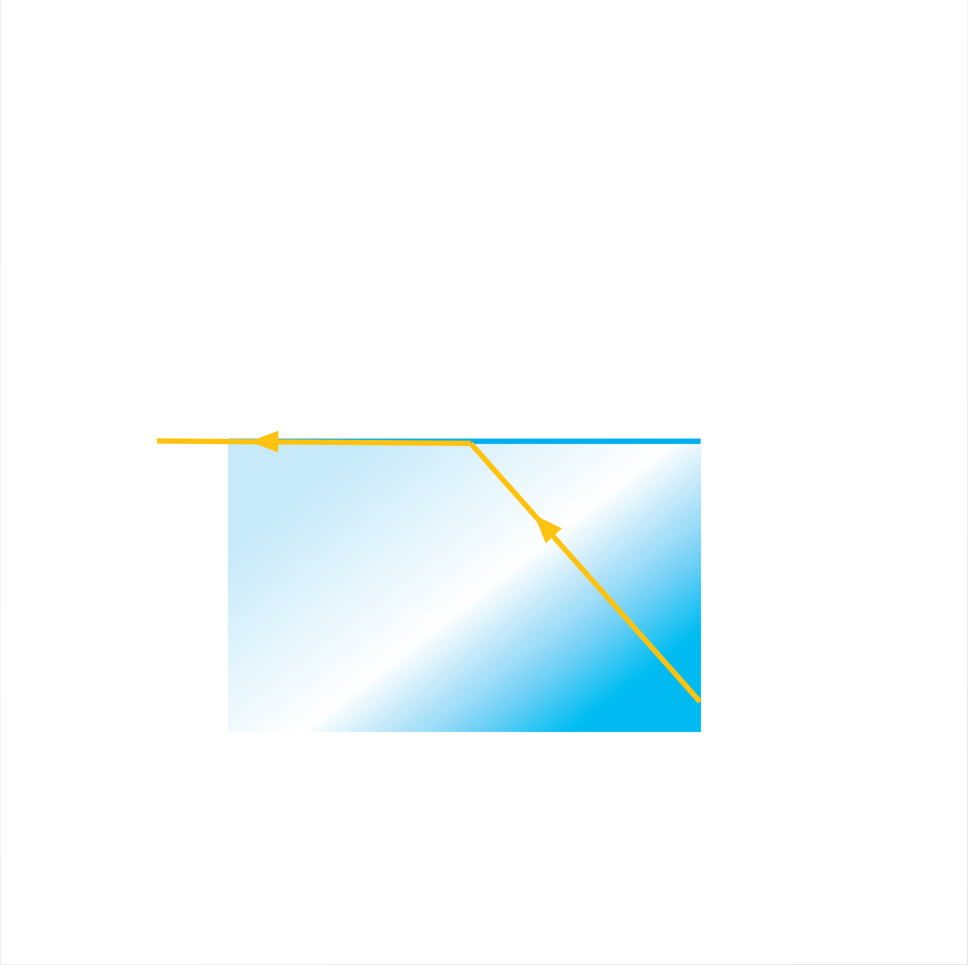


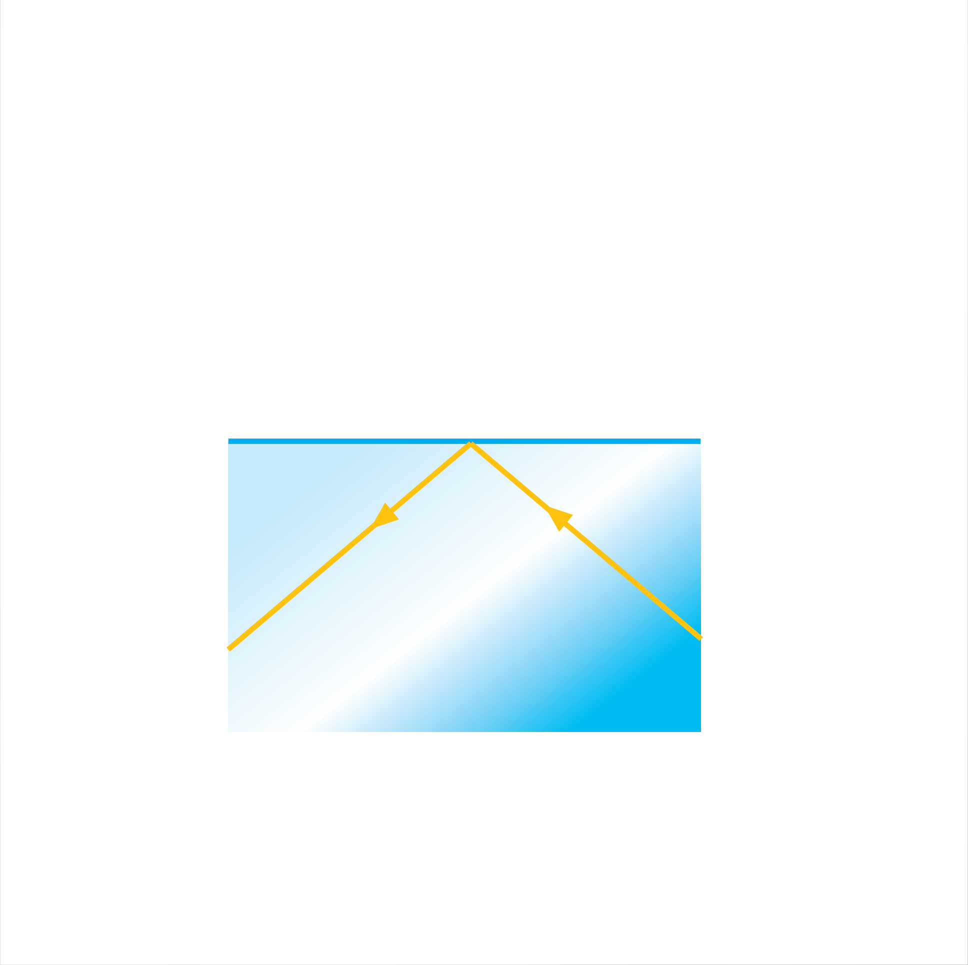
# Waveguiding

## At 'critical angle' bent ray travels along surface



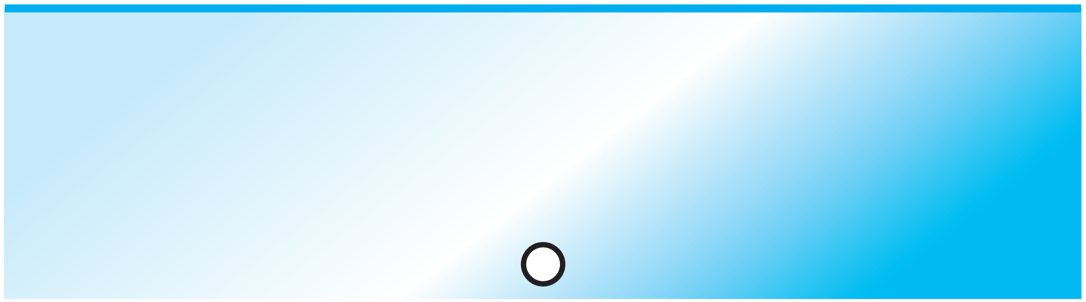
# Waveguiding

## Beyond 'critical angle': total internal reflection



# Waveguiding

## seeing underwater



# Waveguiding

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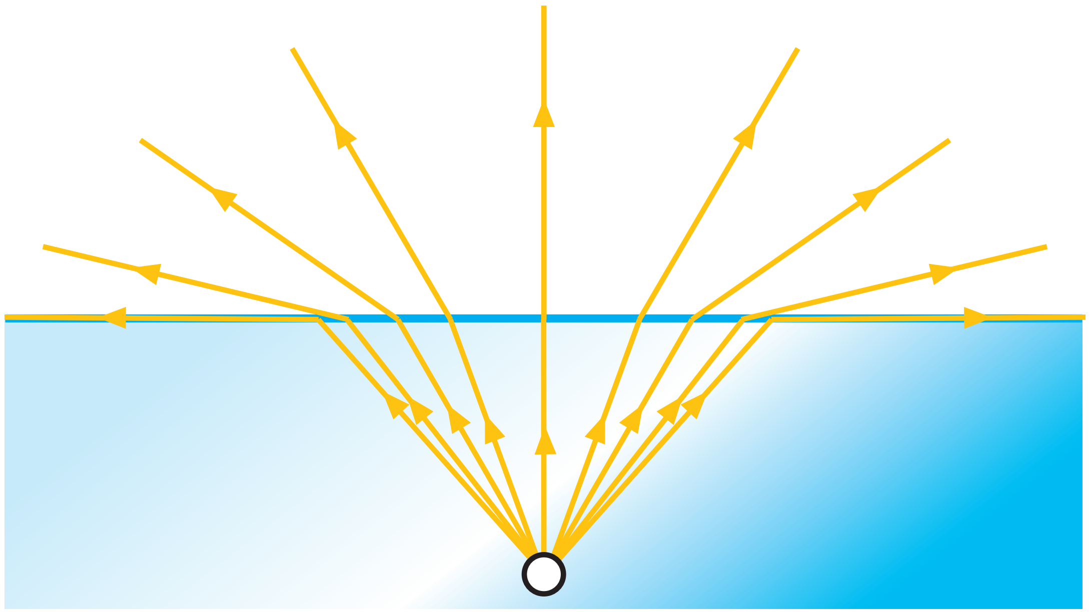
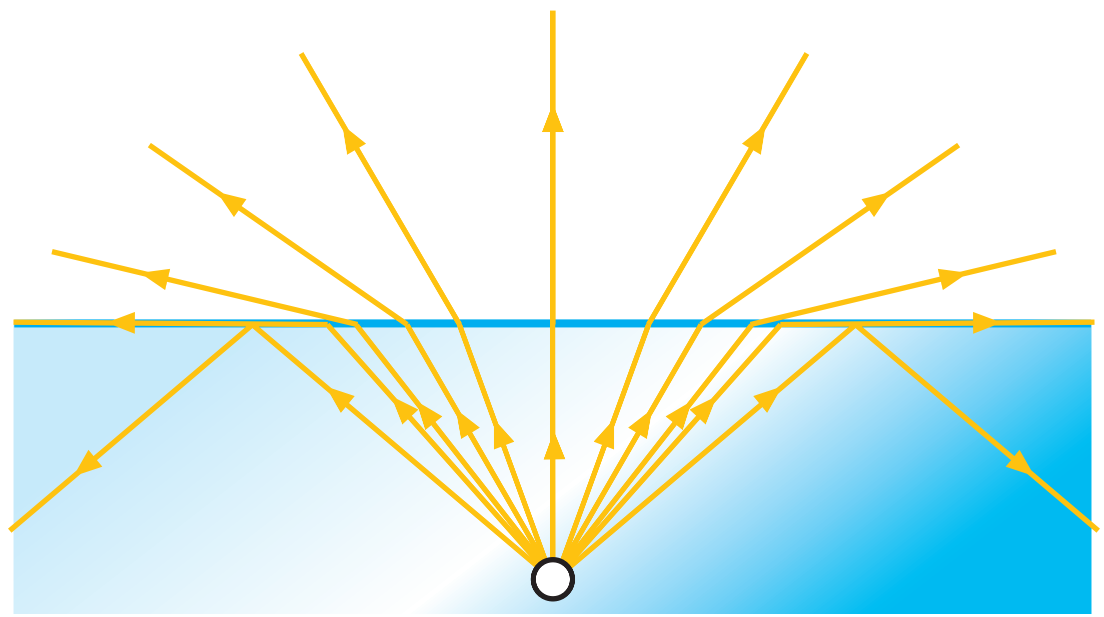


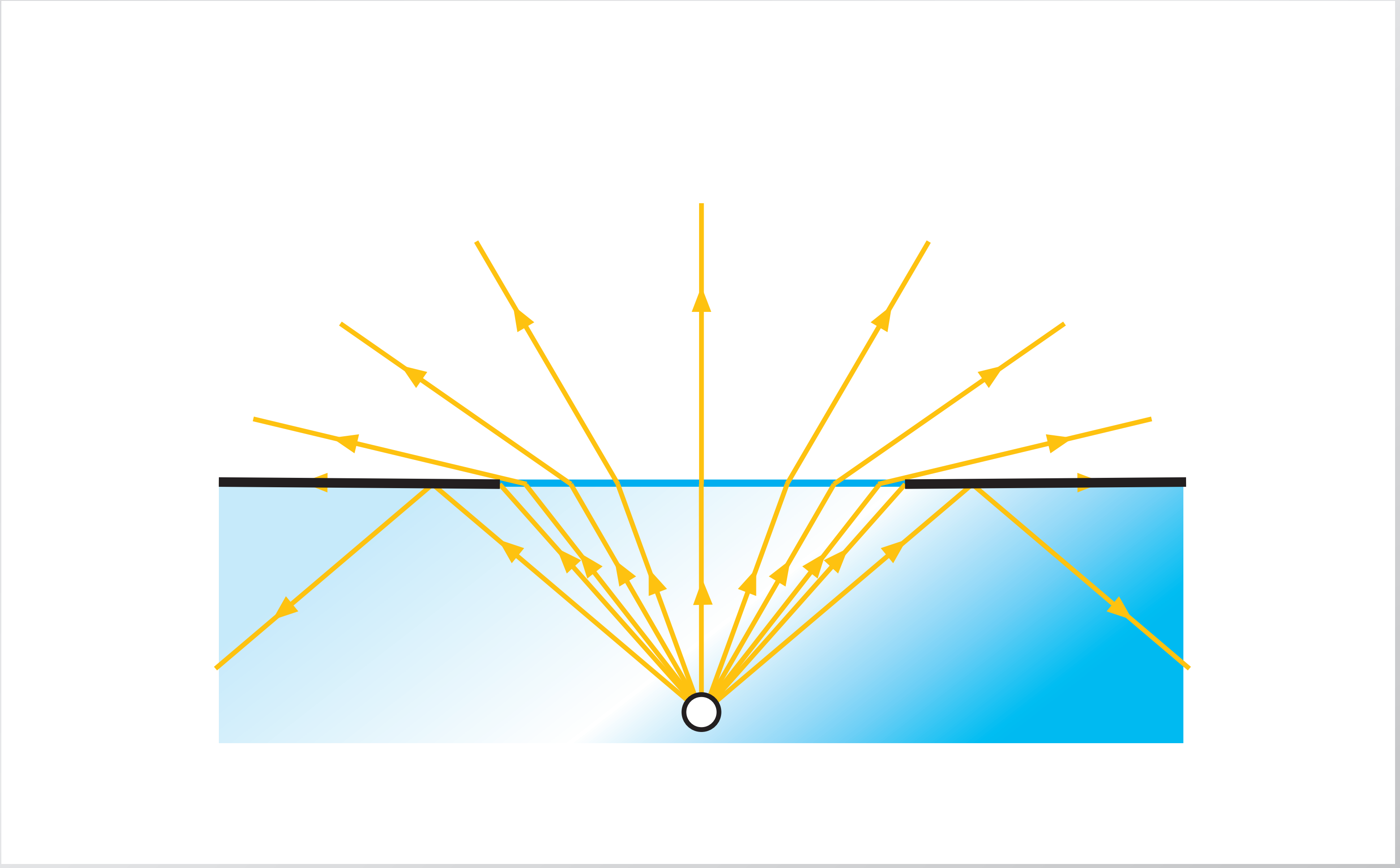
# Waveguiding

## seeing underwater



# Waveguiding

surface looks like mirror with a circular hole



# Waveguiding

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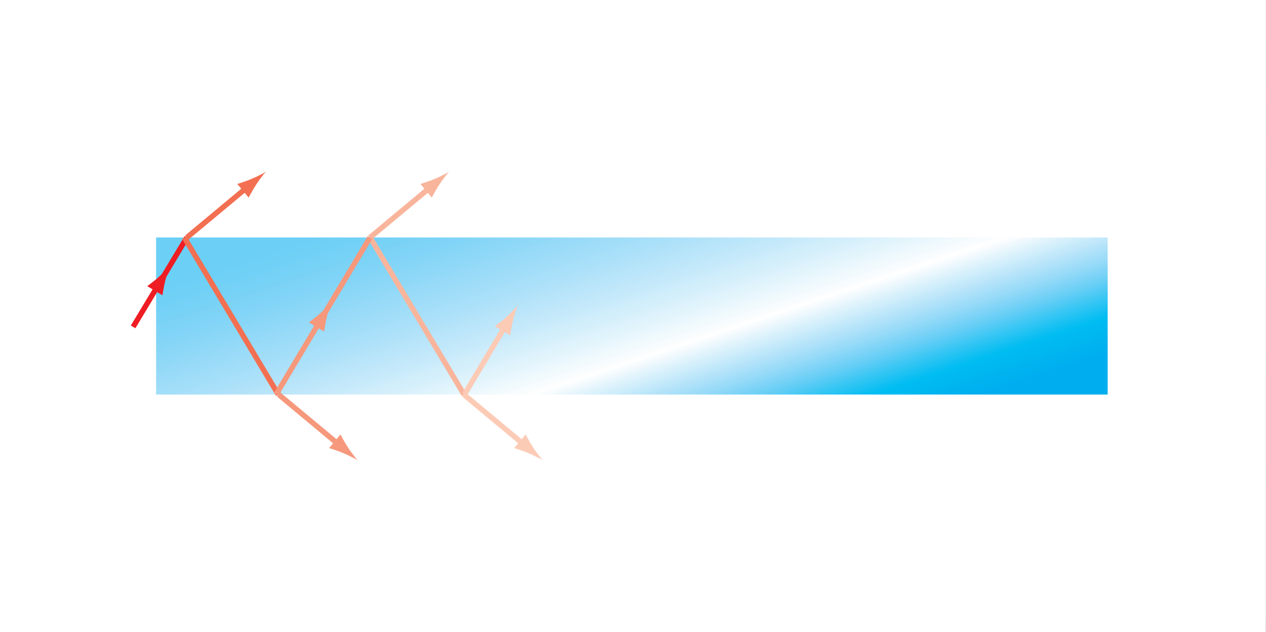
# Waveguiding

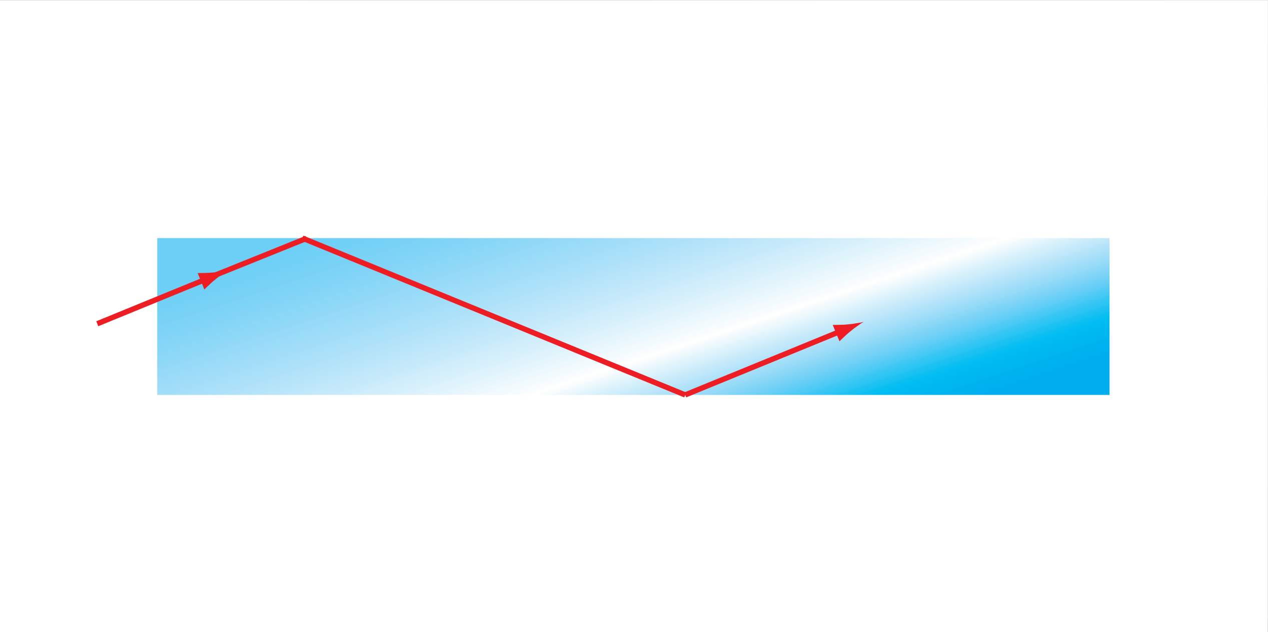
**now consider a planar dielectric waveguide**

# 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

# Outline

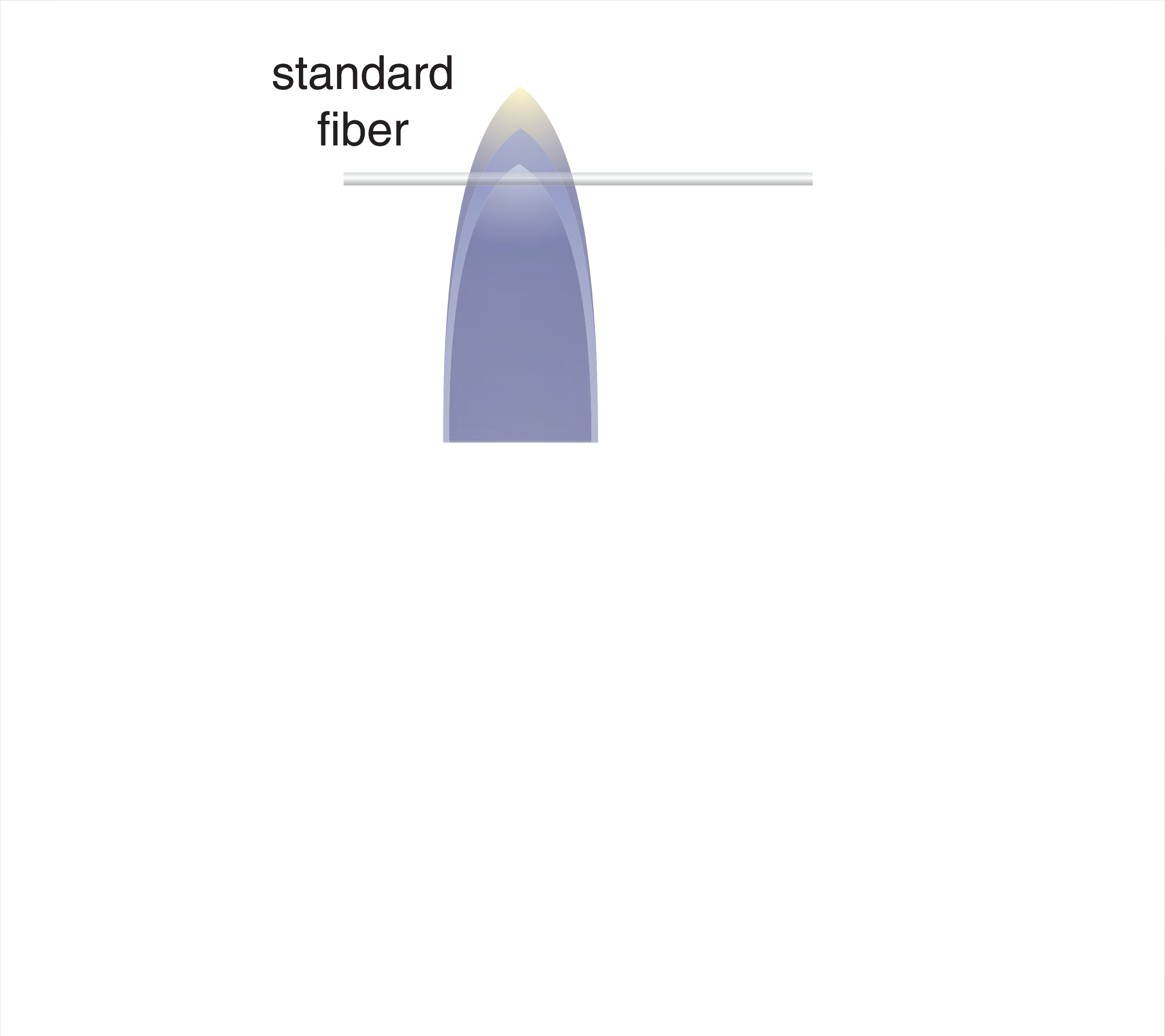
- waveguiding
- **nanowire fabrication**
- optical properties

# Nanowire fabrication

## two-step drawing process

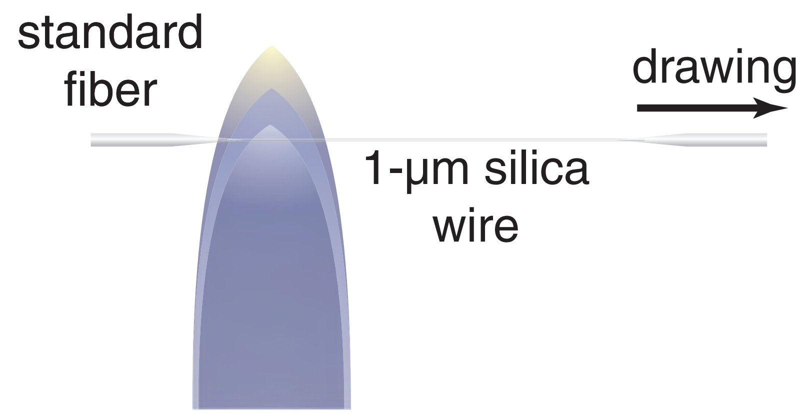
# Nanowire fabrication

## two-step drawing process



# Nanowire fabrication

## two-step drawing process



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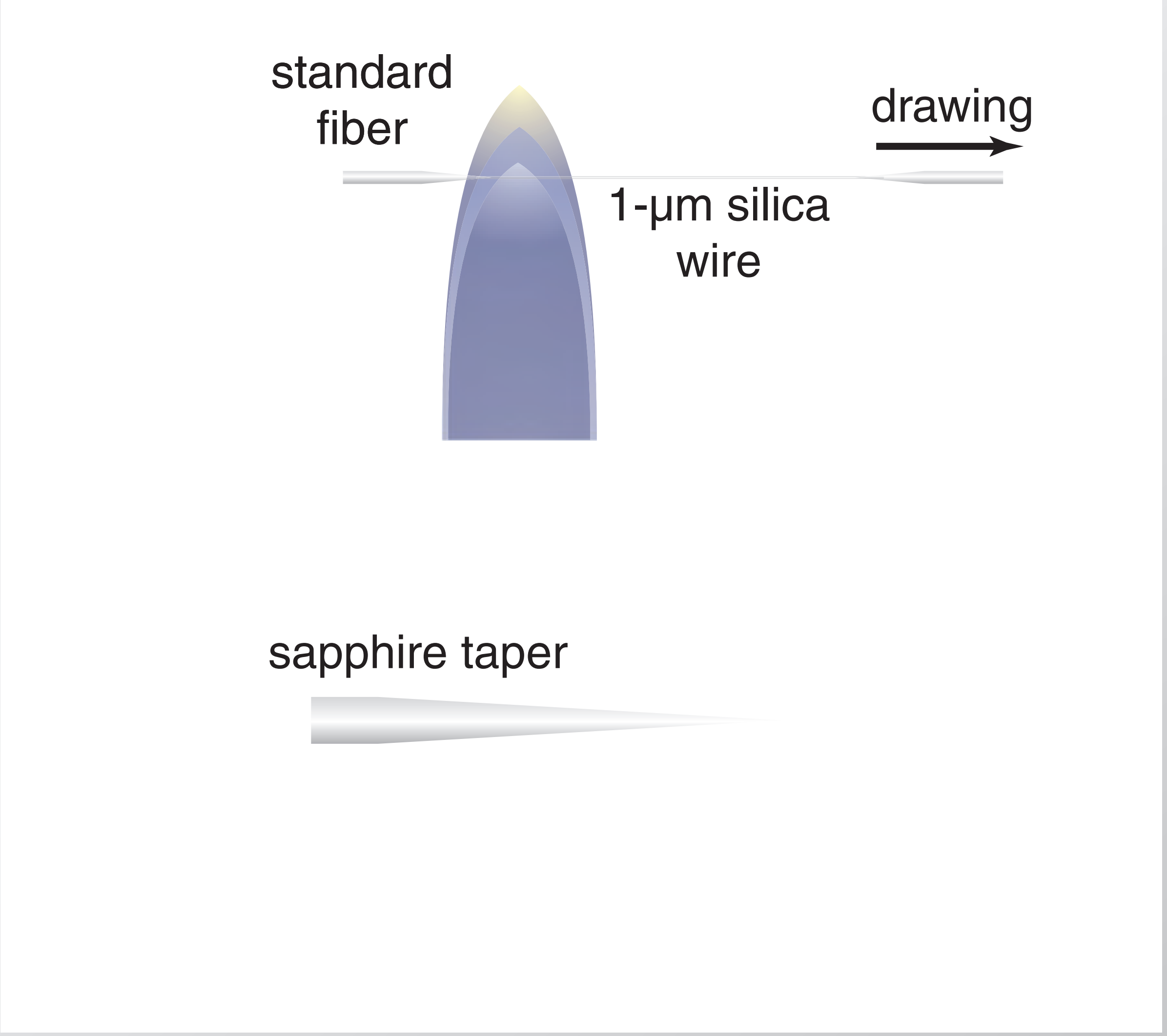

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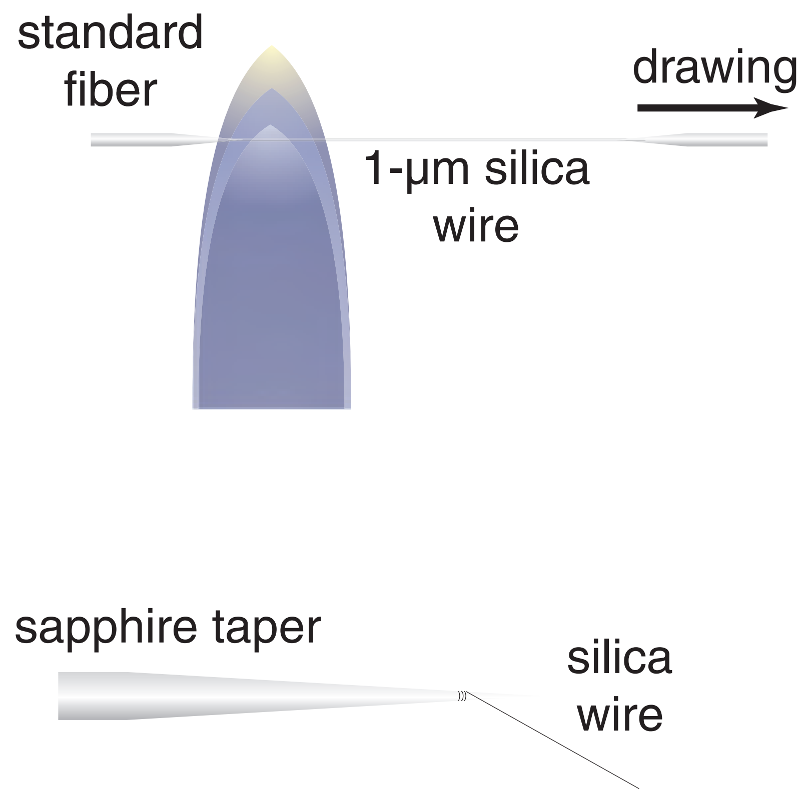
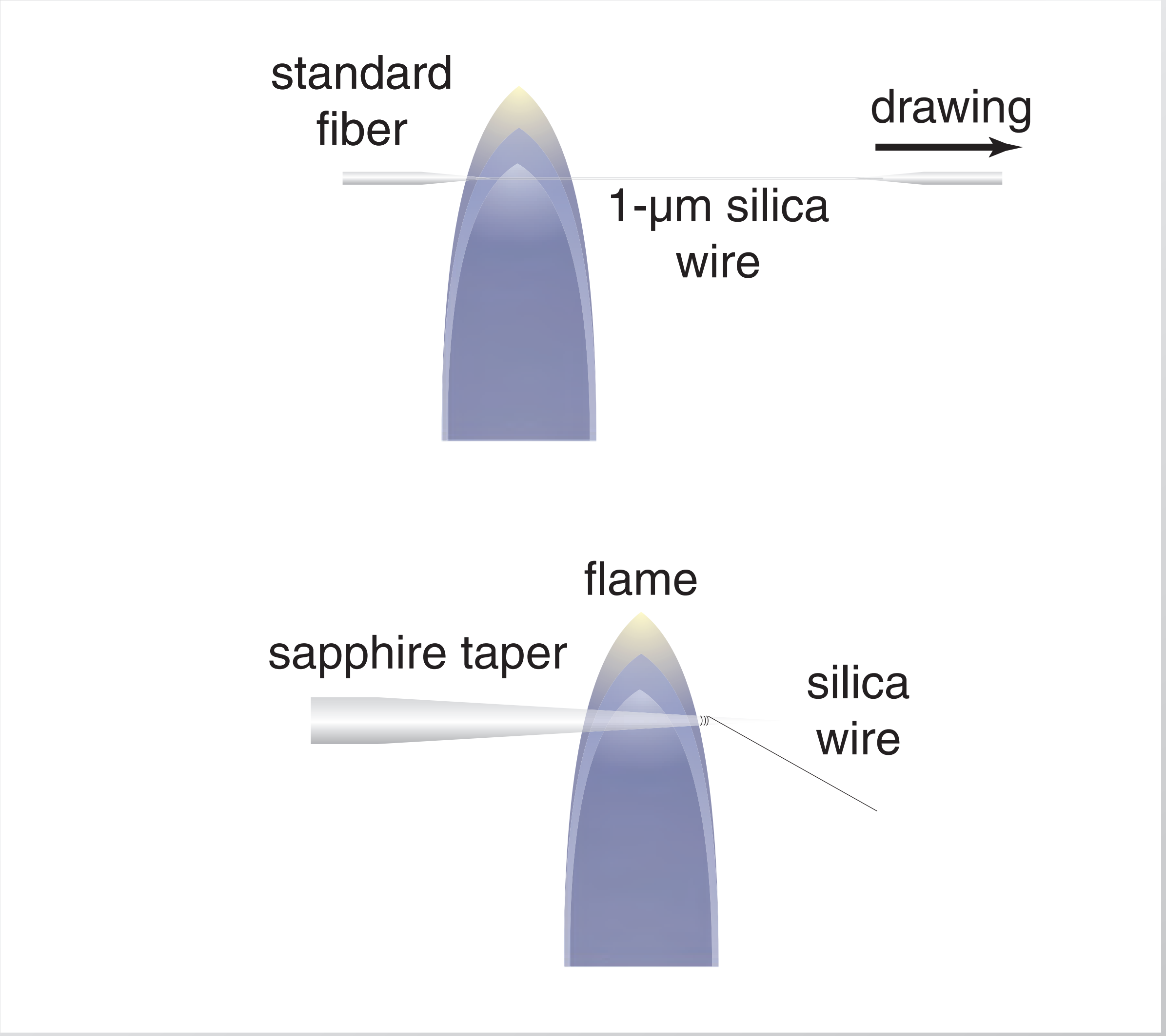


# Nanowire fabrication

## two-step drawing process



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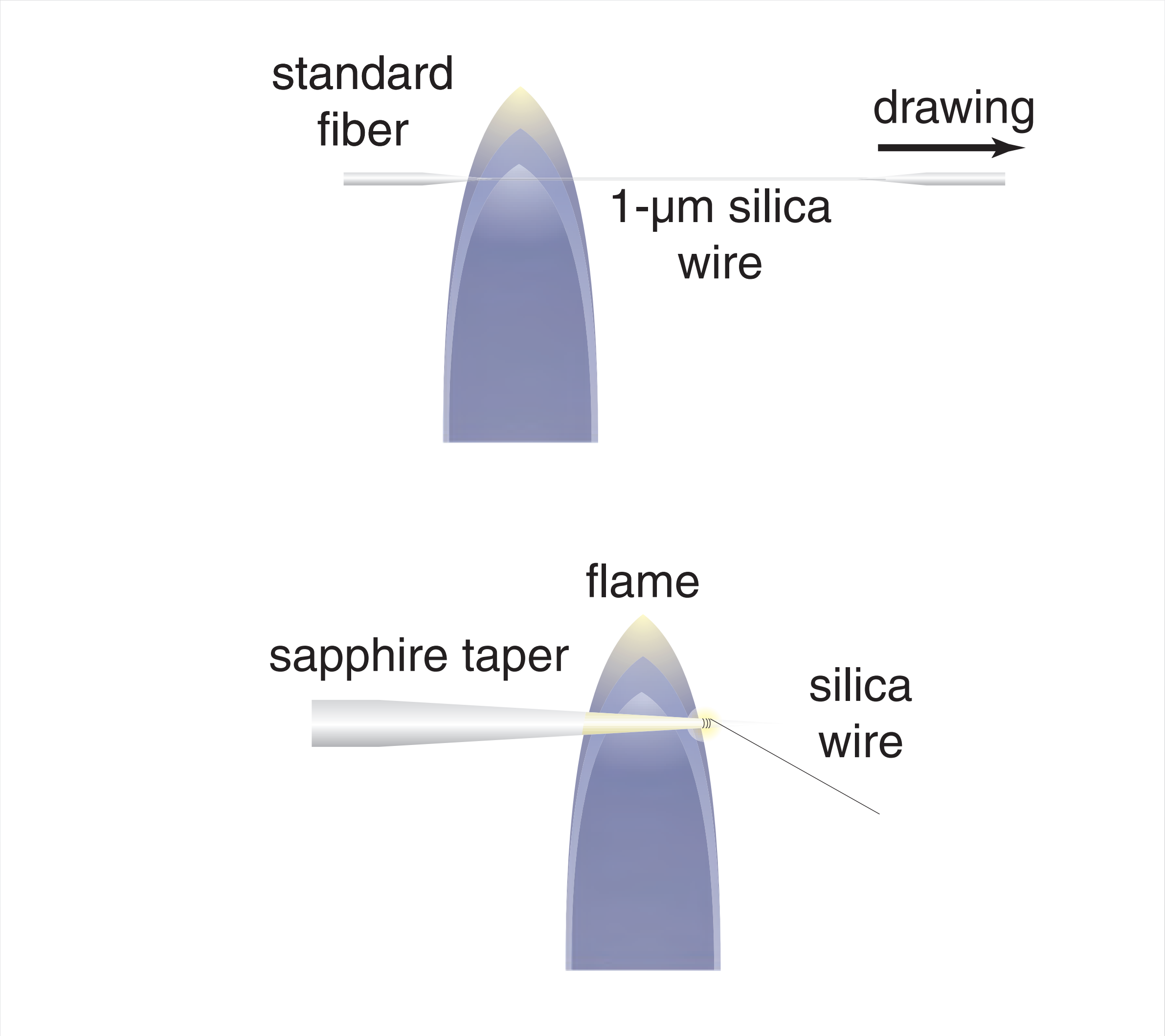

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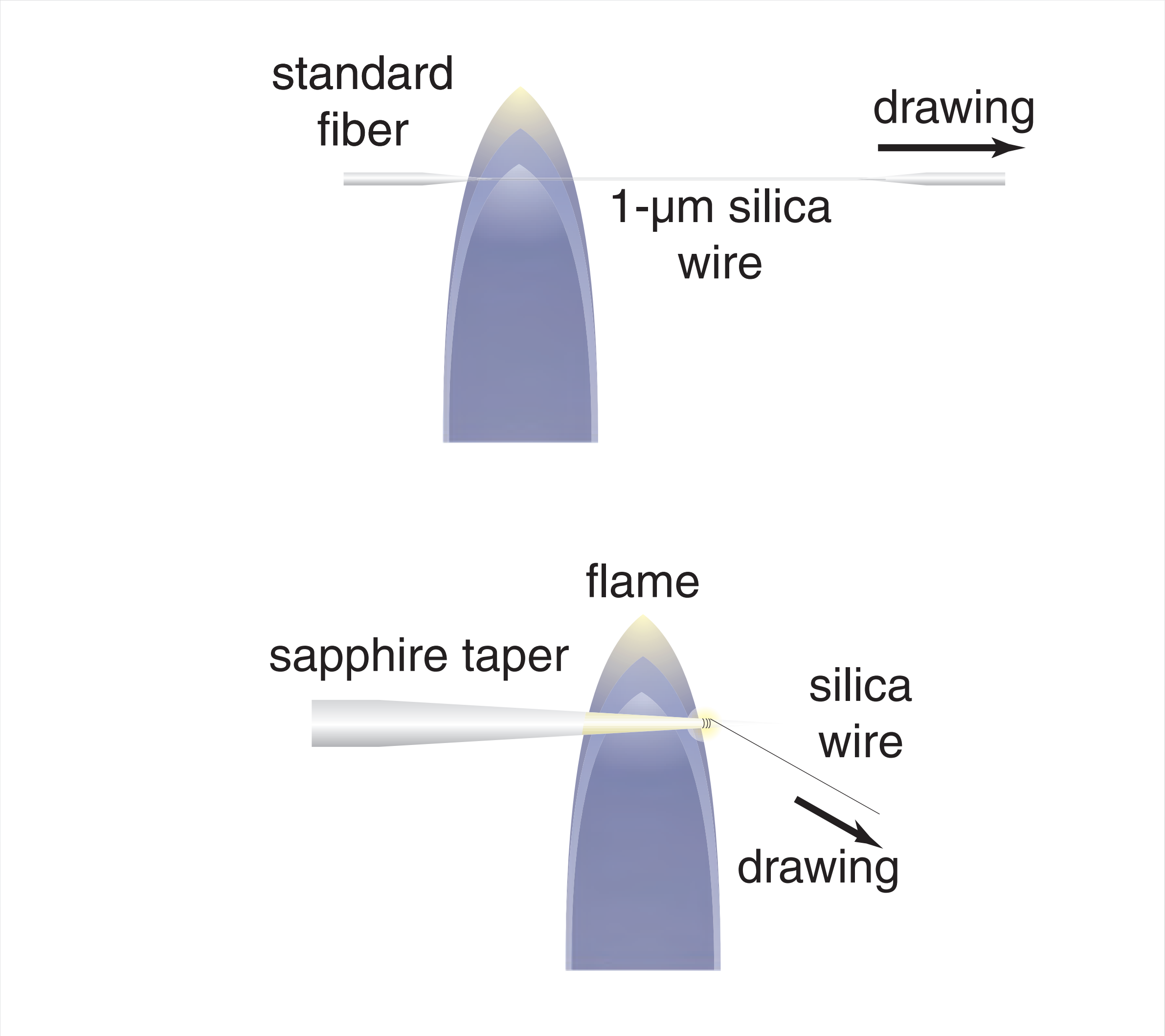

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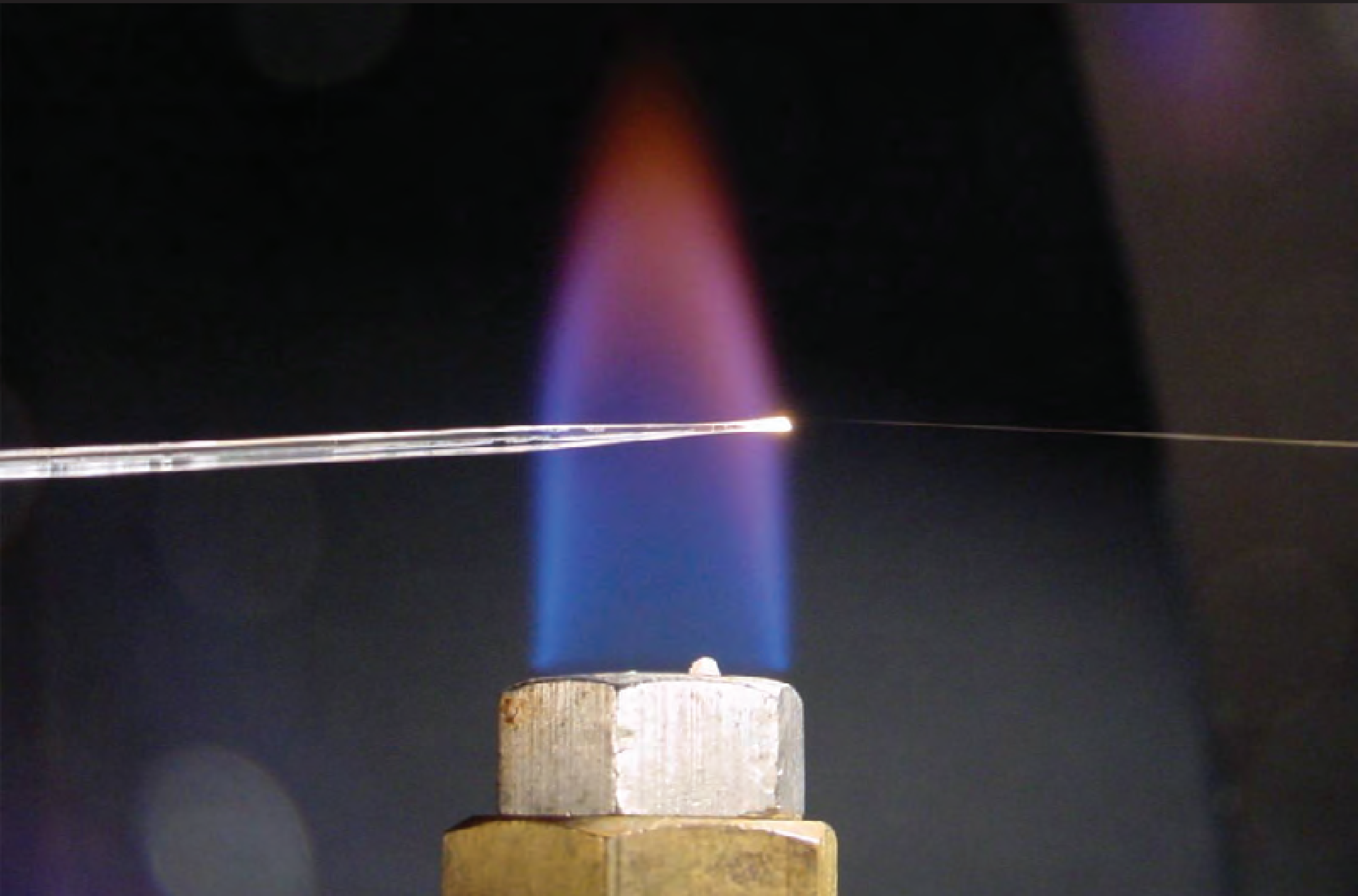

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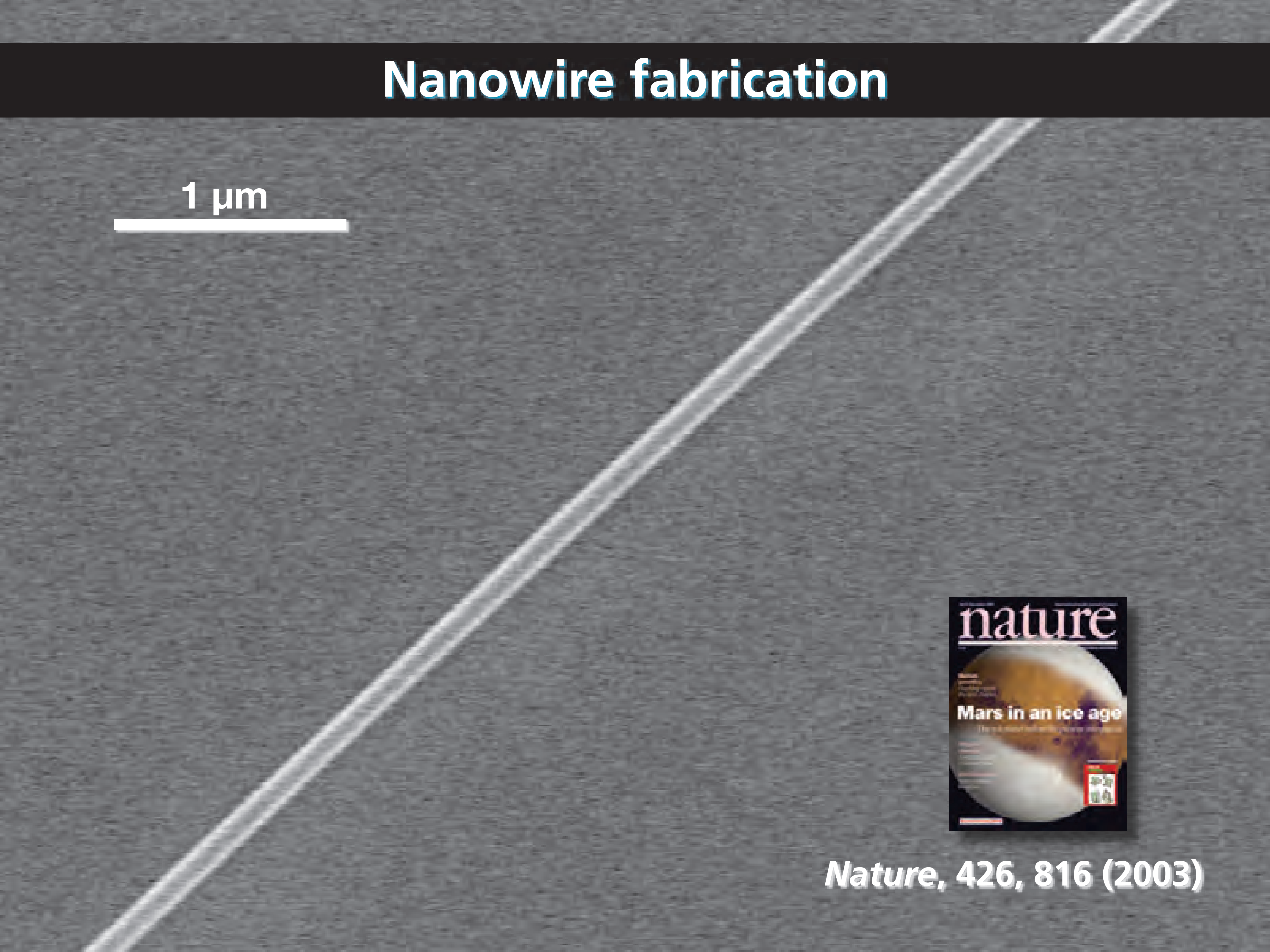
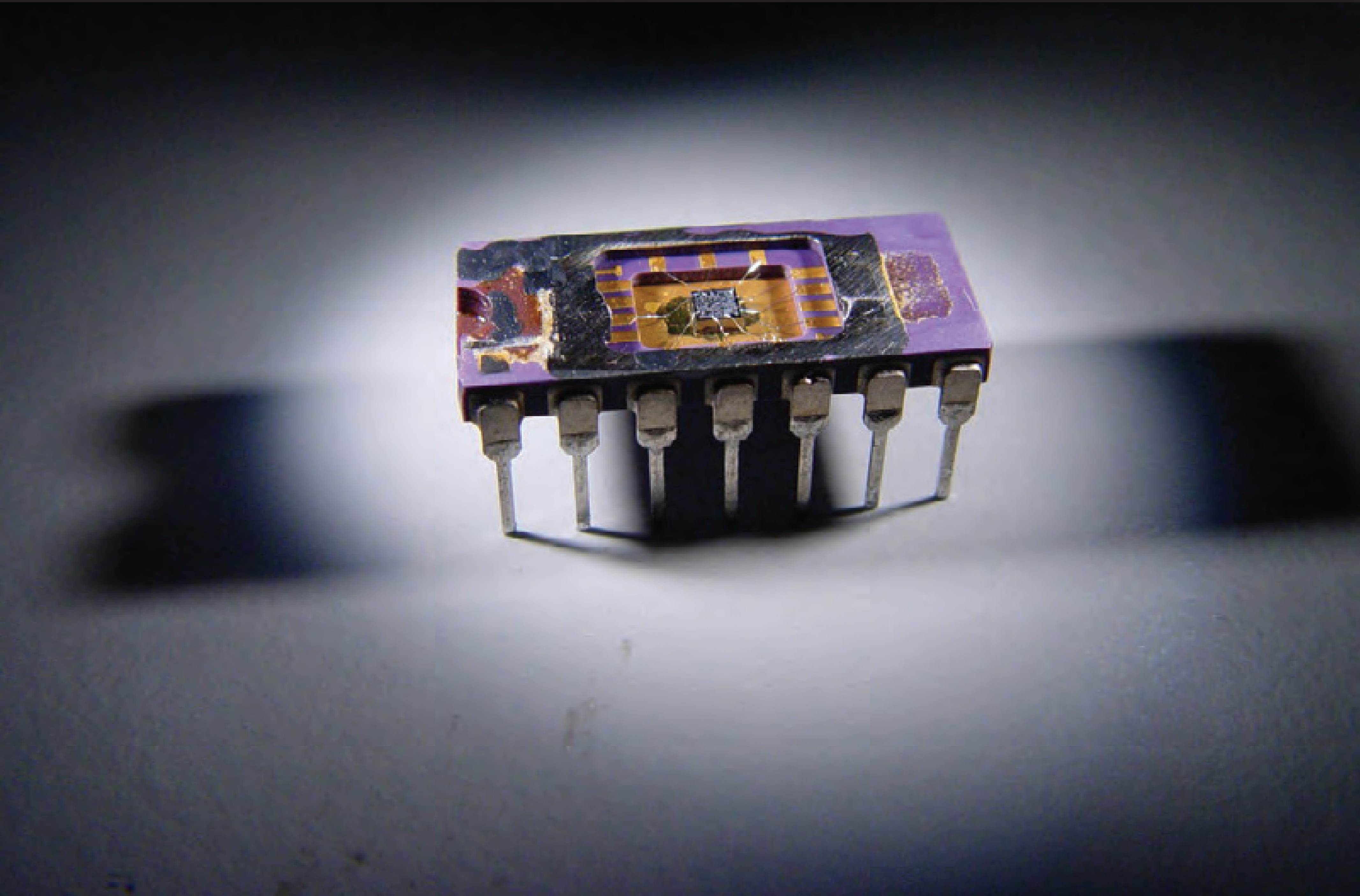



*Nature*, 426, 816 (2003)

# Nanowire fabrication



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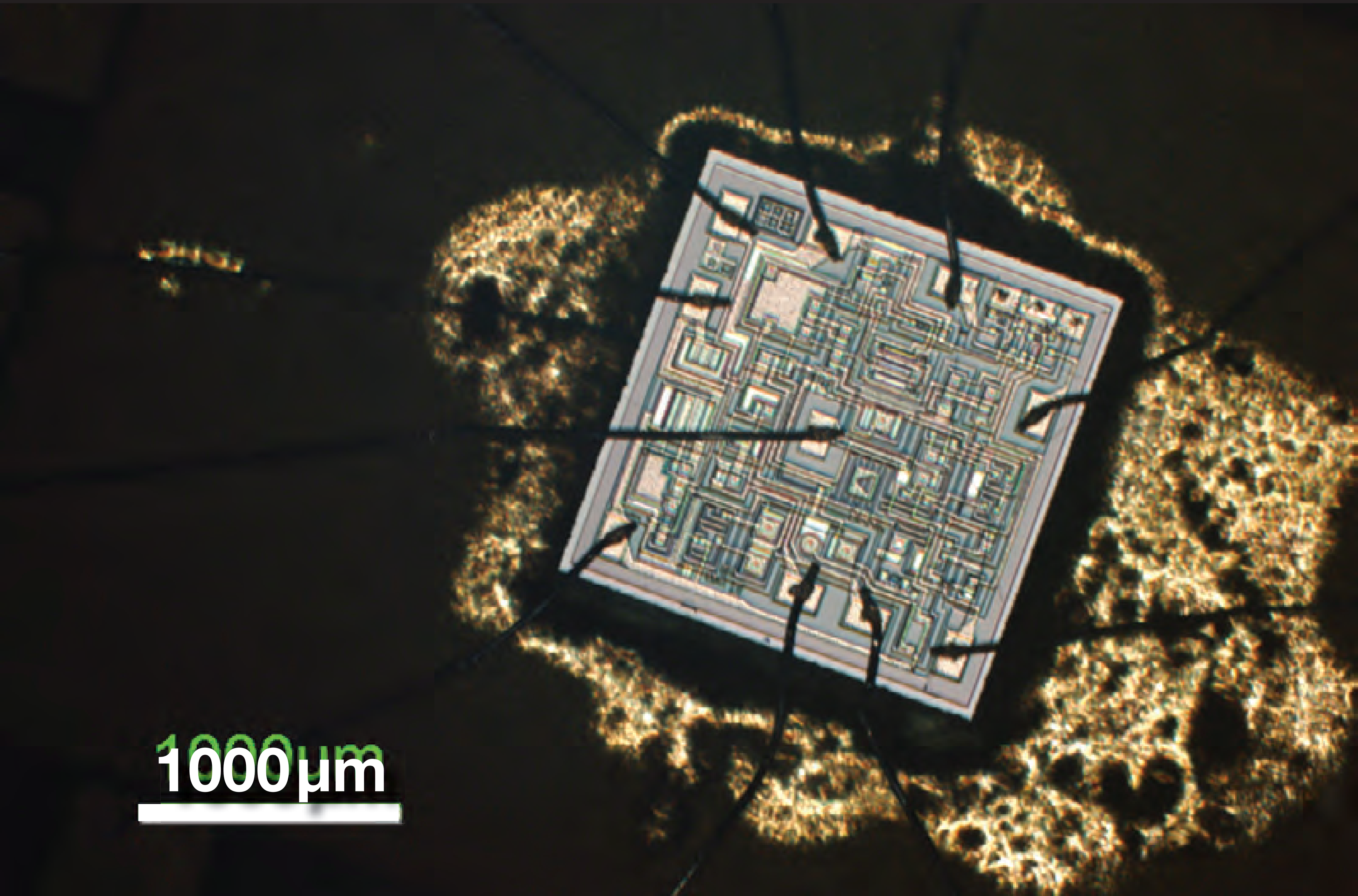

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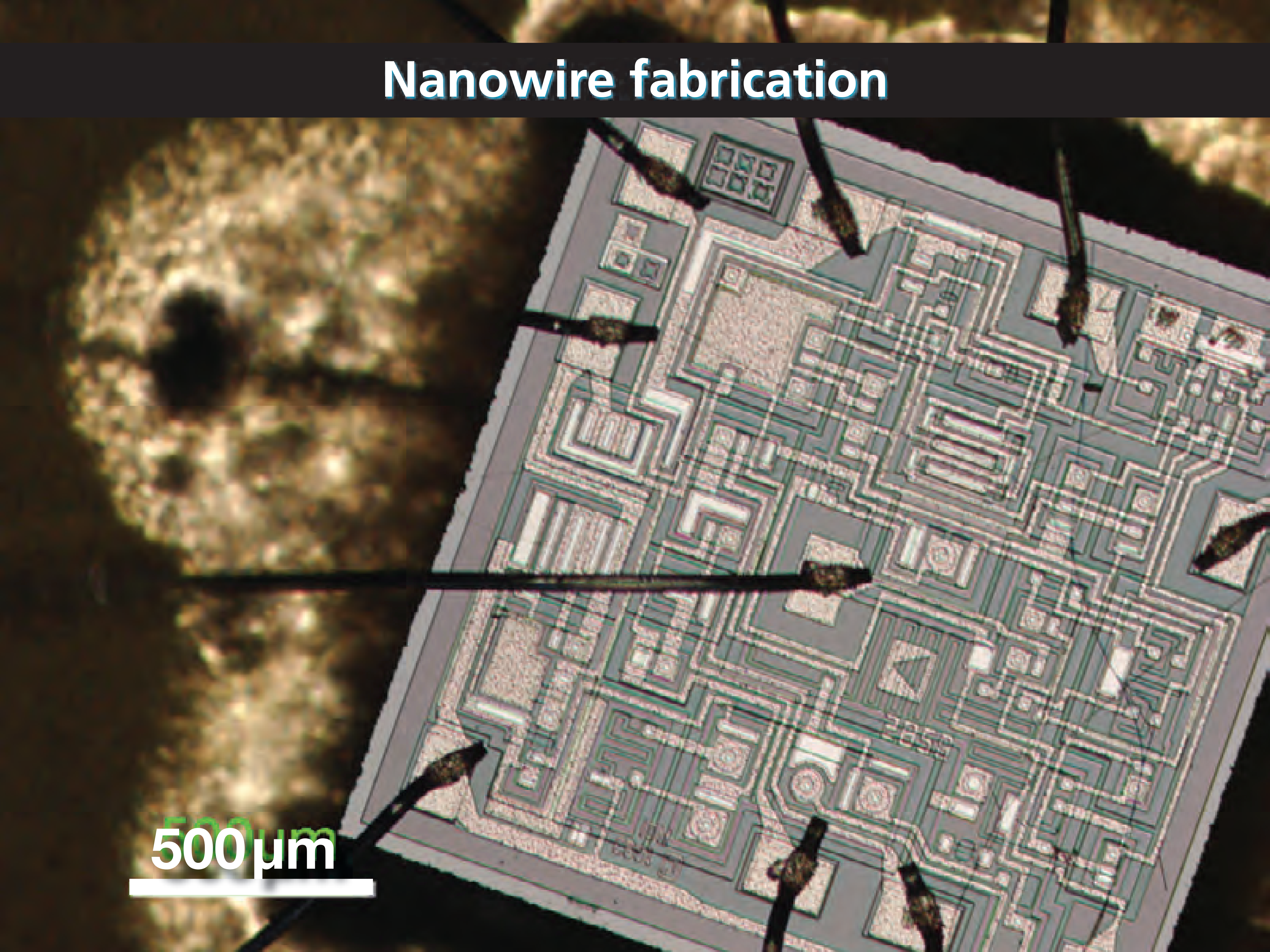

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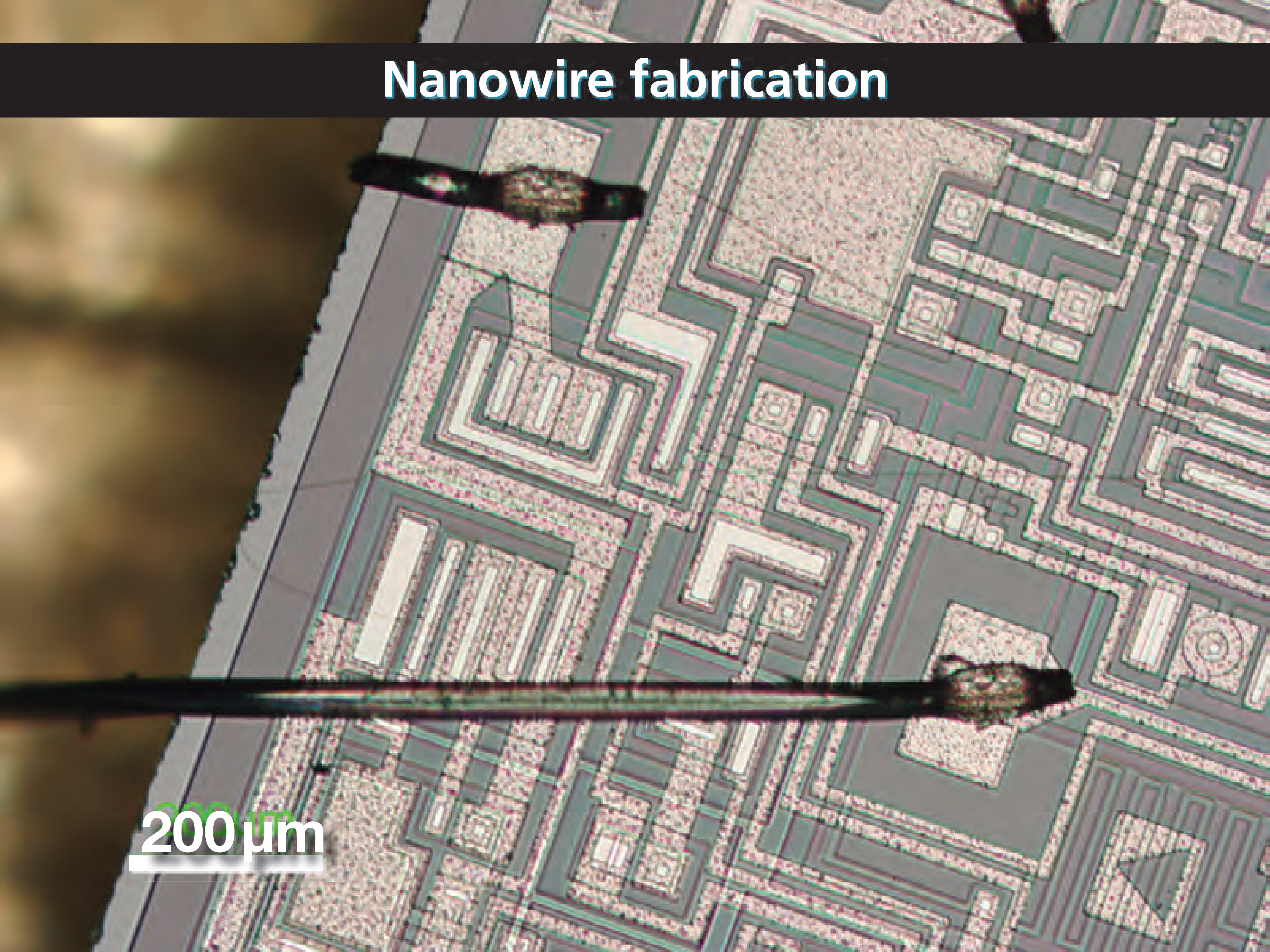

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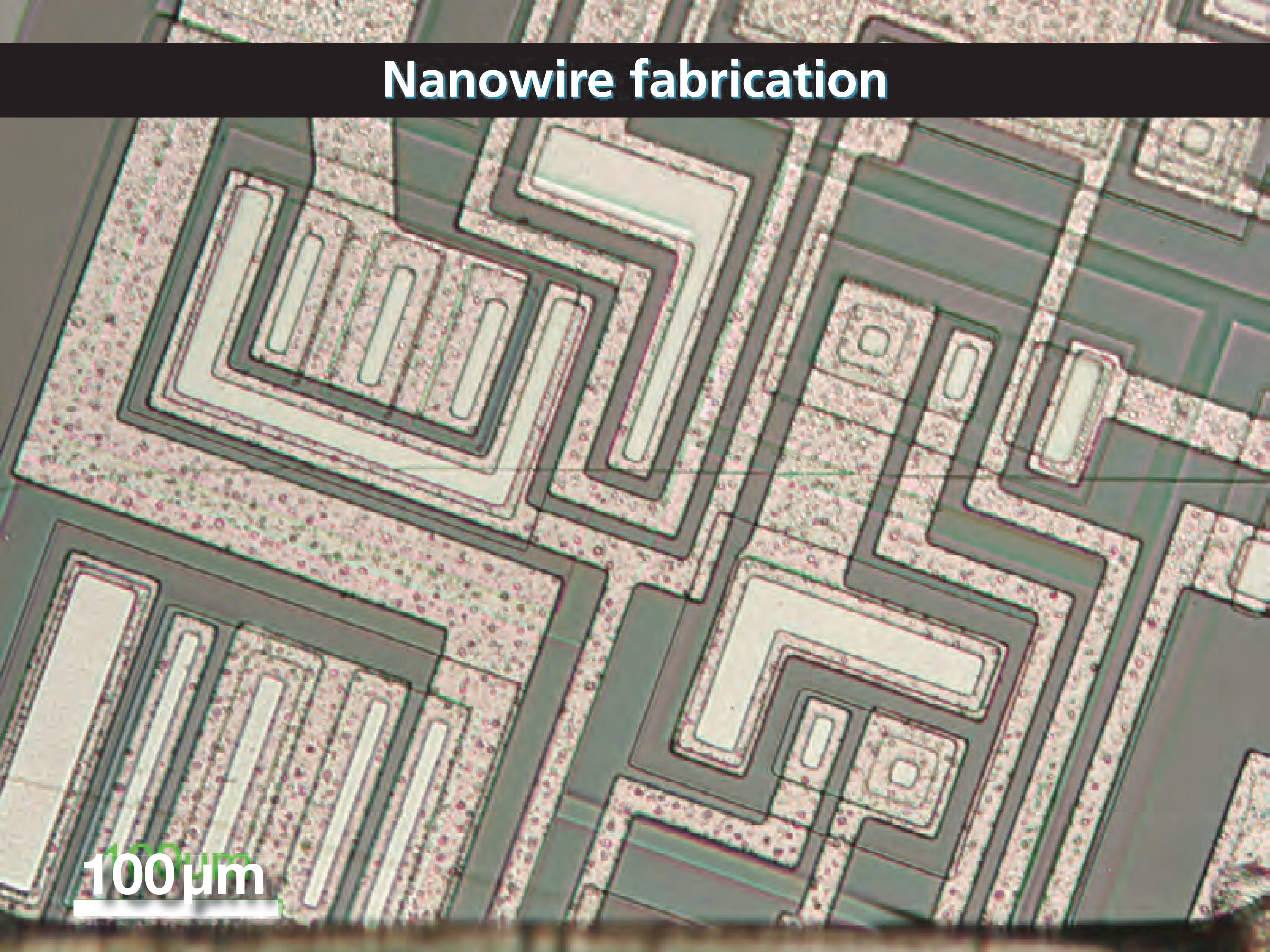

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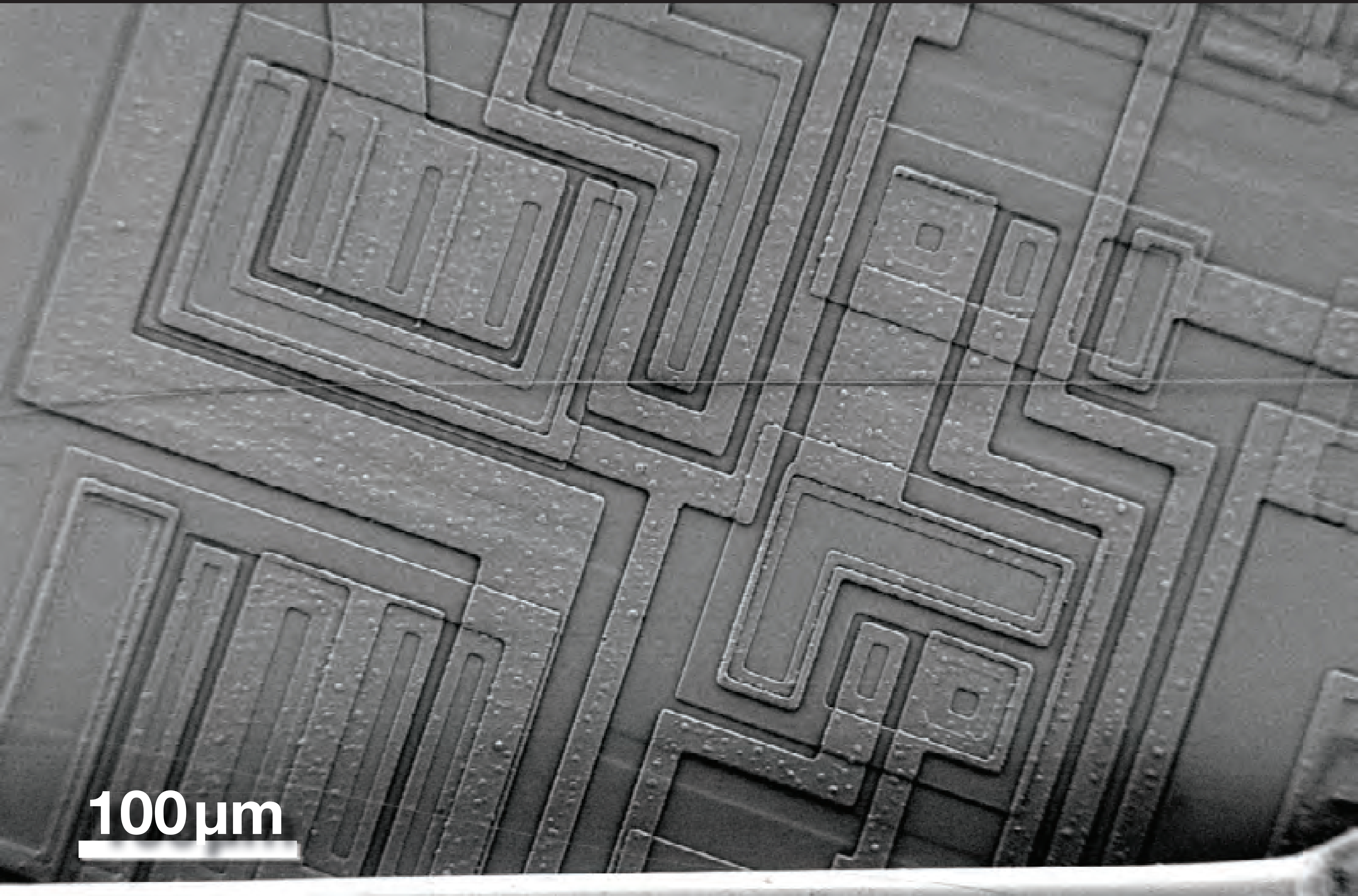
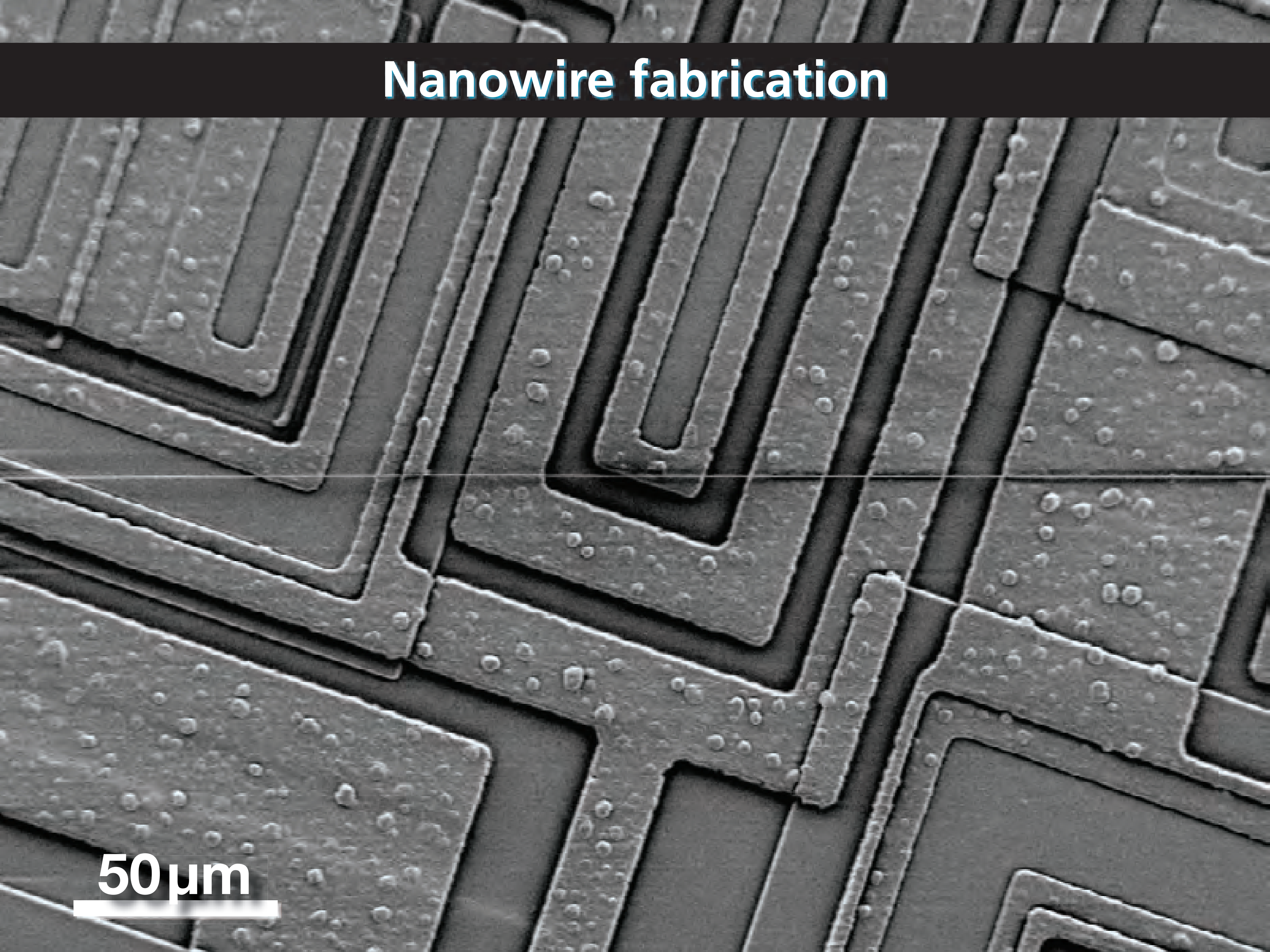
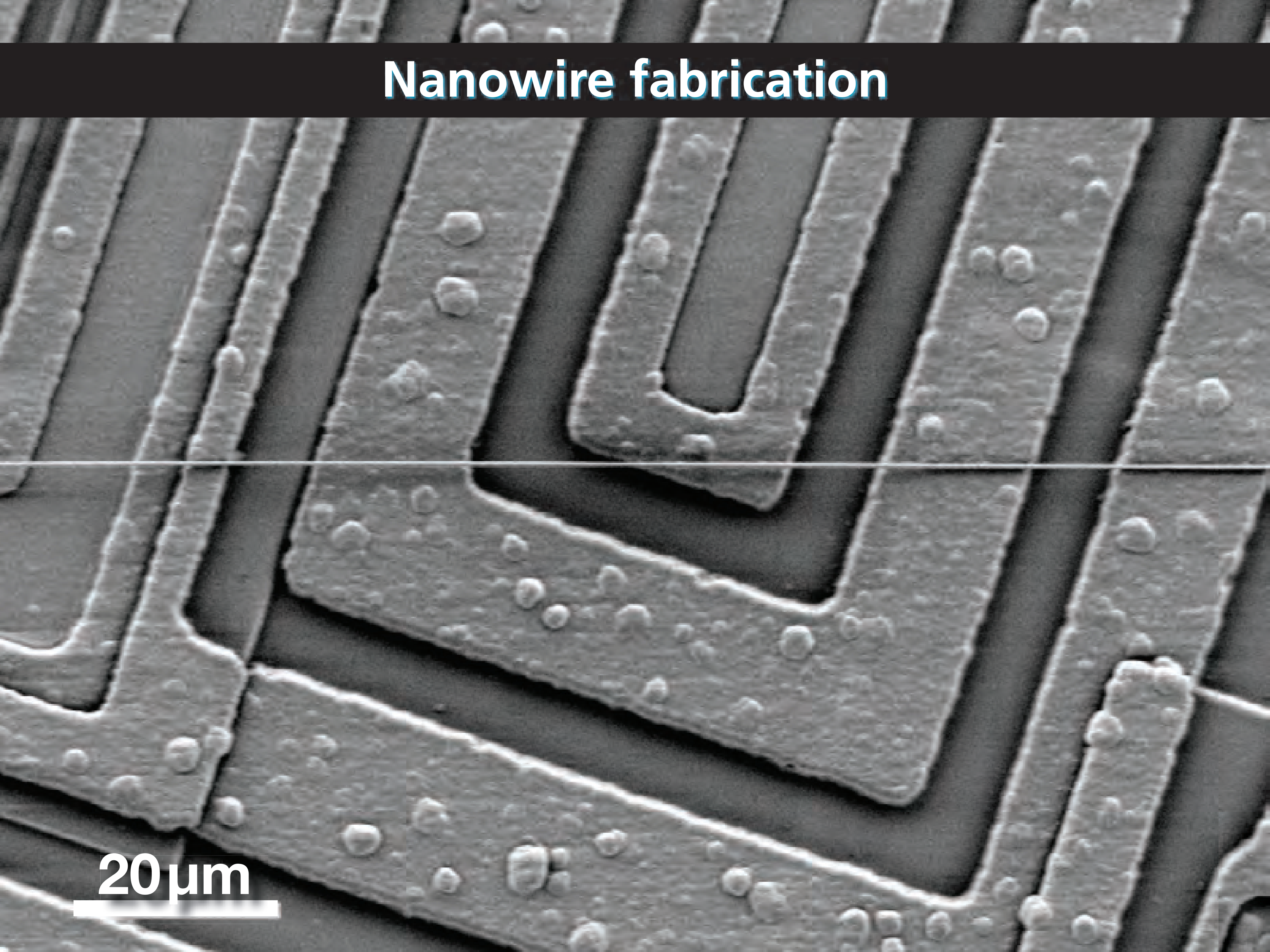
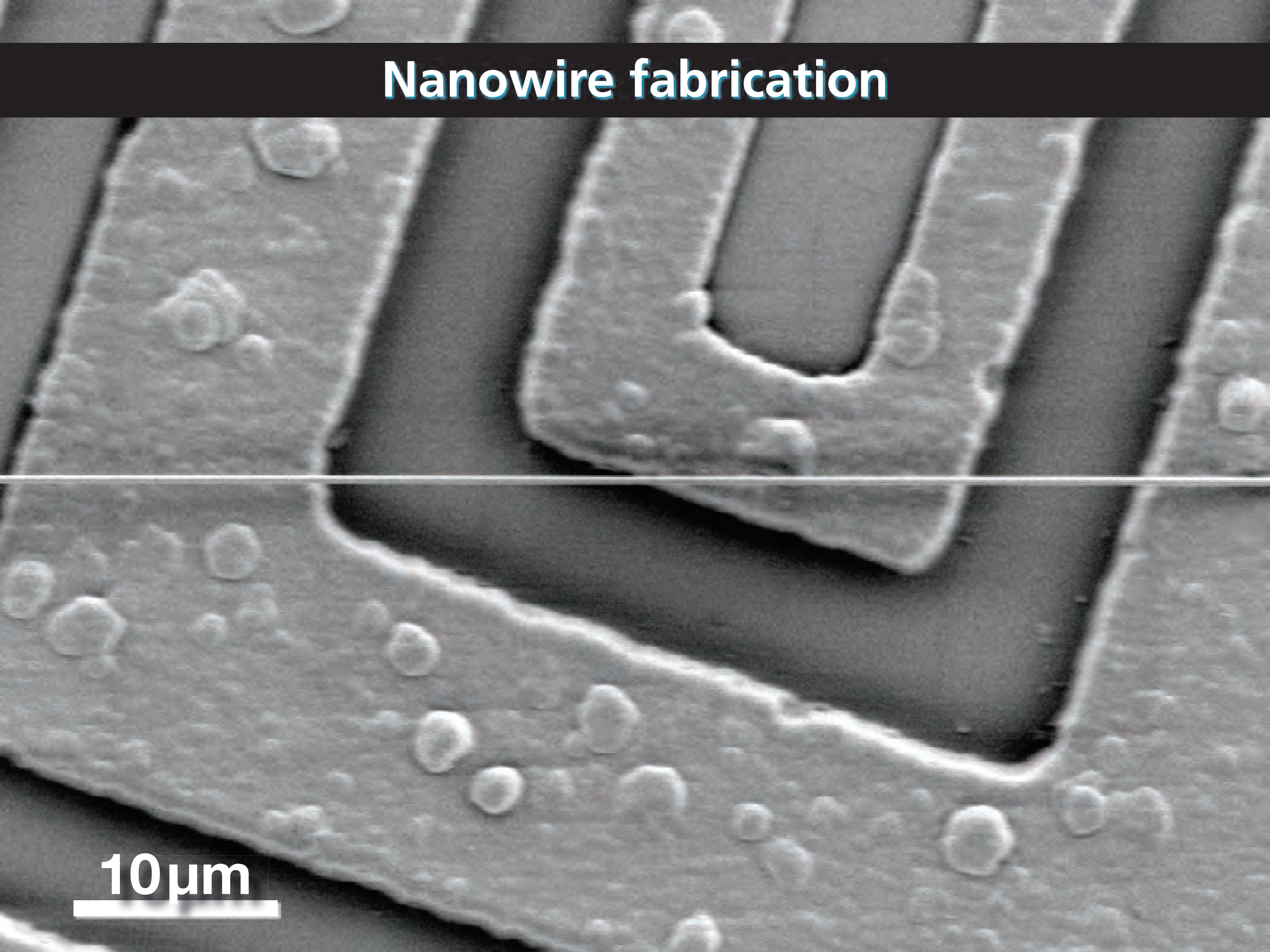
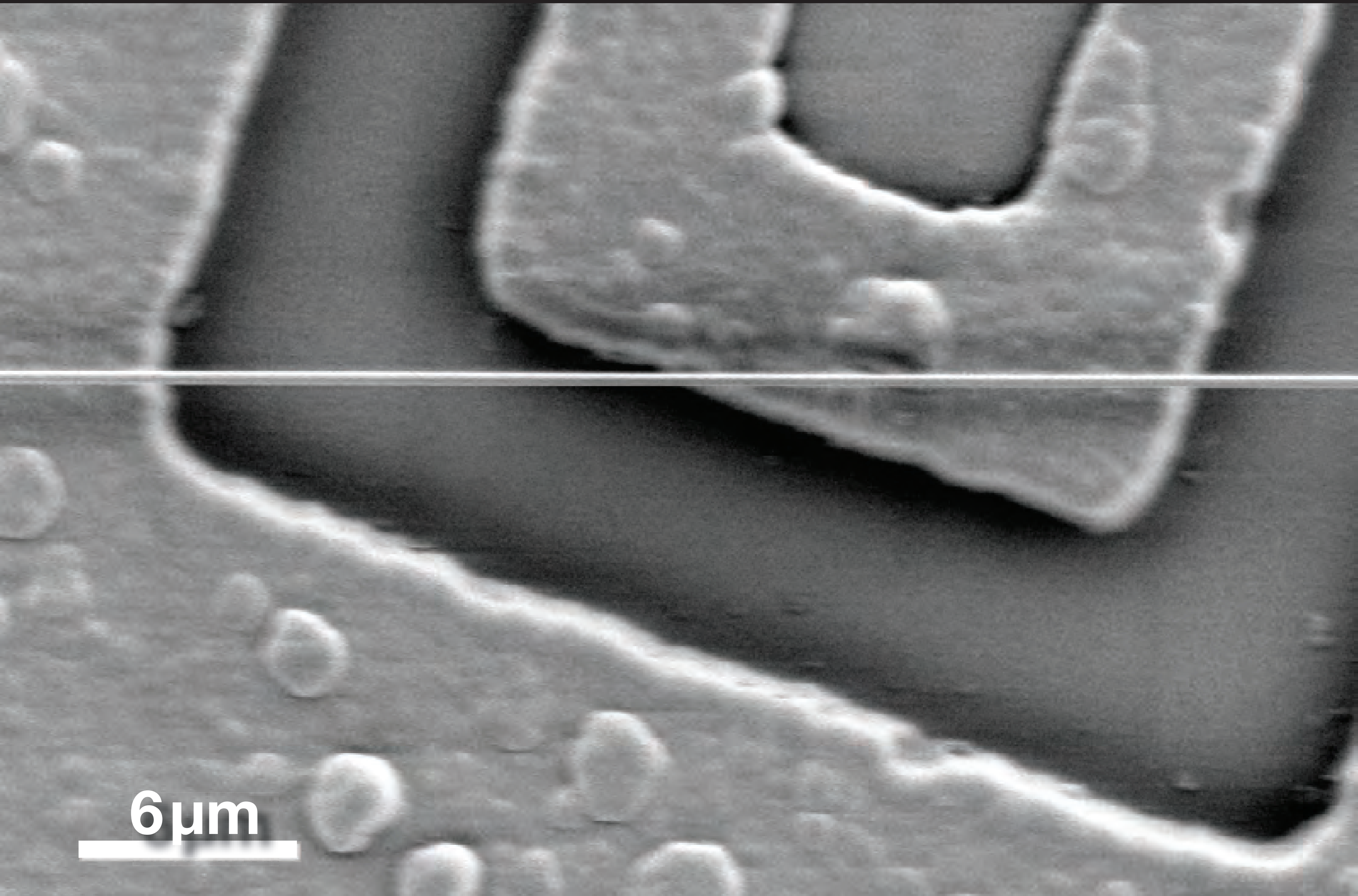


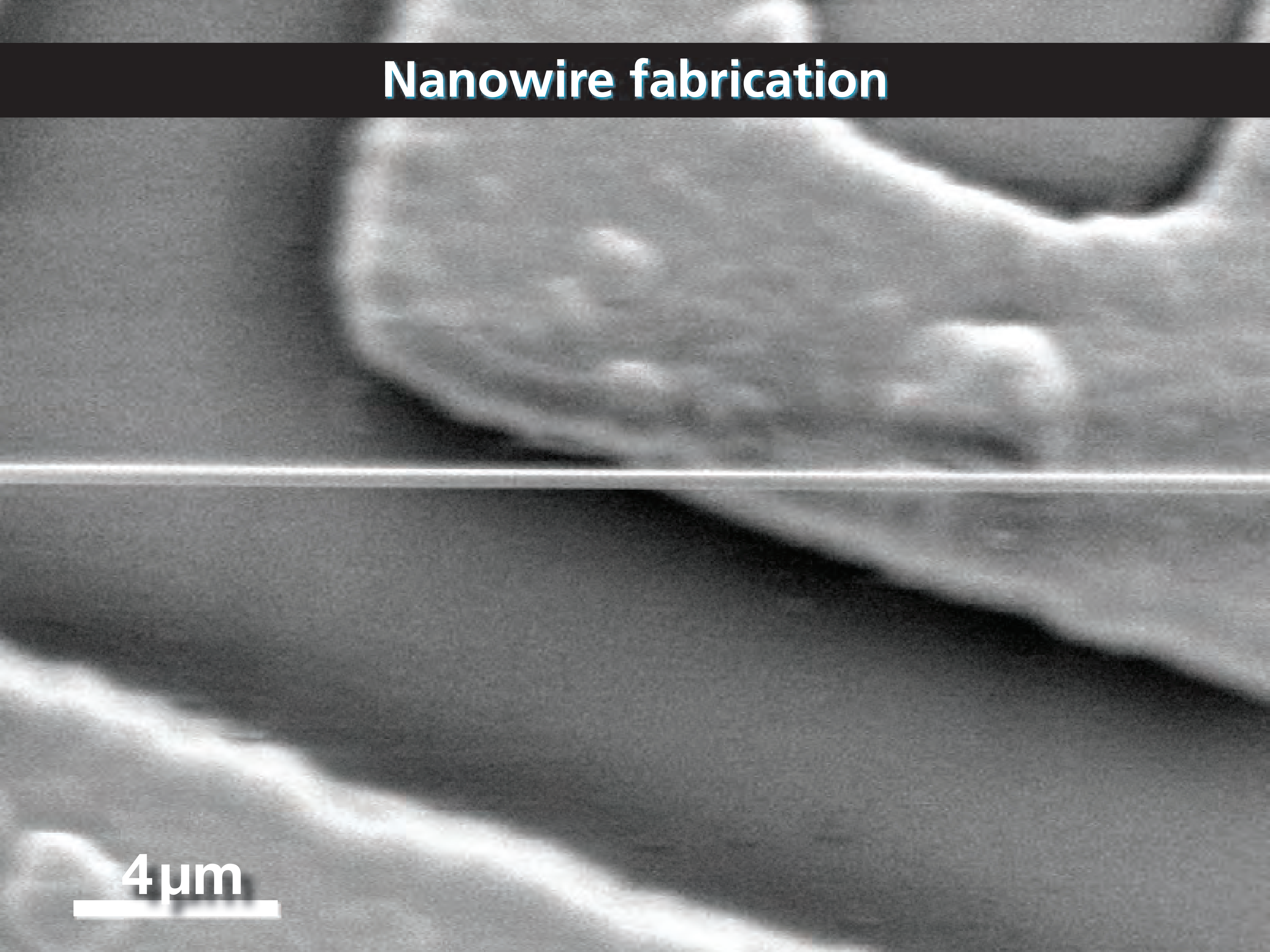

Nanowire fabrication
50 µm


Nanowire fabrication
20 μm

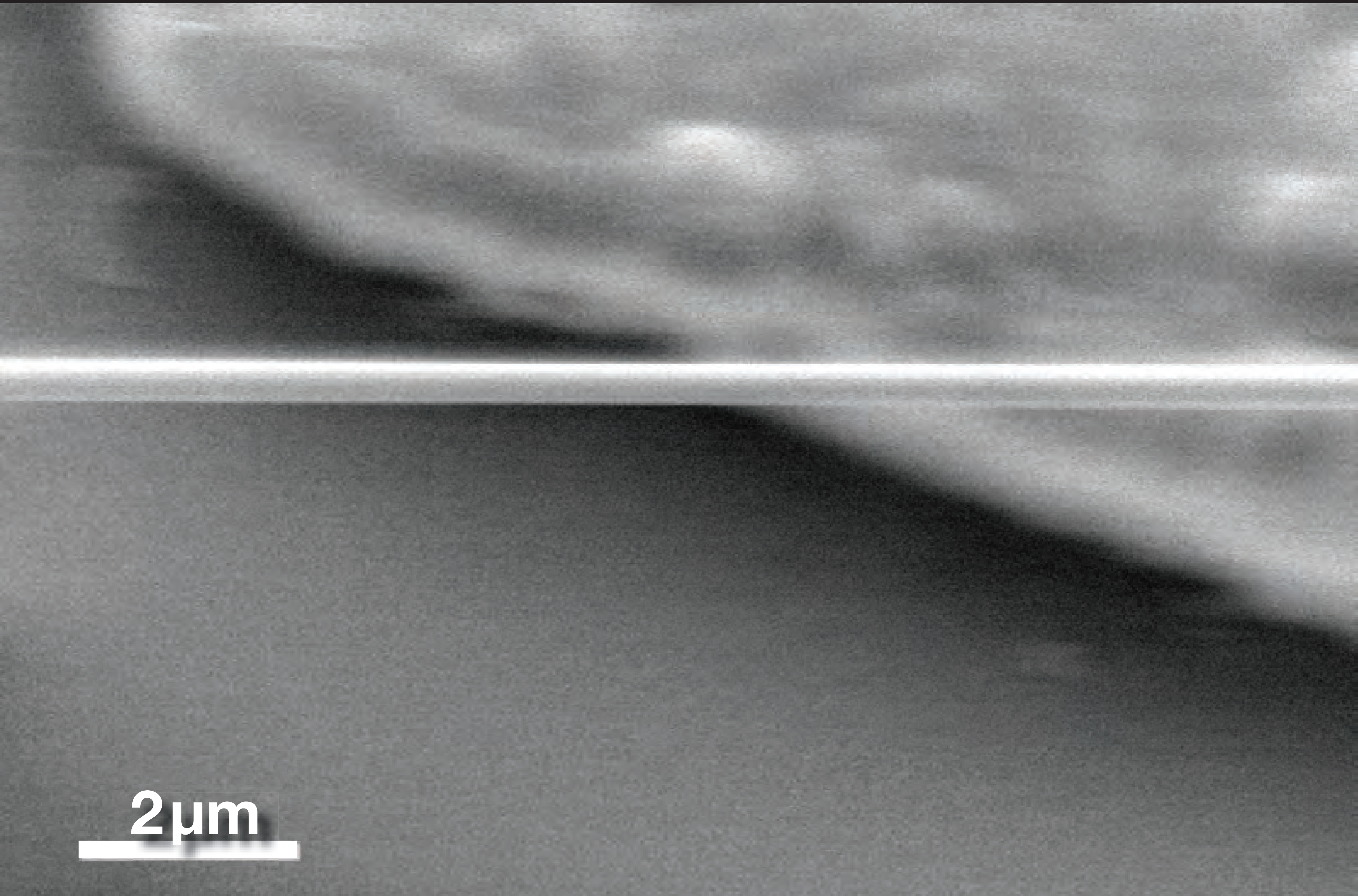

Nanowire fabrication
10 μm

# Nanowire fabrication




Nanowire fabrication
4 µm

# Nanowire fabrication



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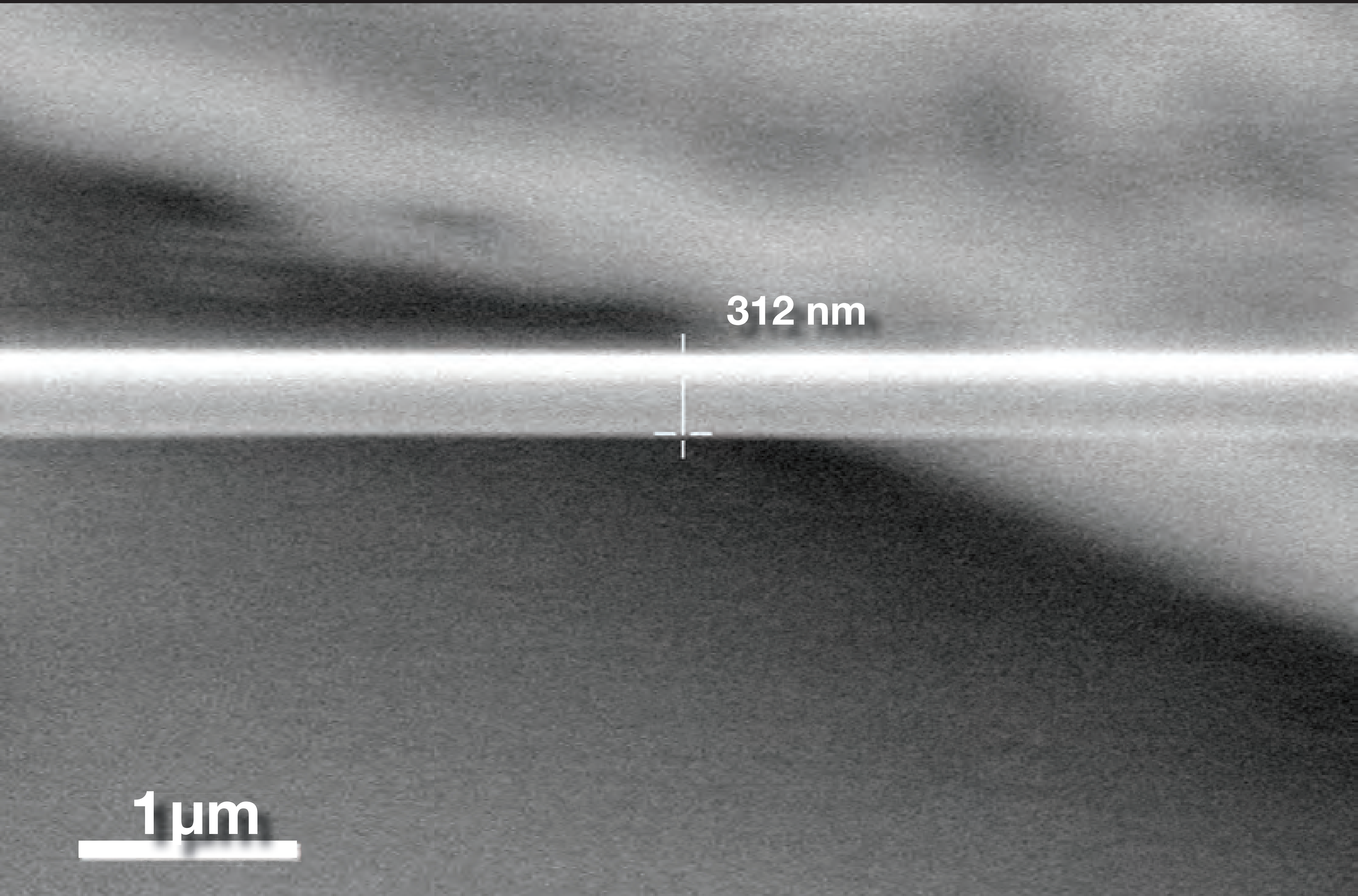


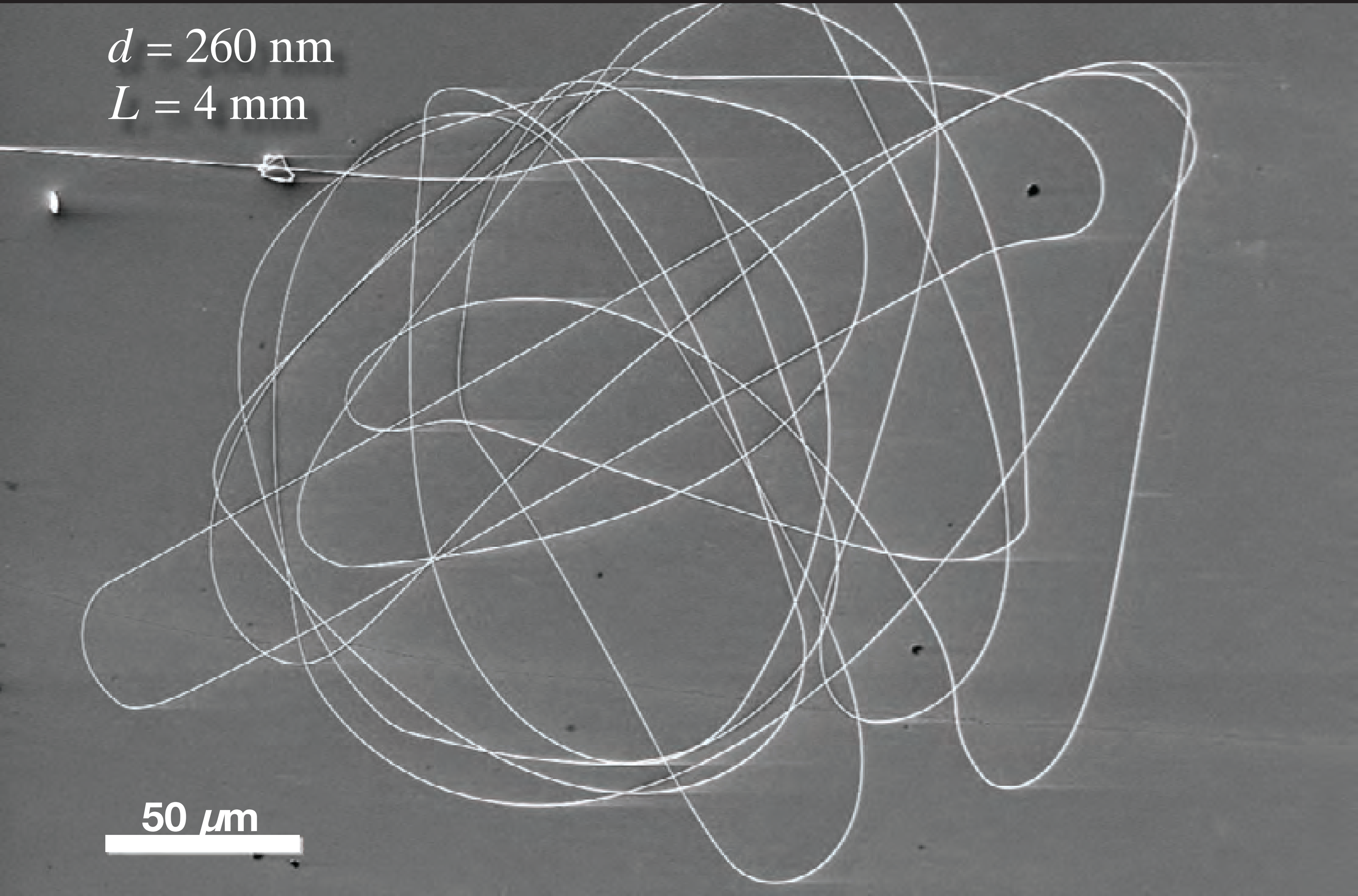
# Waveguiding

## Specifications

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

*Nature*, 426, 816 (2003)

# Nanowire fabrication



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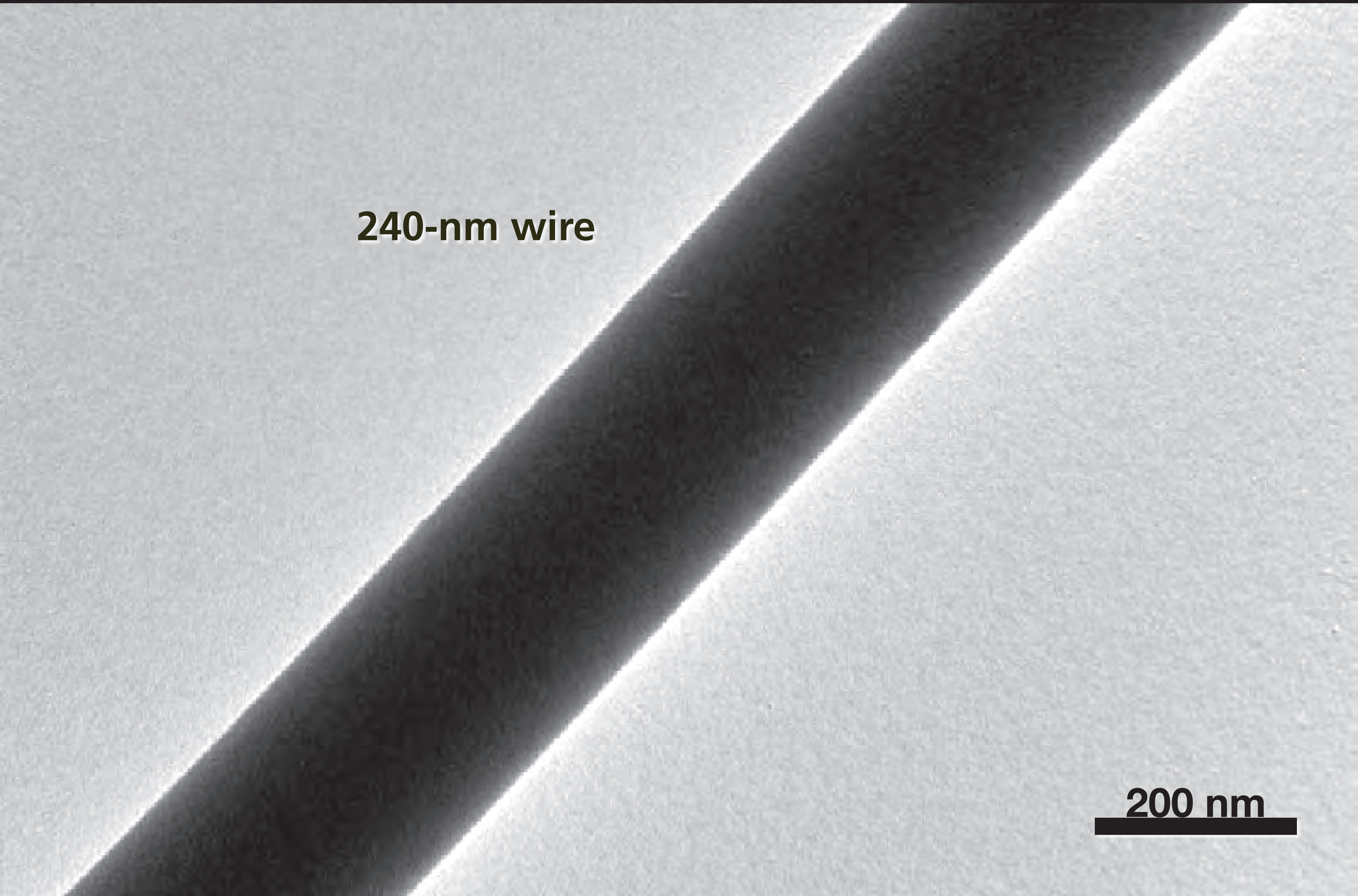

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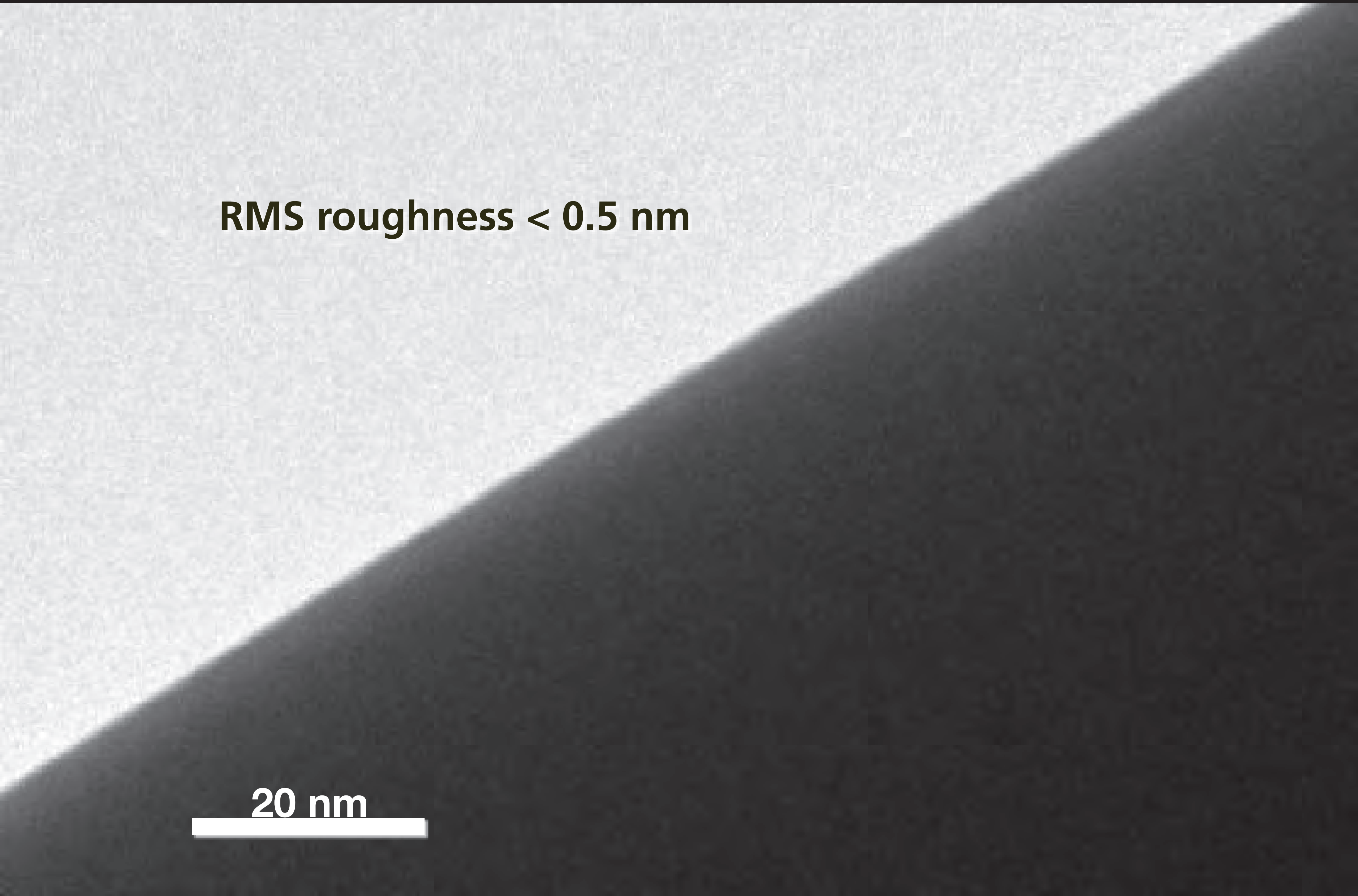

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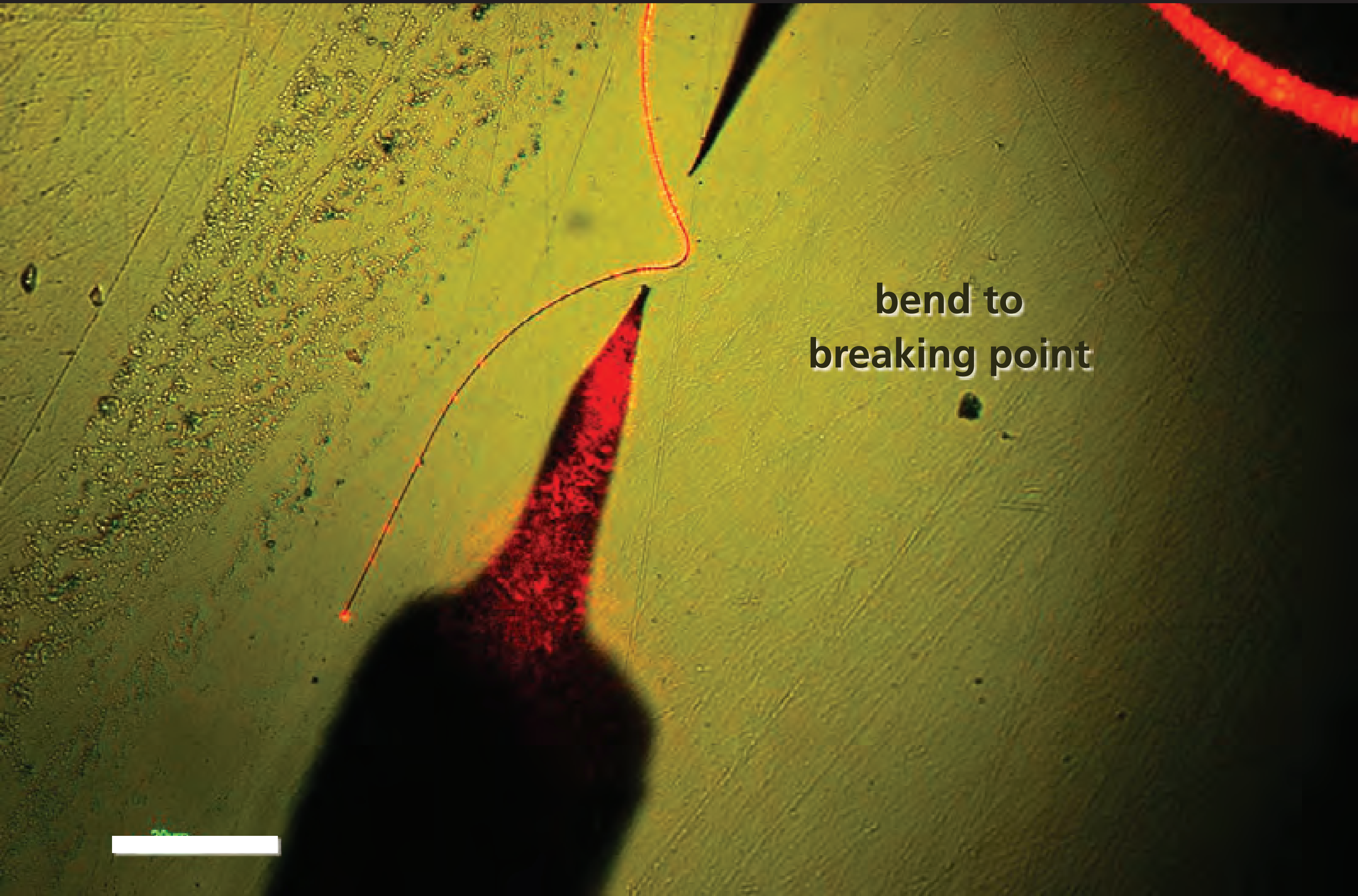

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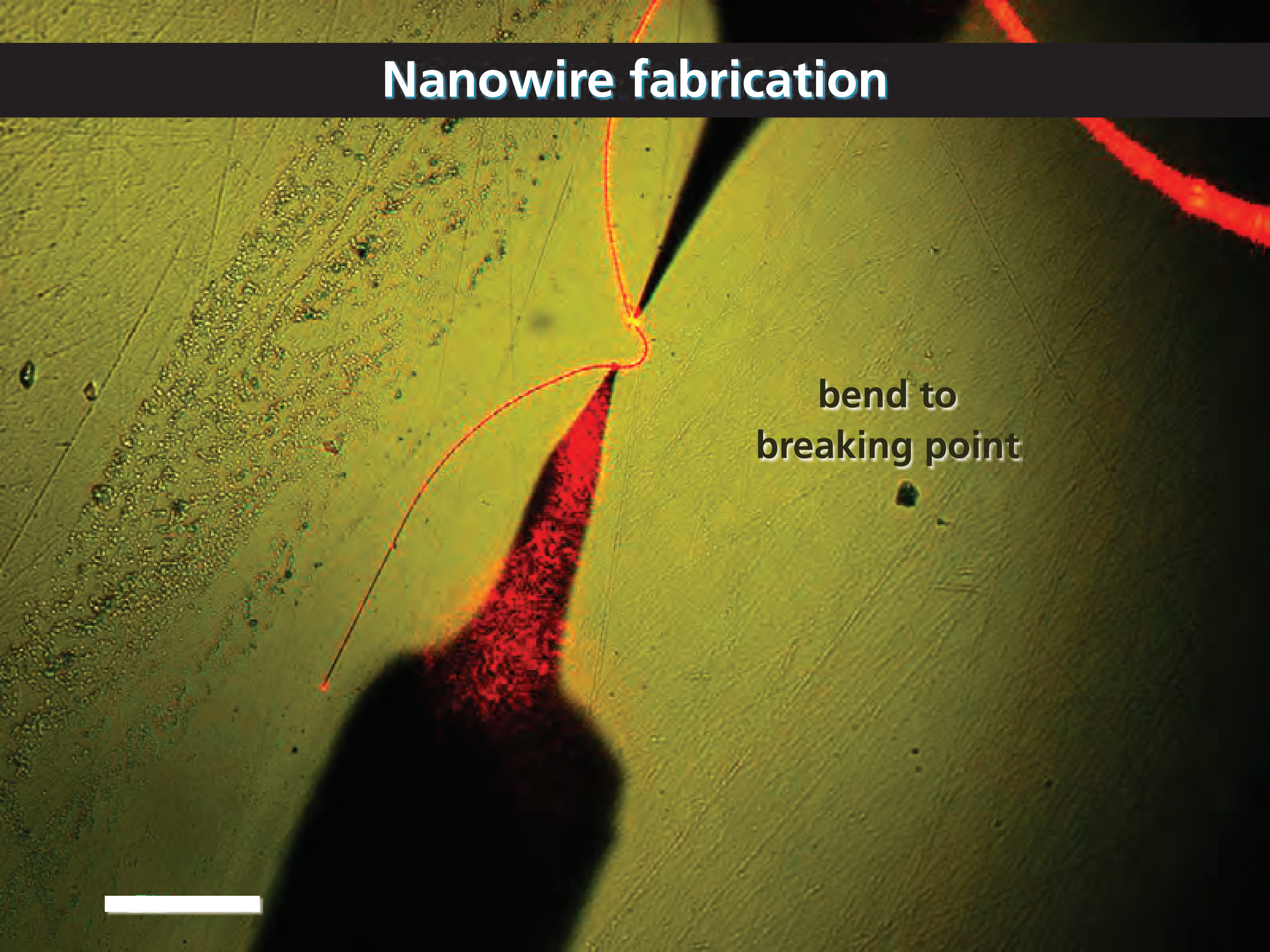

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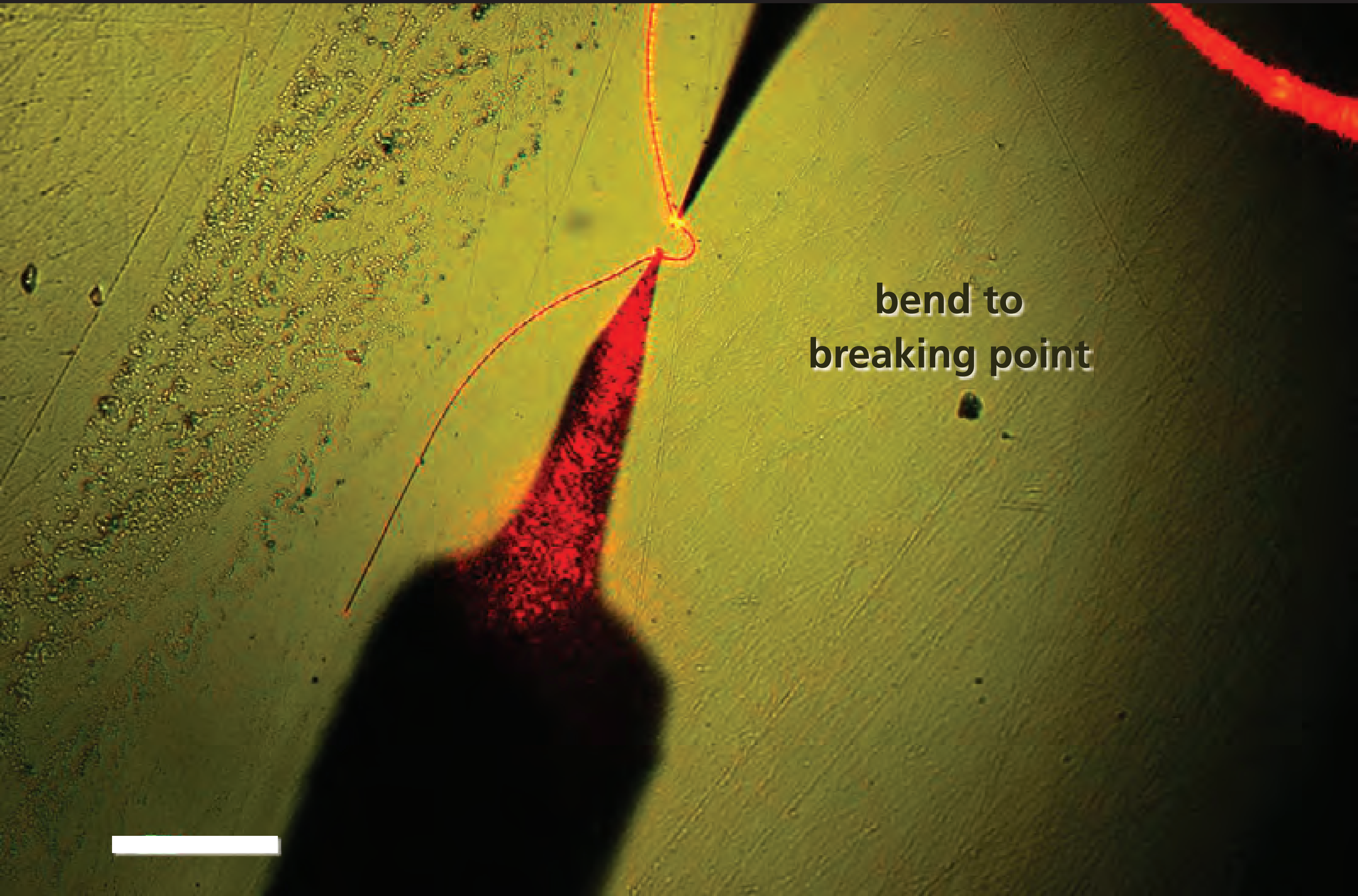

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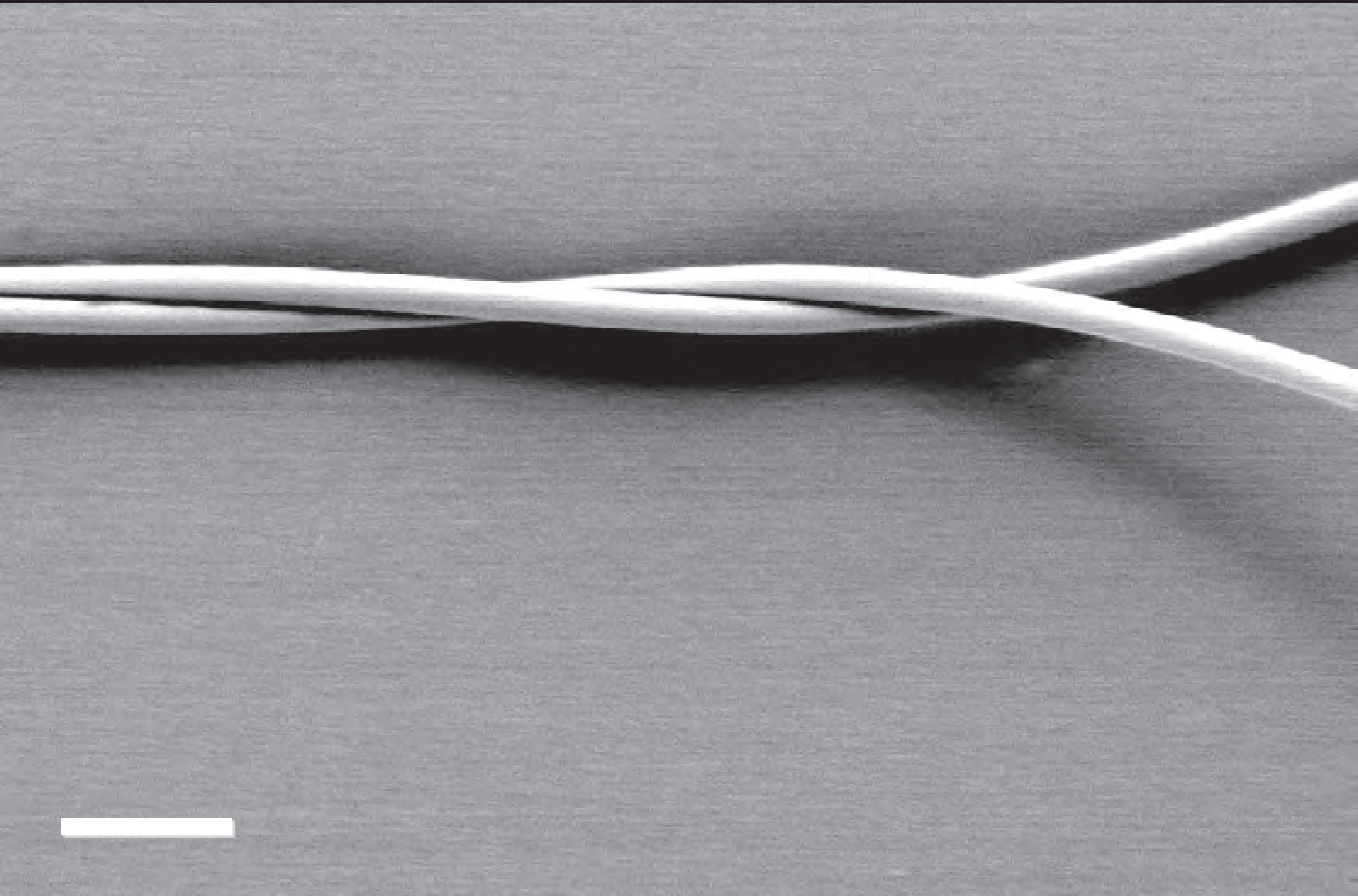
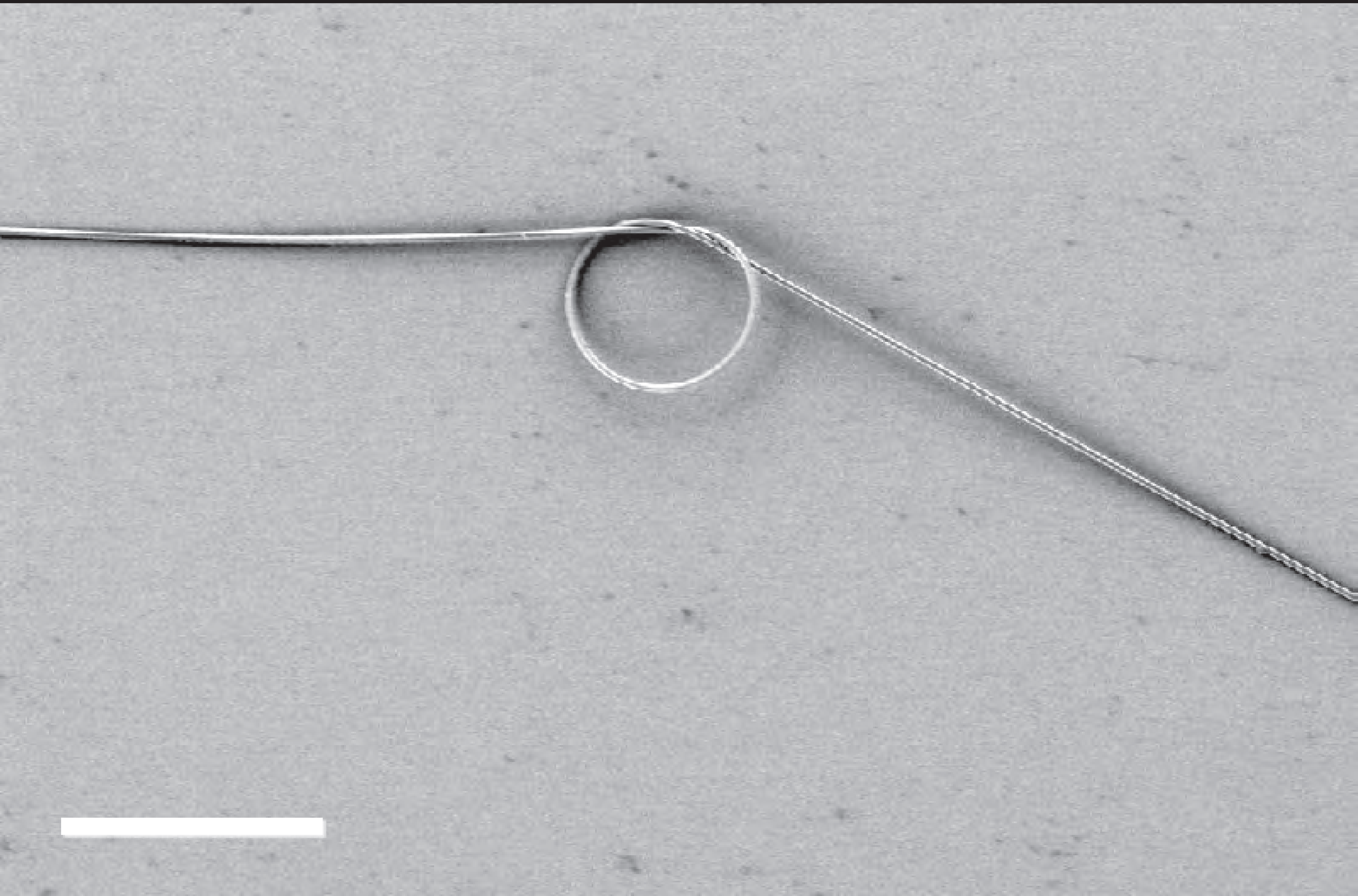
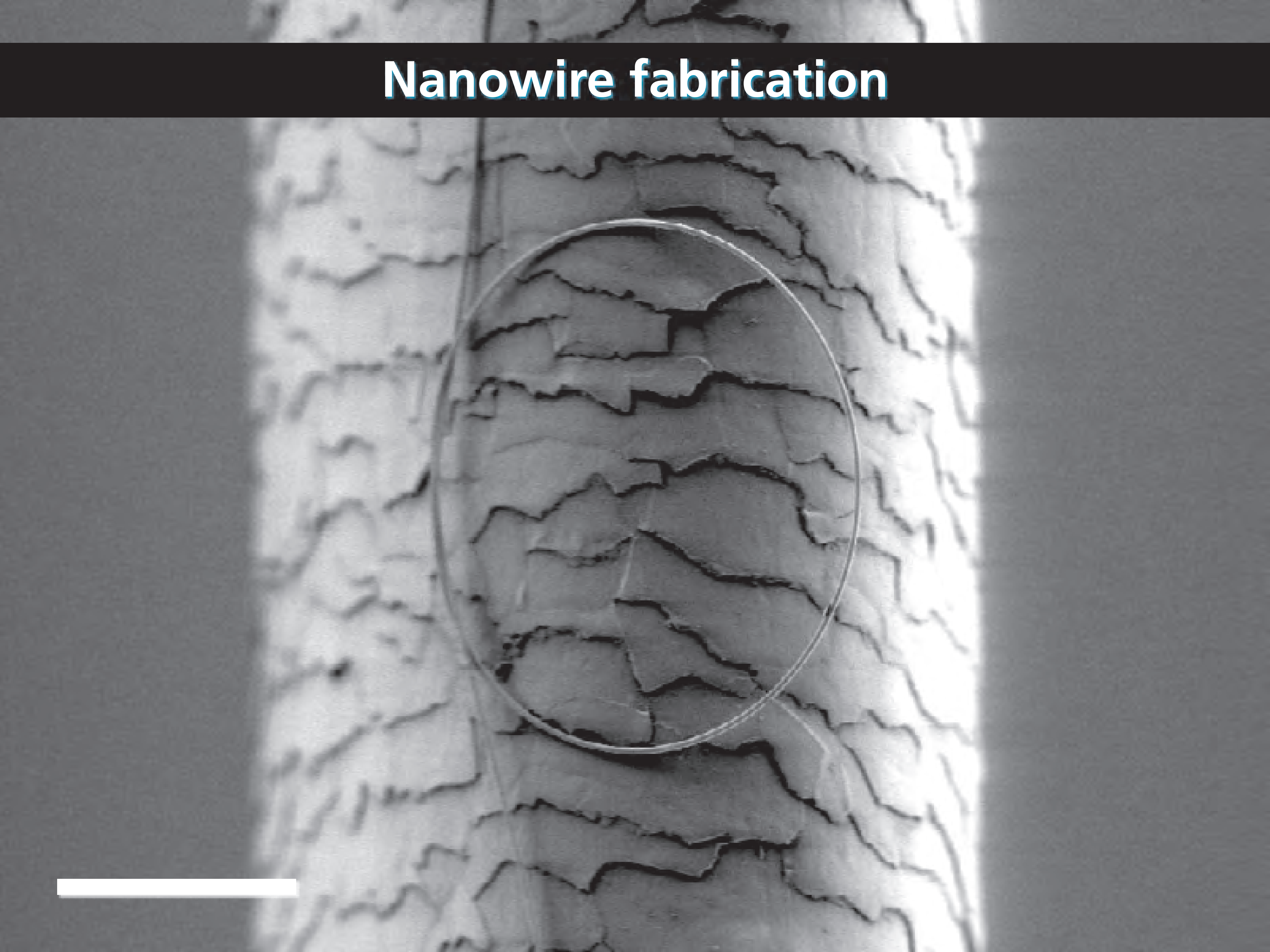


# Nanowire fabrication



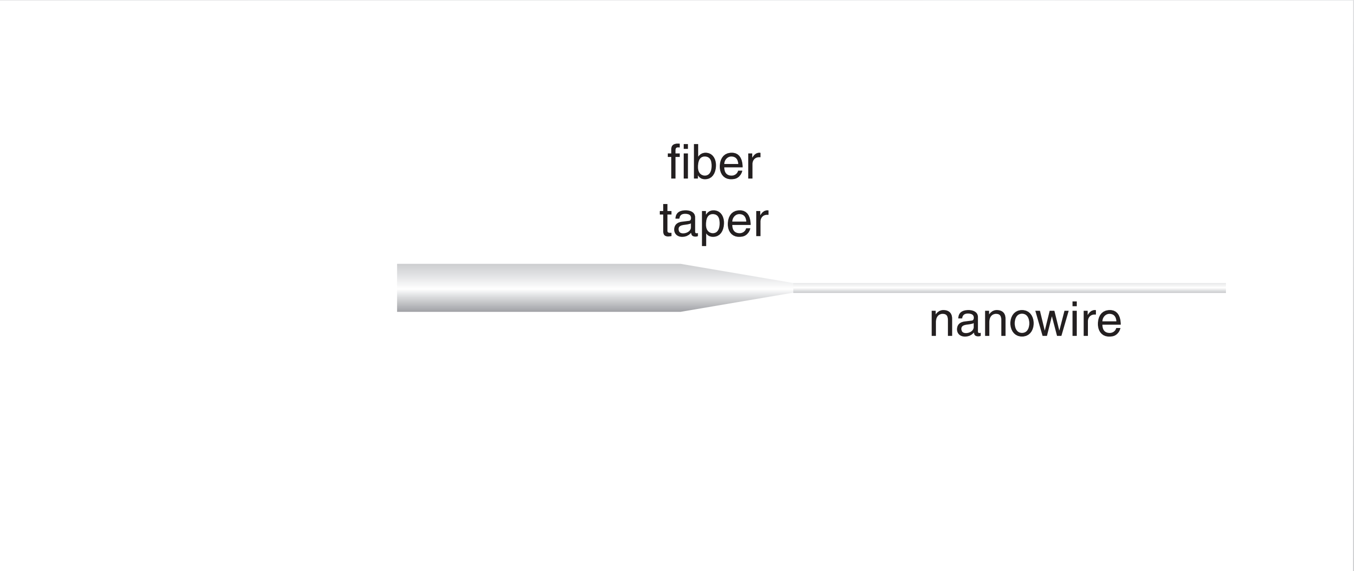

Nanowire fabrication

# Outline

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

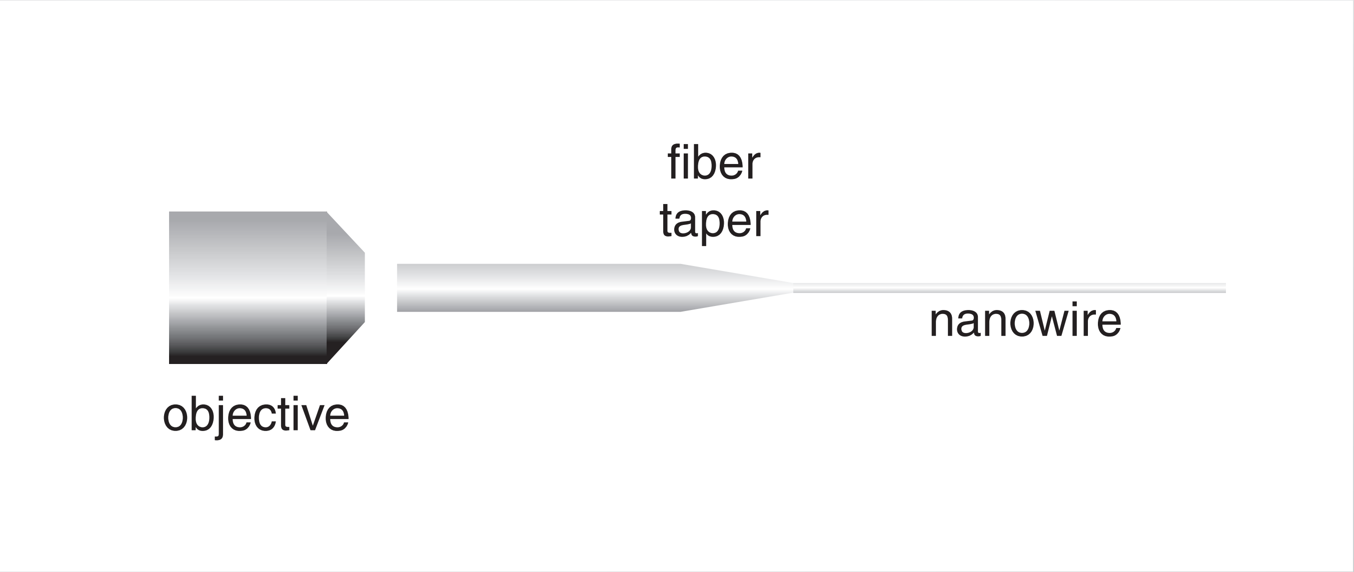
# Optical properties

## coupling light into nanowires



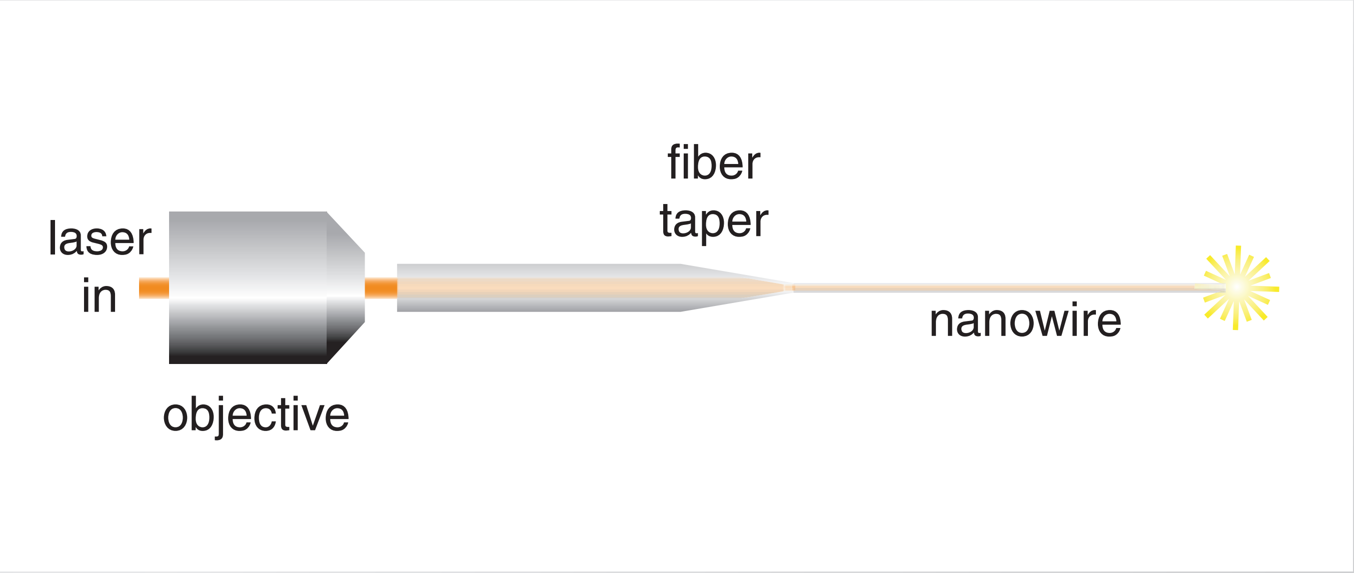
# Optical properties

## coupling light into nanowires

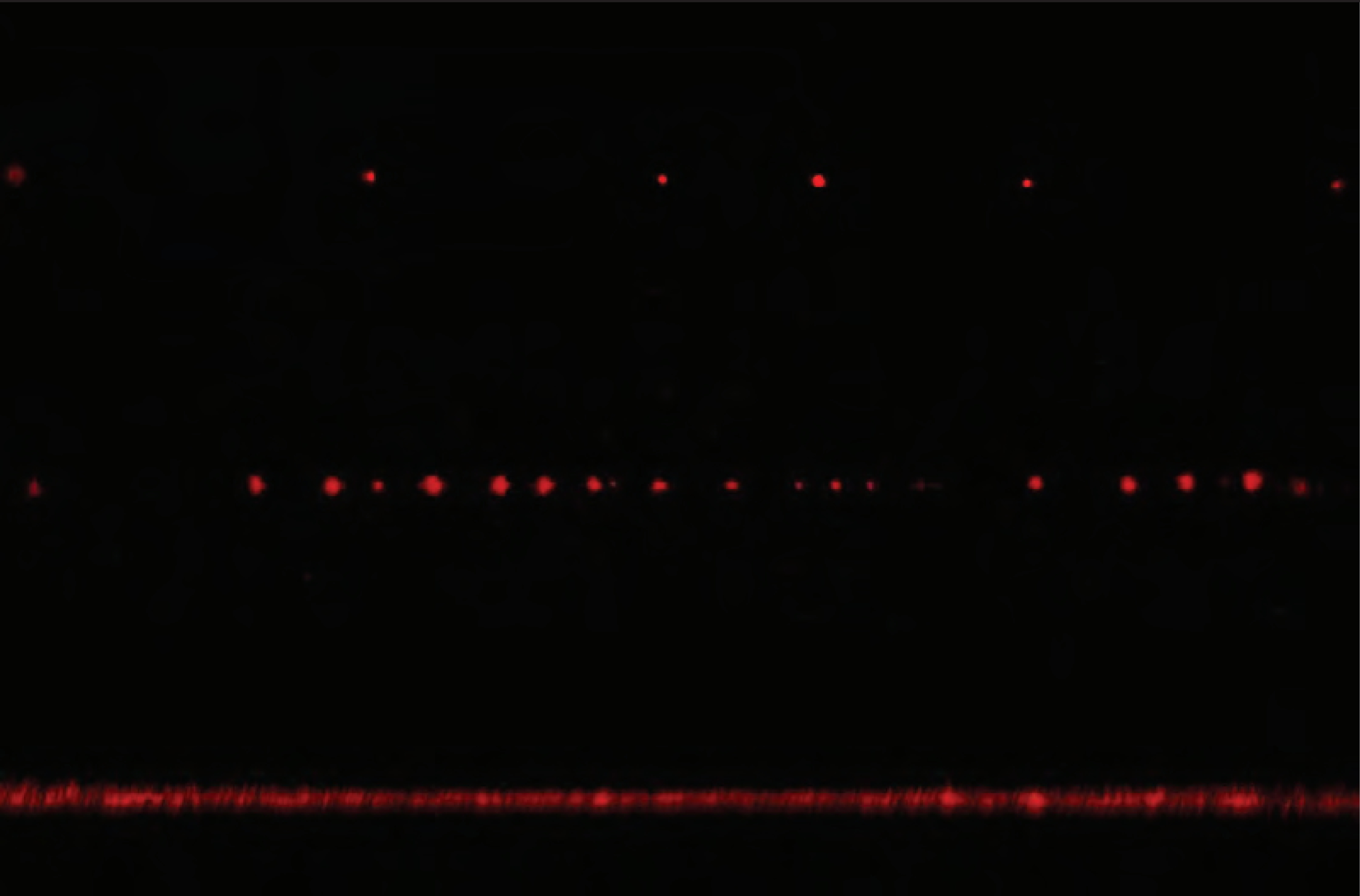


# Optical properties

## coupling light into nanowires



# Optical properties



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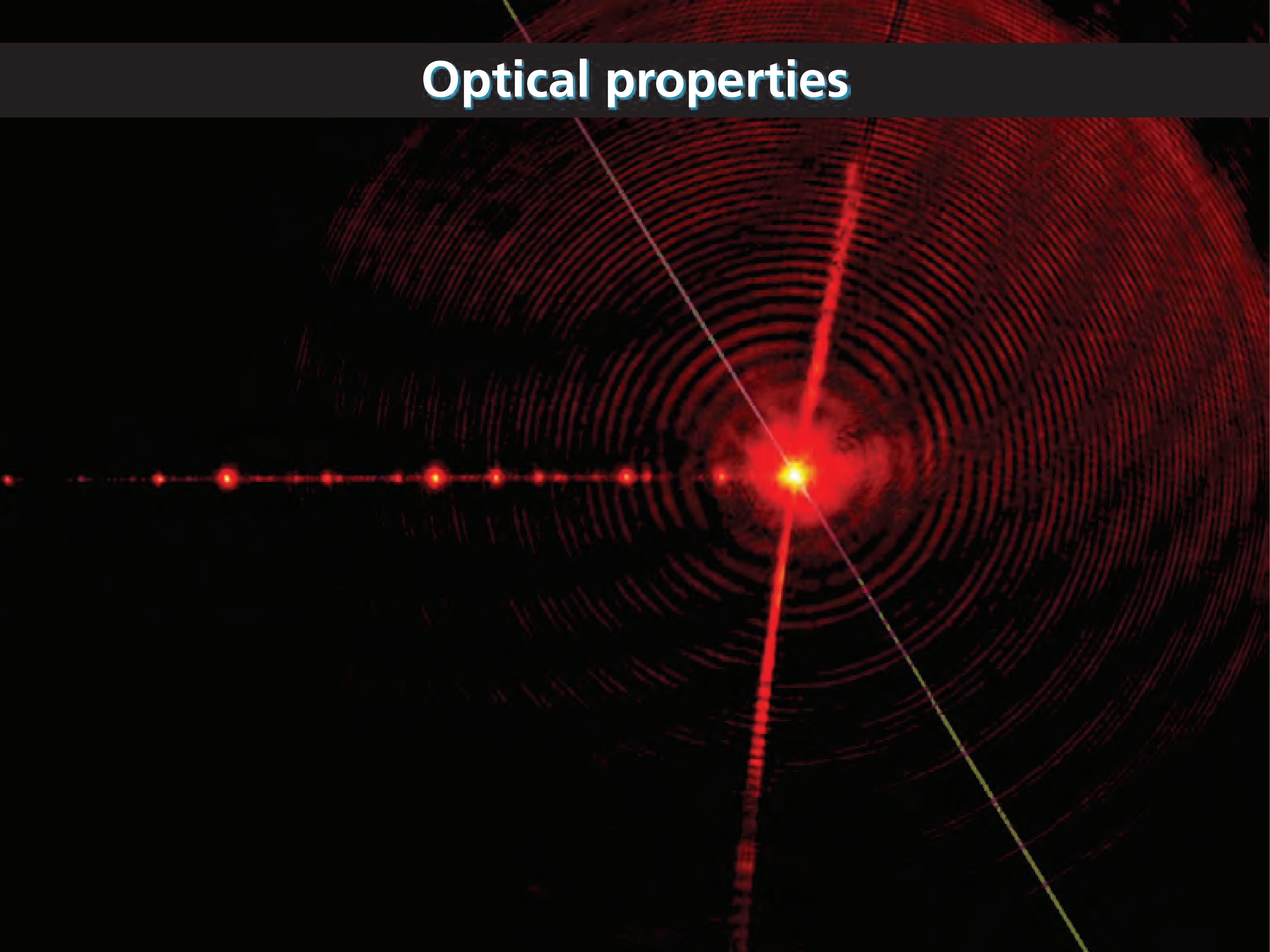
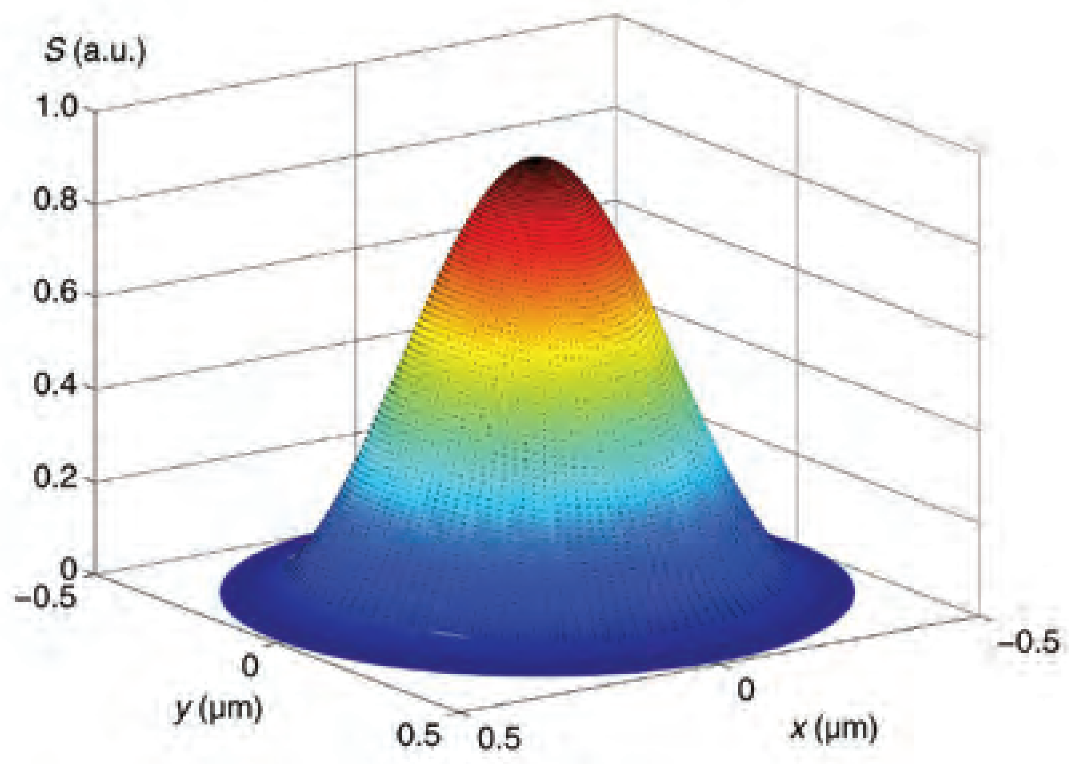


# Optical properties

# Optical properties

## Poynting vector profile for 800-nm nanowire



# Optical properties

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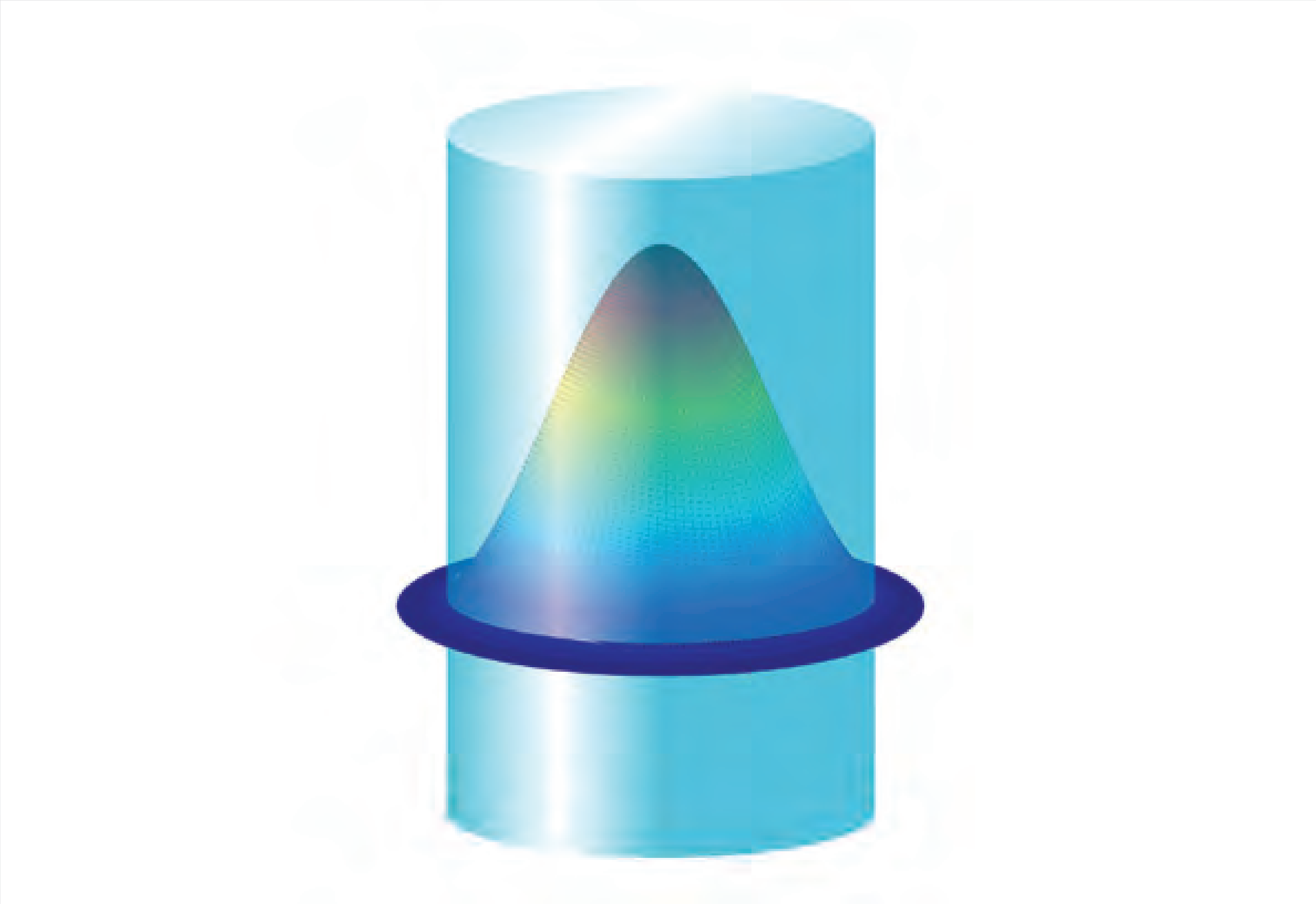

# Optical properties

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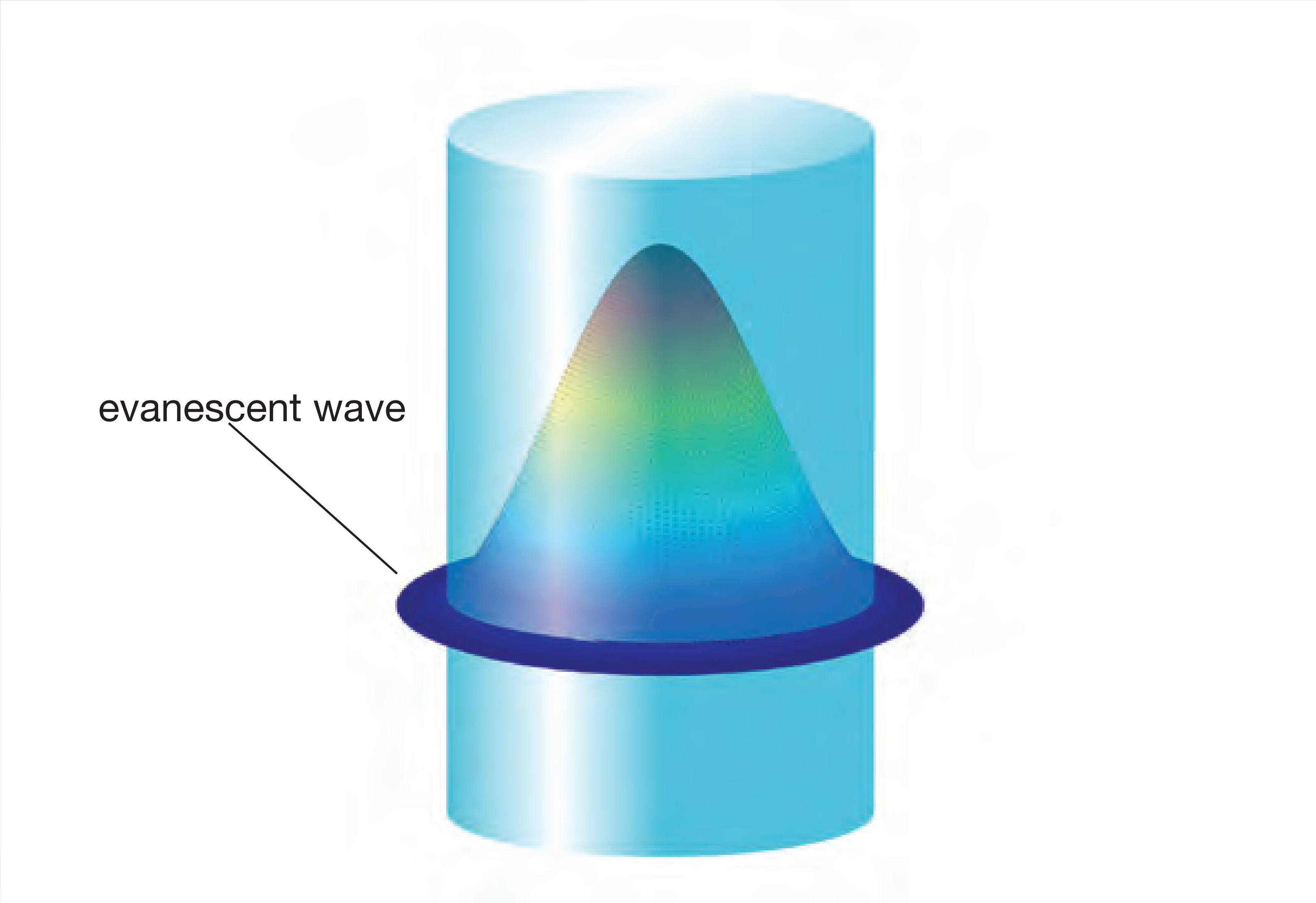
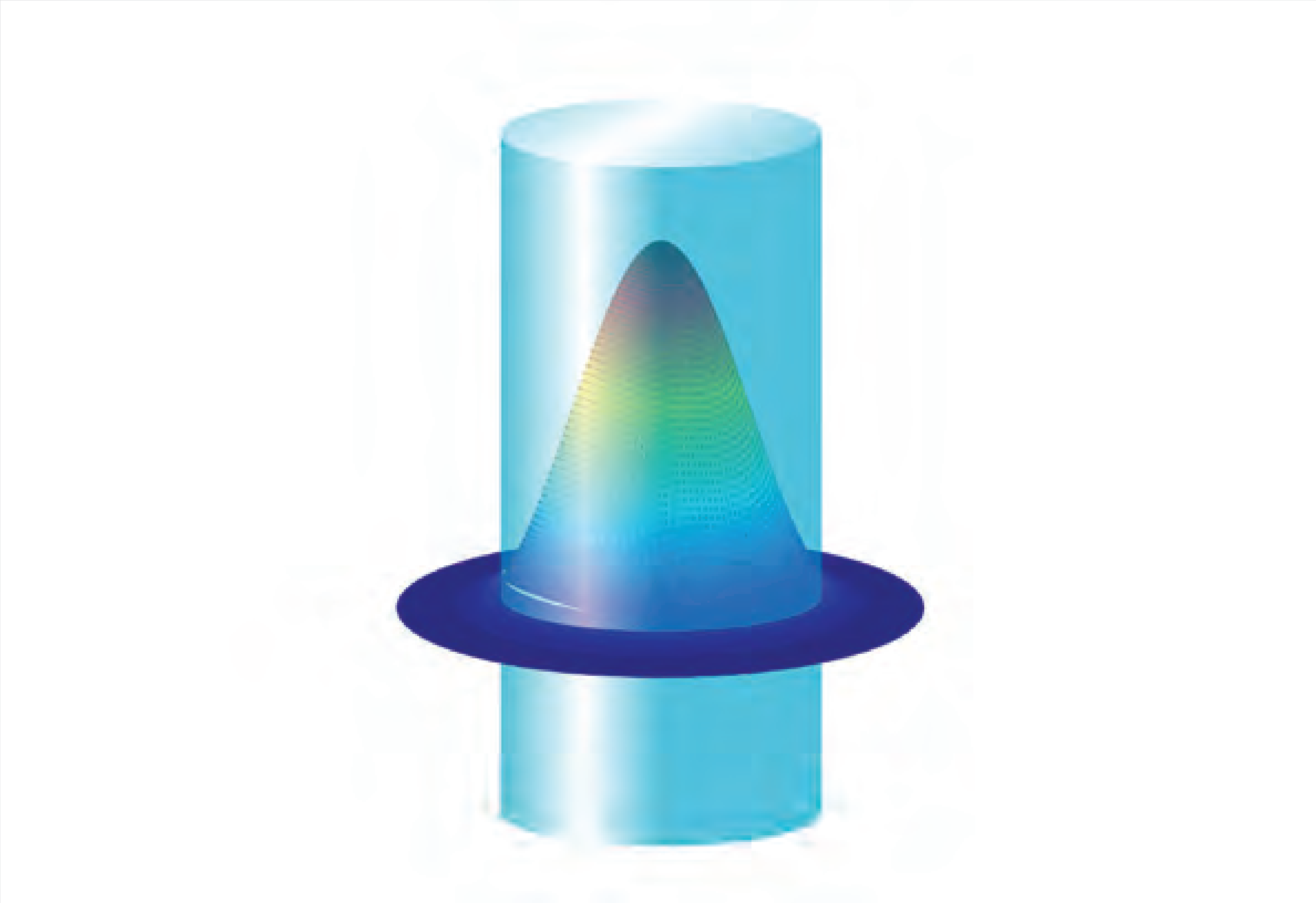


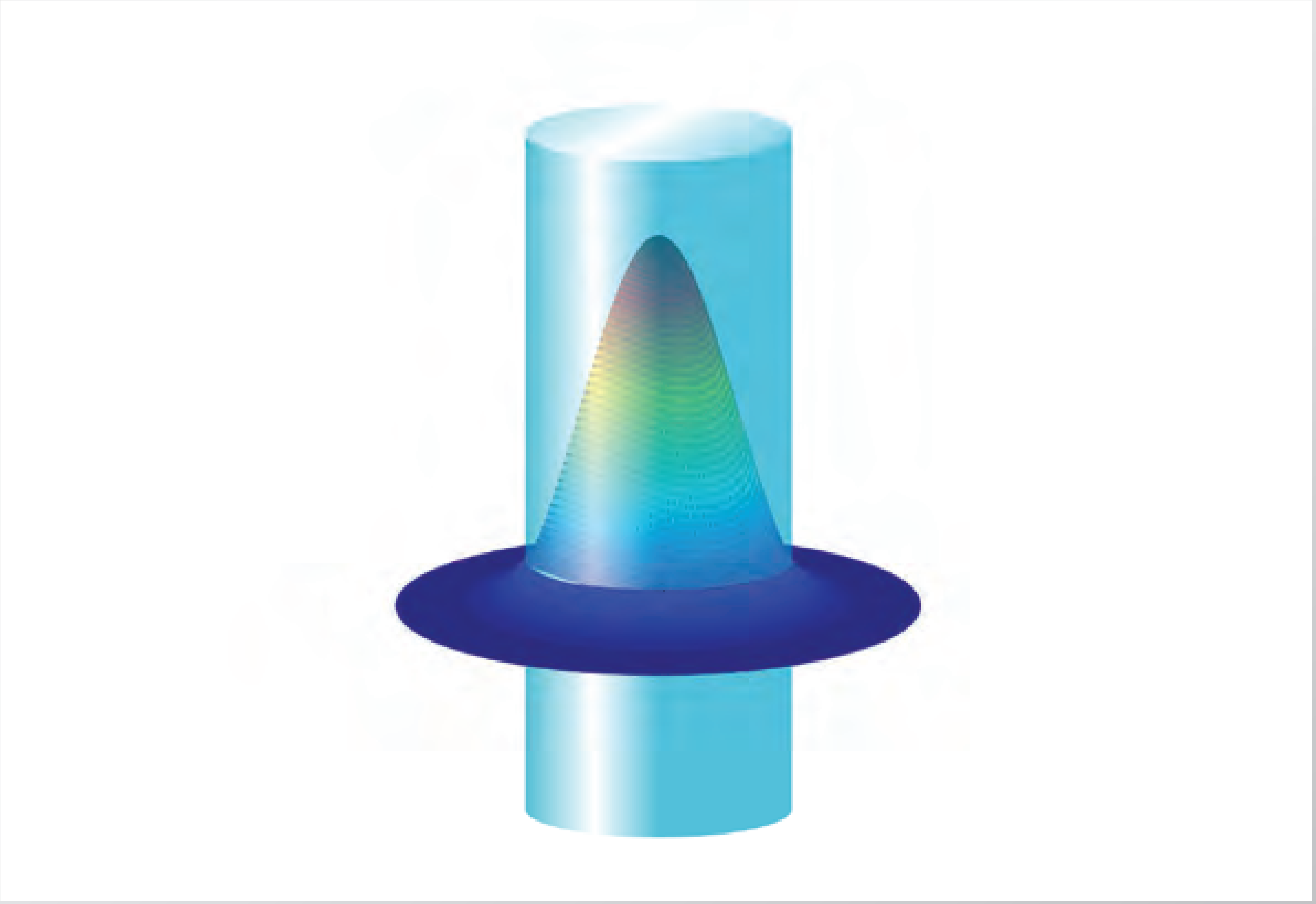
# Optical properties

## Poynting vector profile for 600-nm nanowire



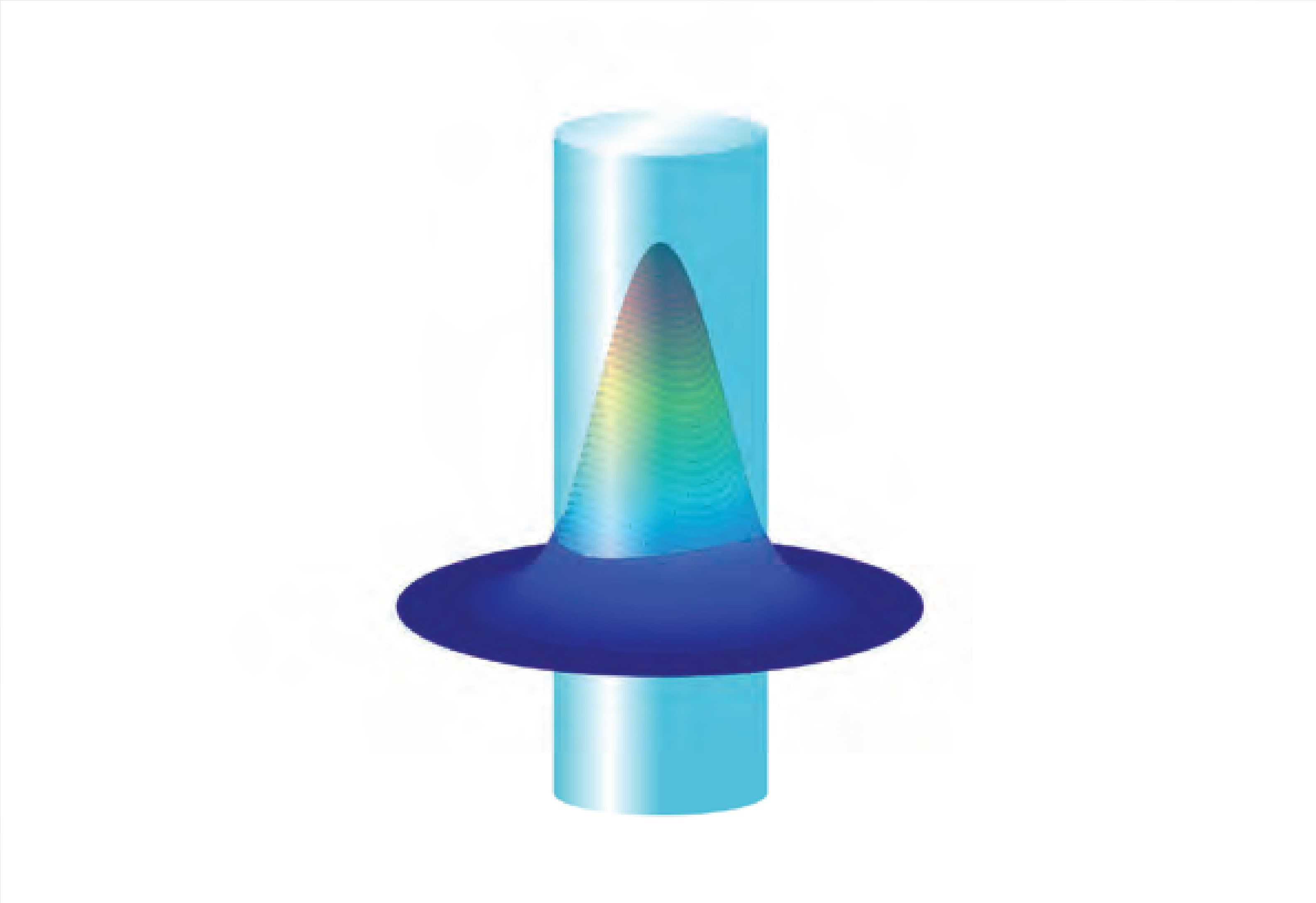
# Optical properties

## Poynting vector profile for 500-nm nanowire



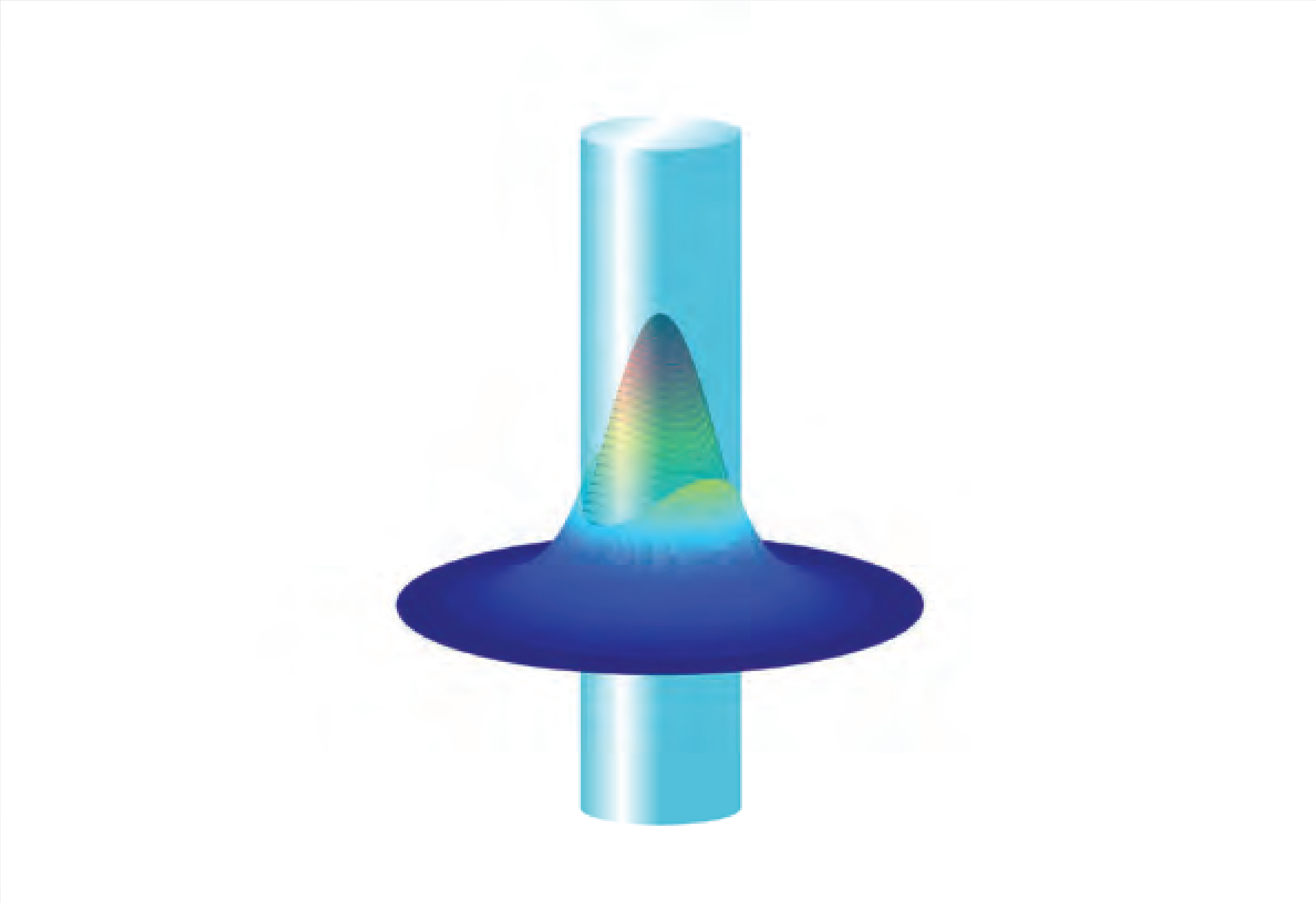
# Optical properties

## Poynting vector profile for 400-nm nanowire



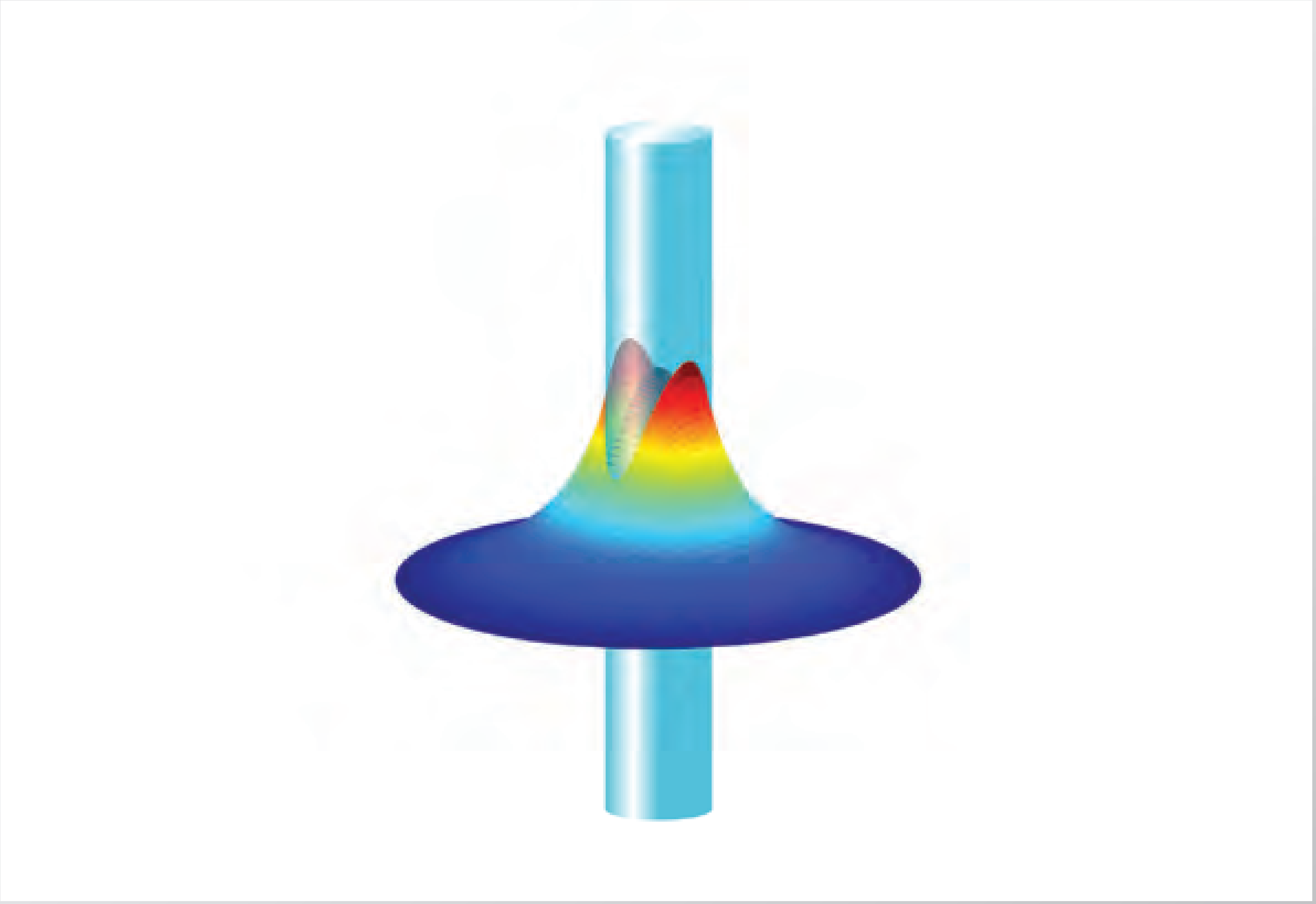
# Optical properties

## Poynting vector profile for 300-nm nanowire



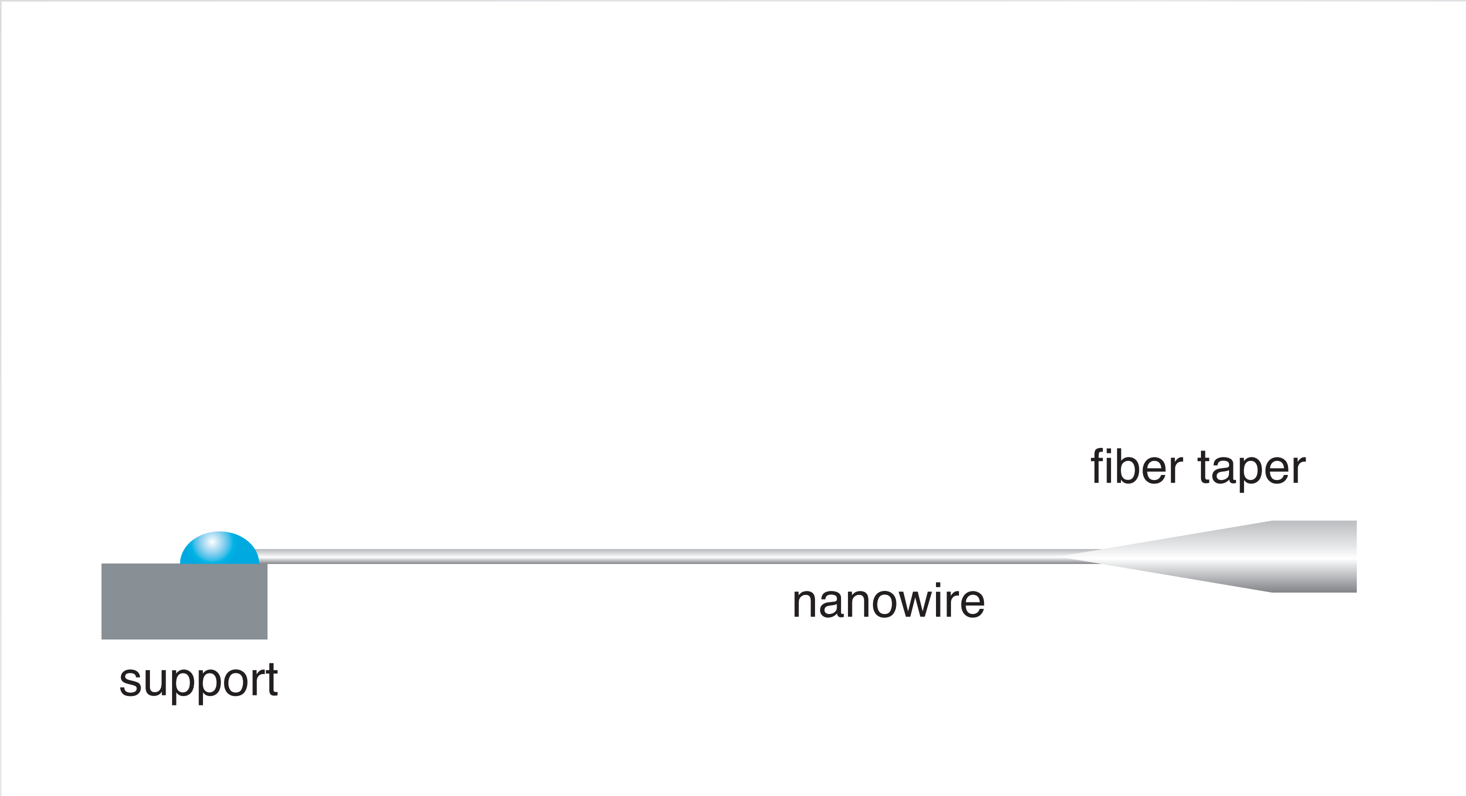
# Optical properties

## Poynting vector profile for 200-nm nanowire



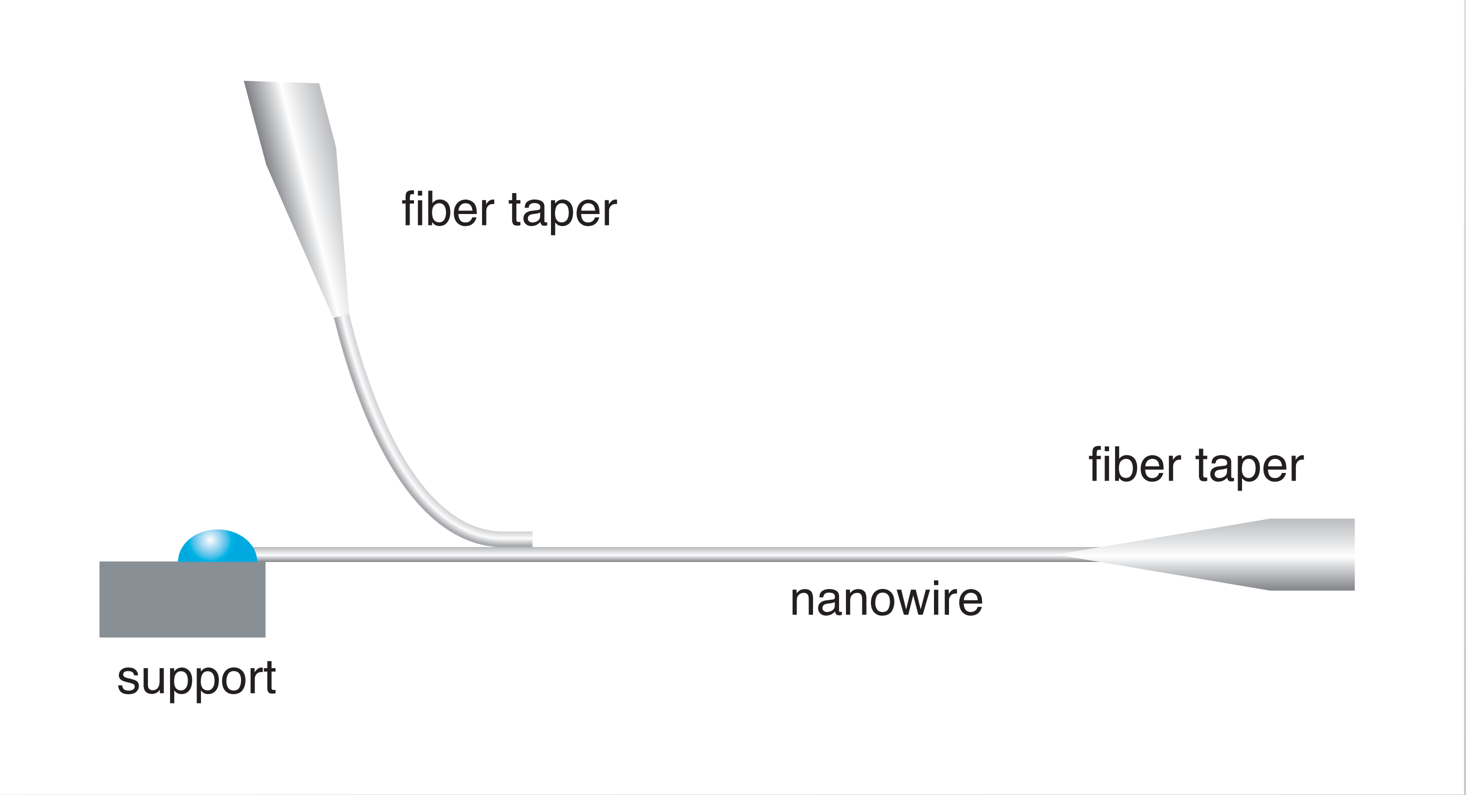
# Optical properties

## coupling light between nanowires



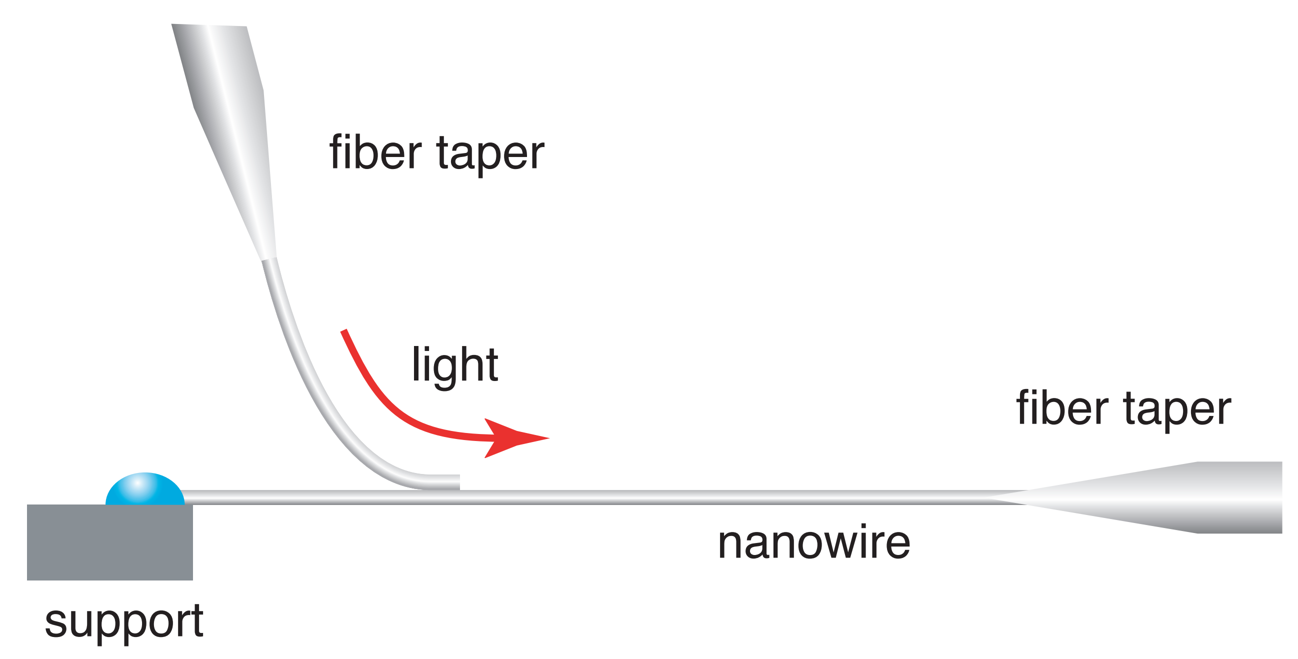
# Optical properties

## coupling light between nanowires



# Optical properties

## coupling light between nanowires



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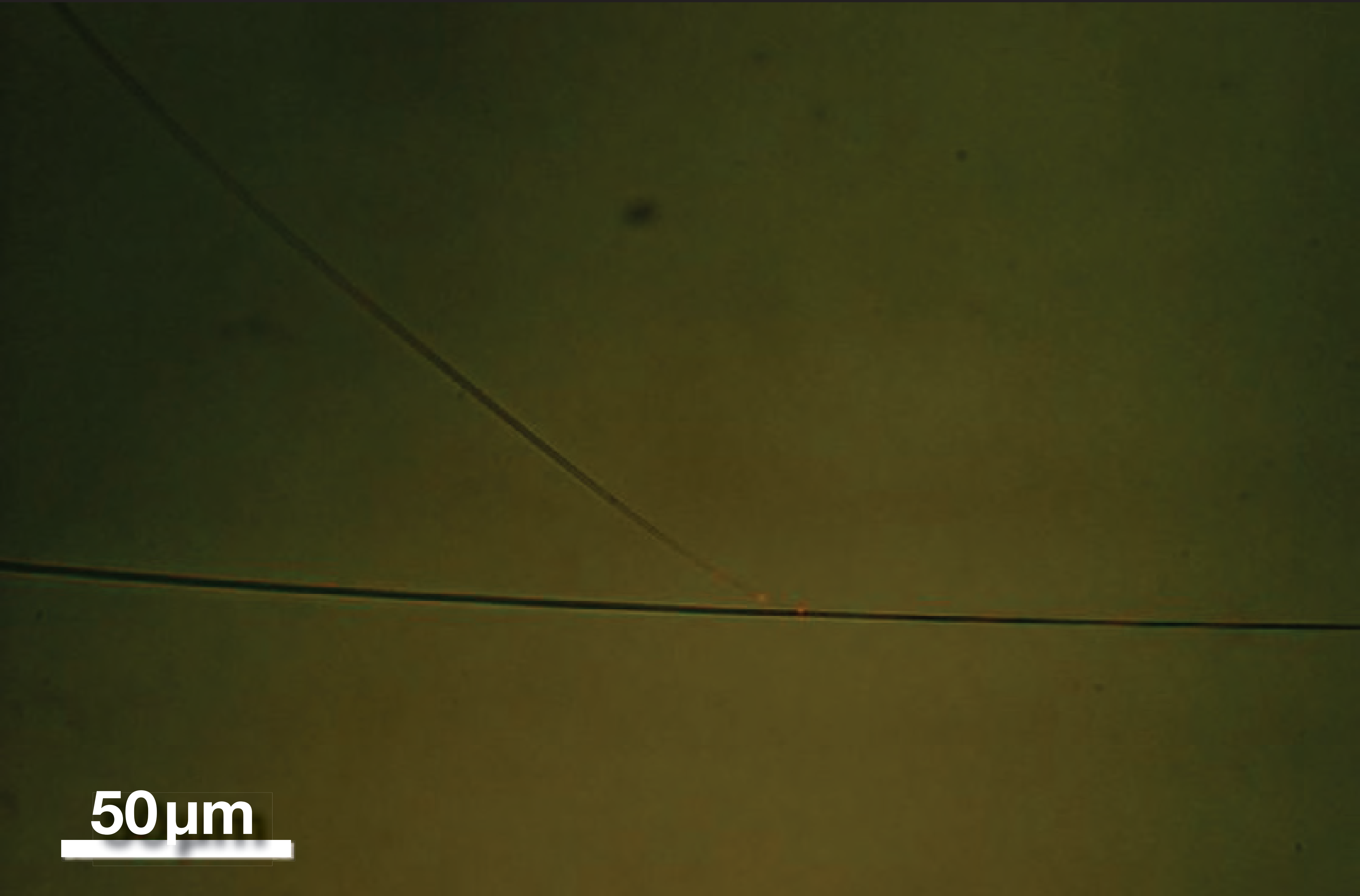

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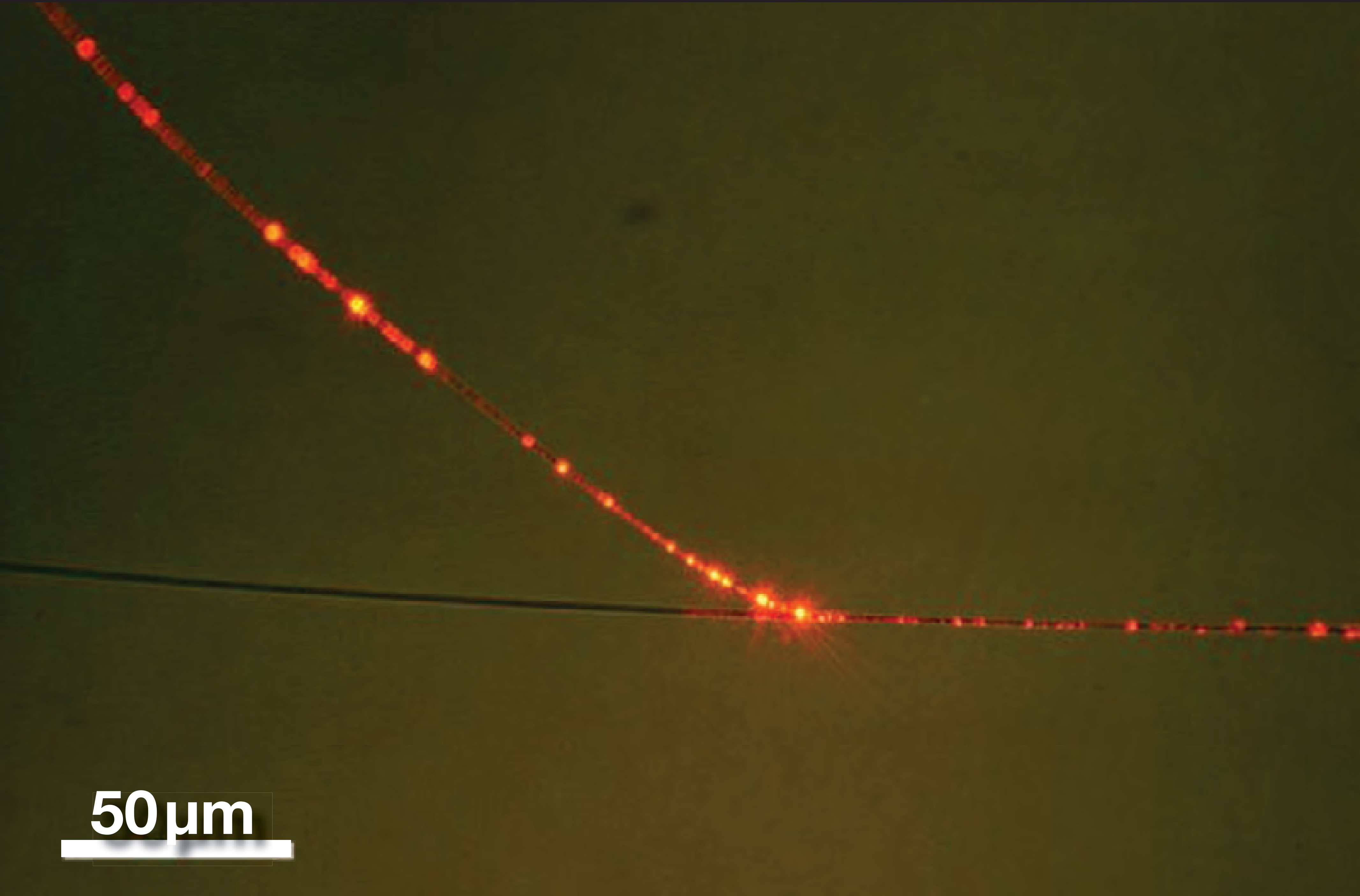

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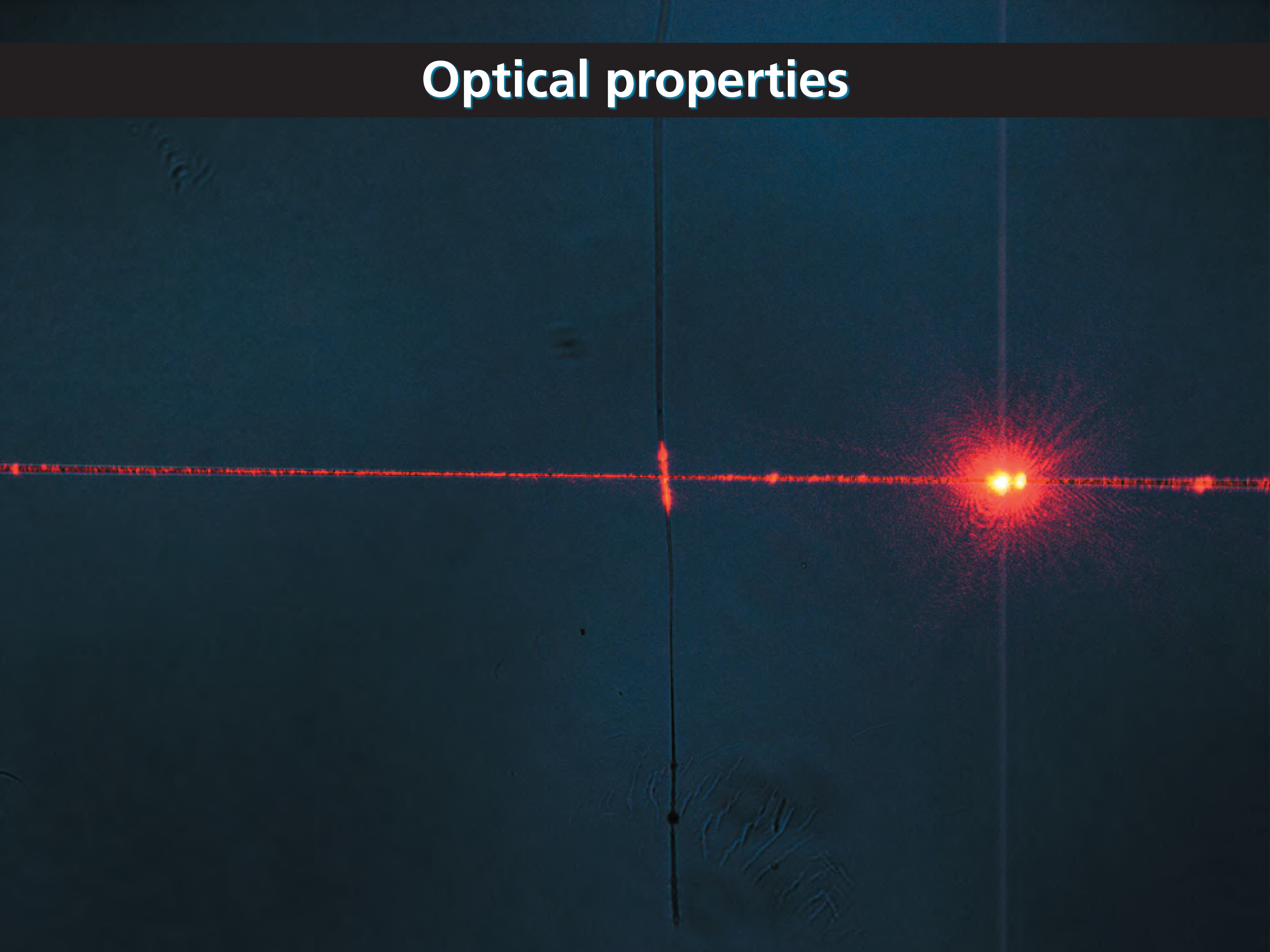

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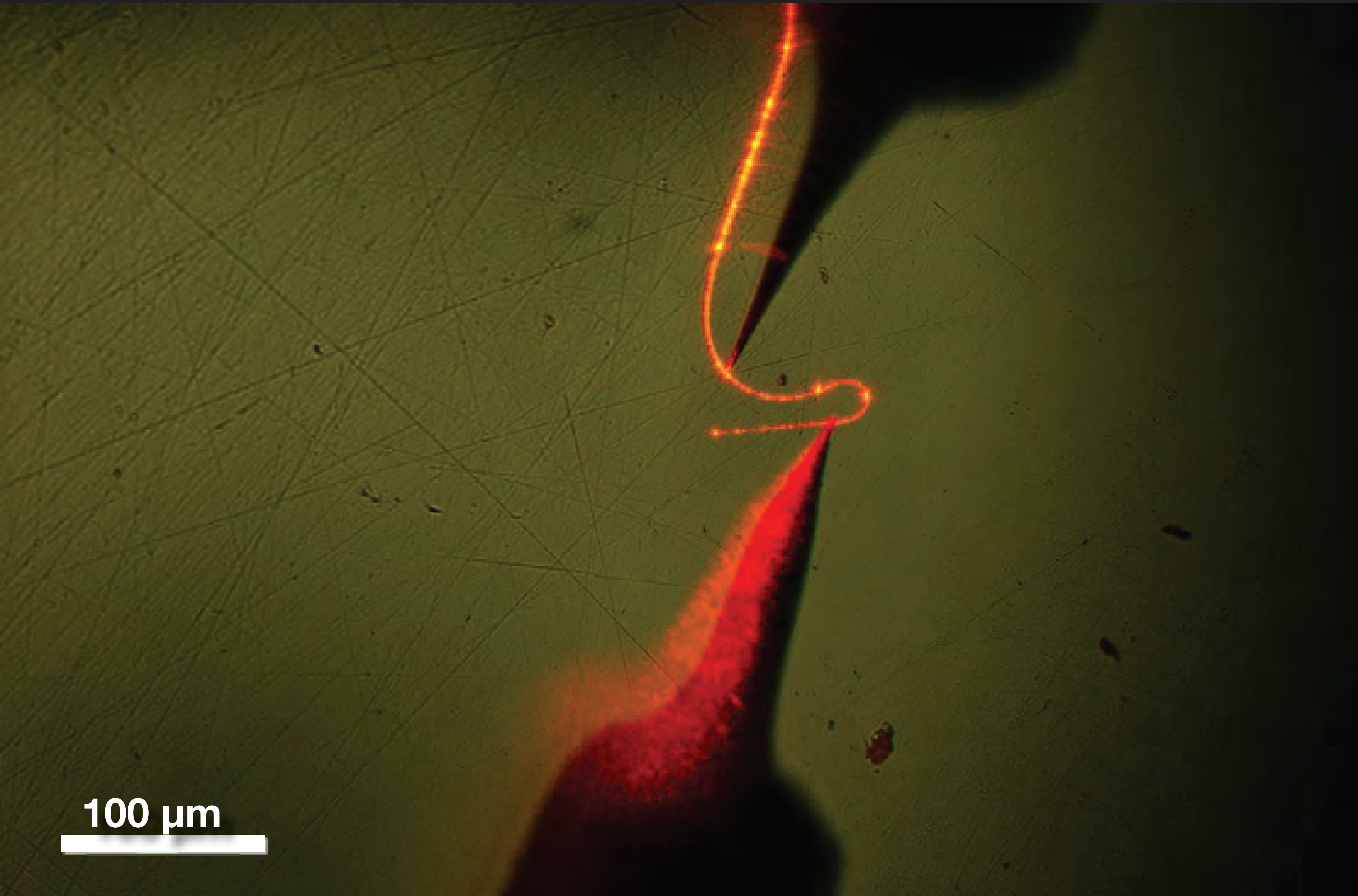

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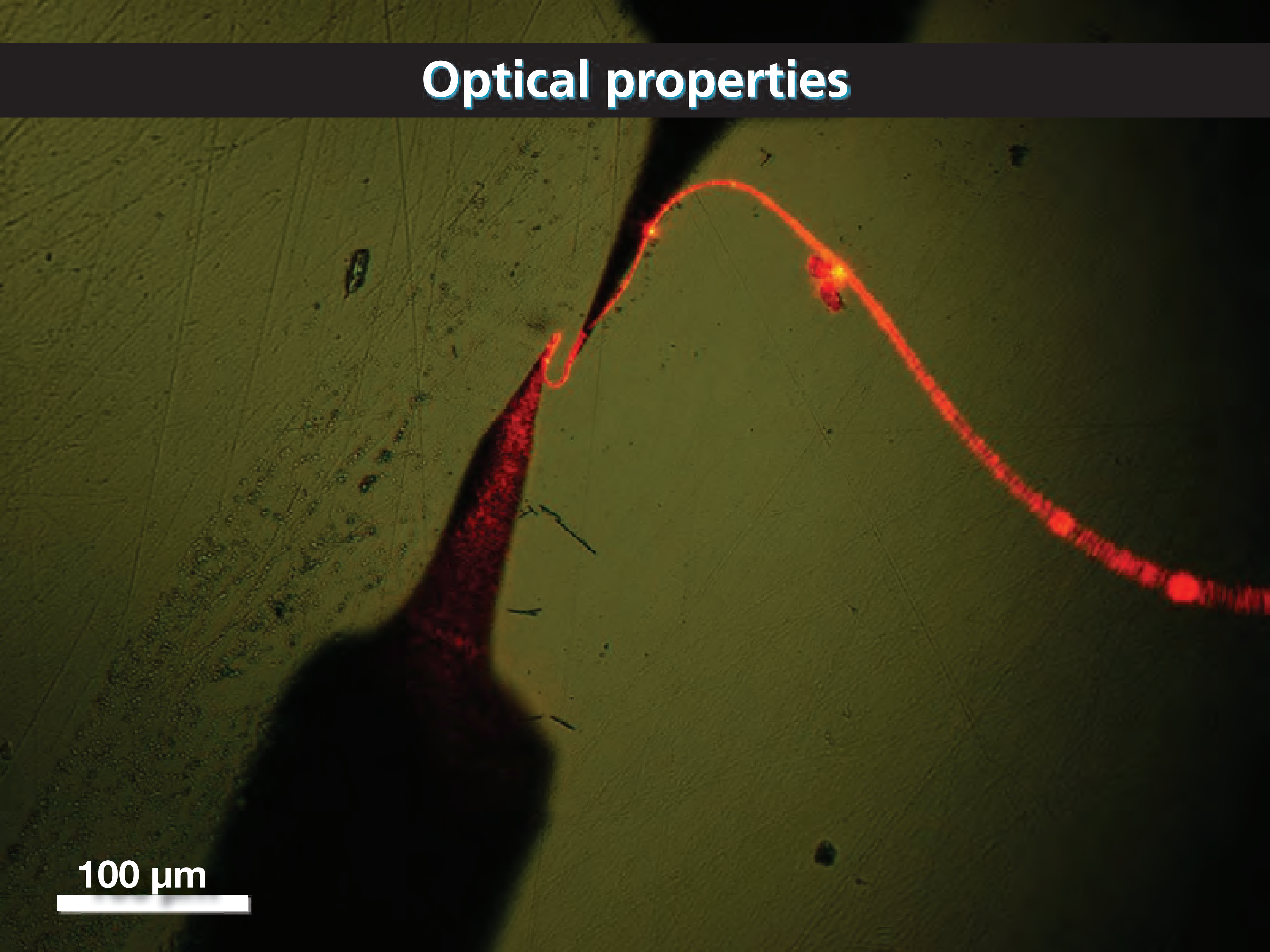

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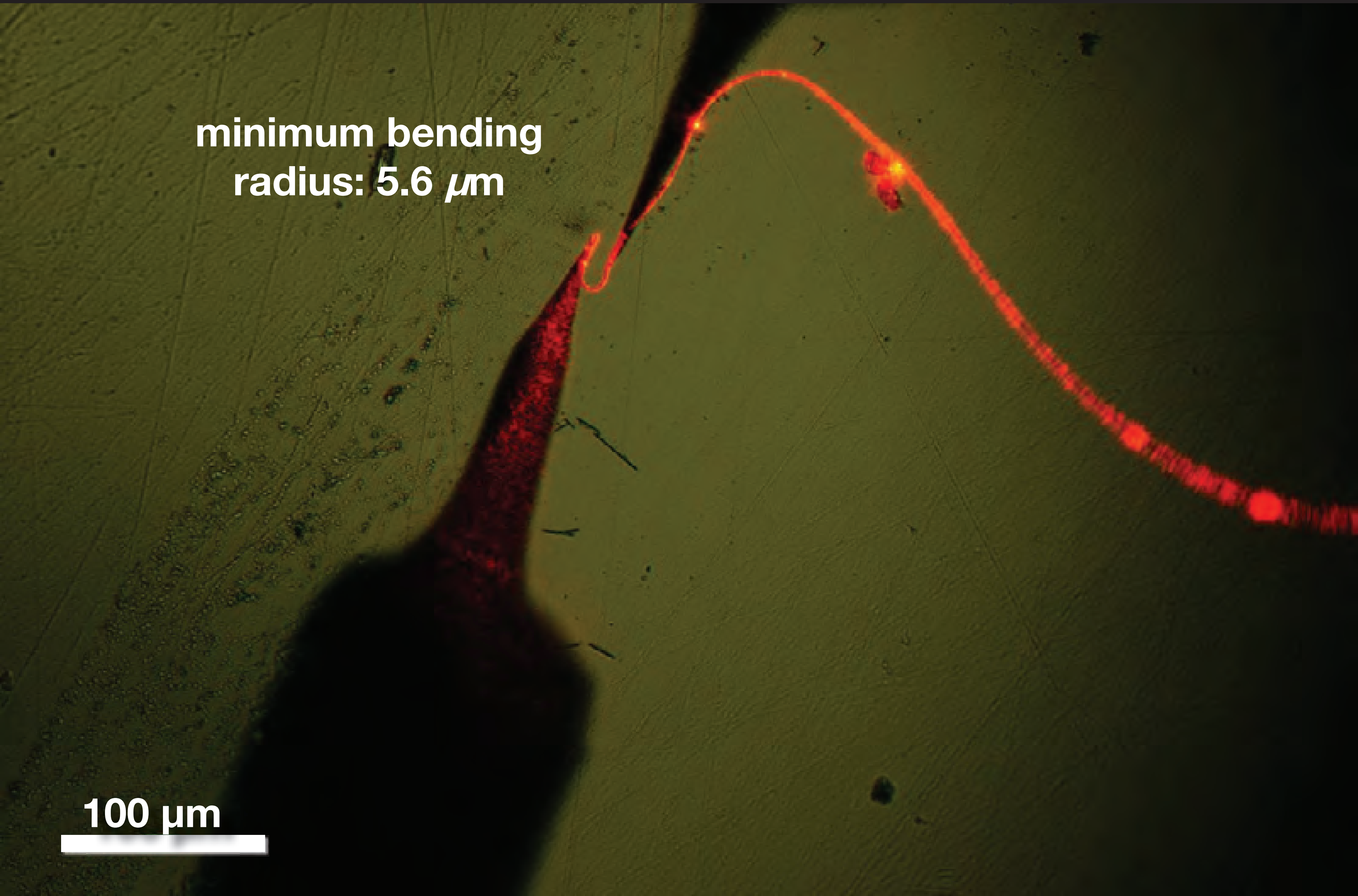

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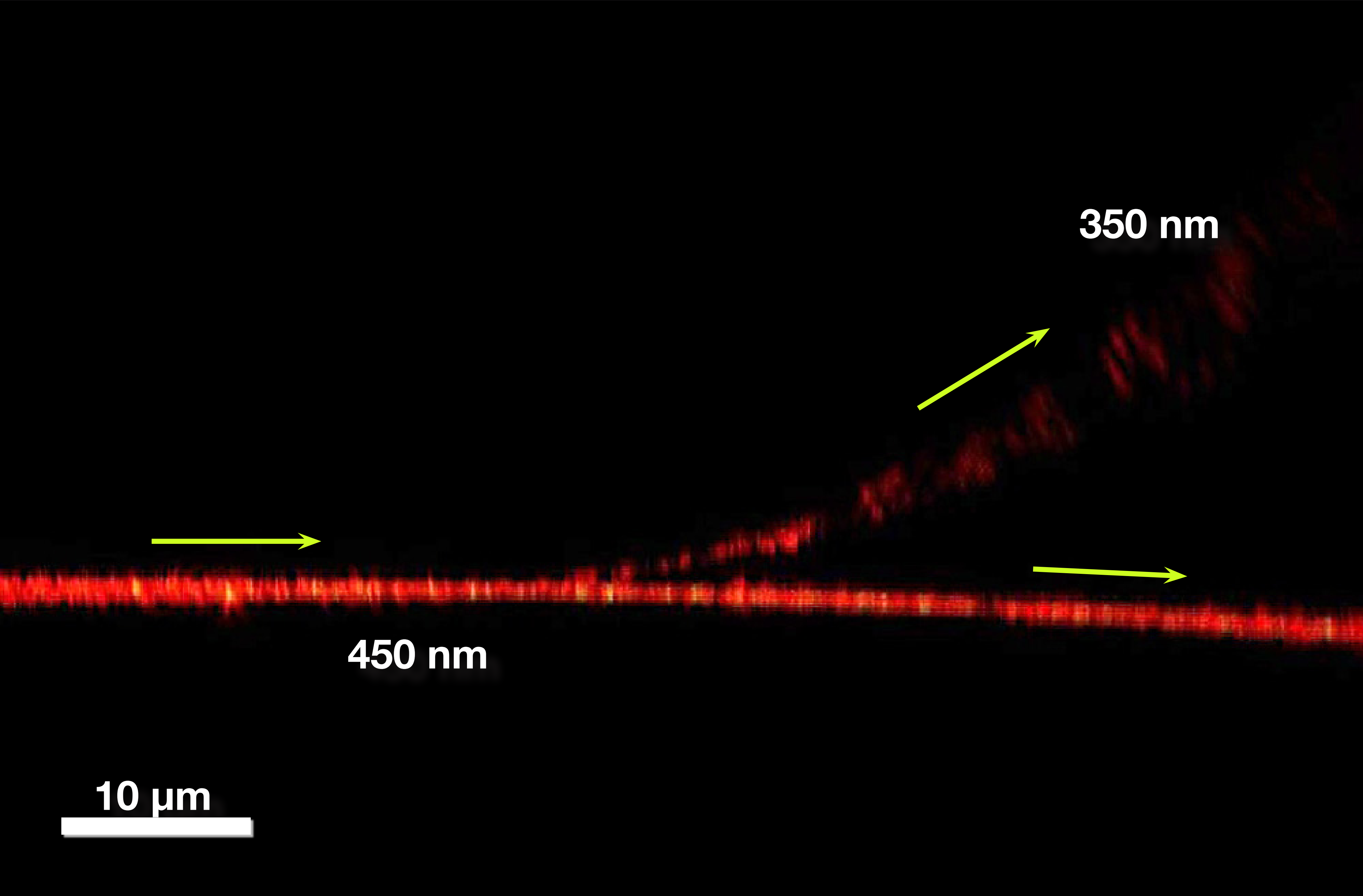
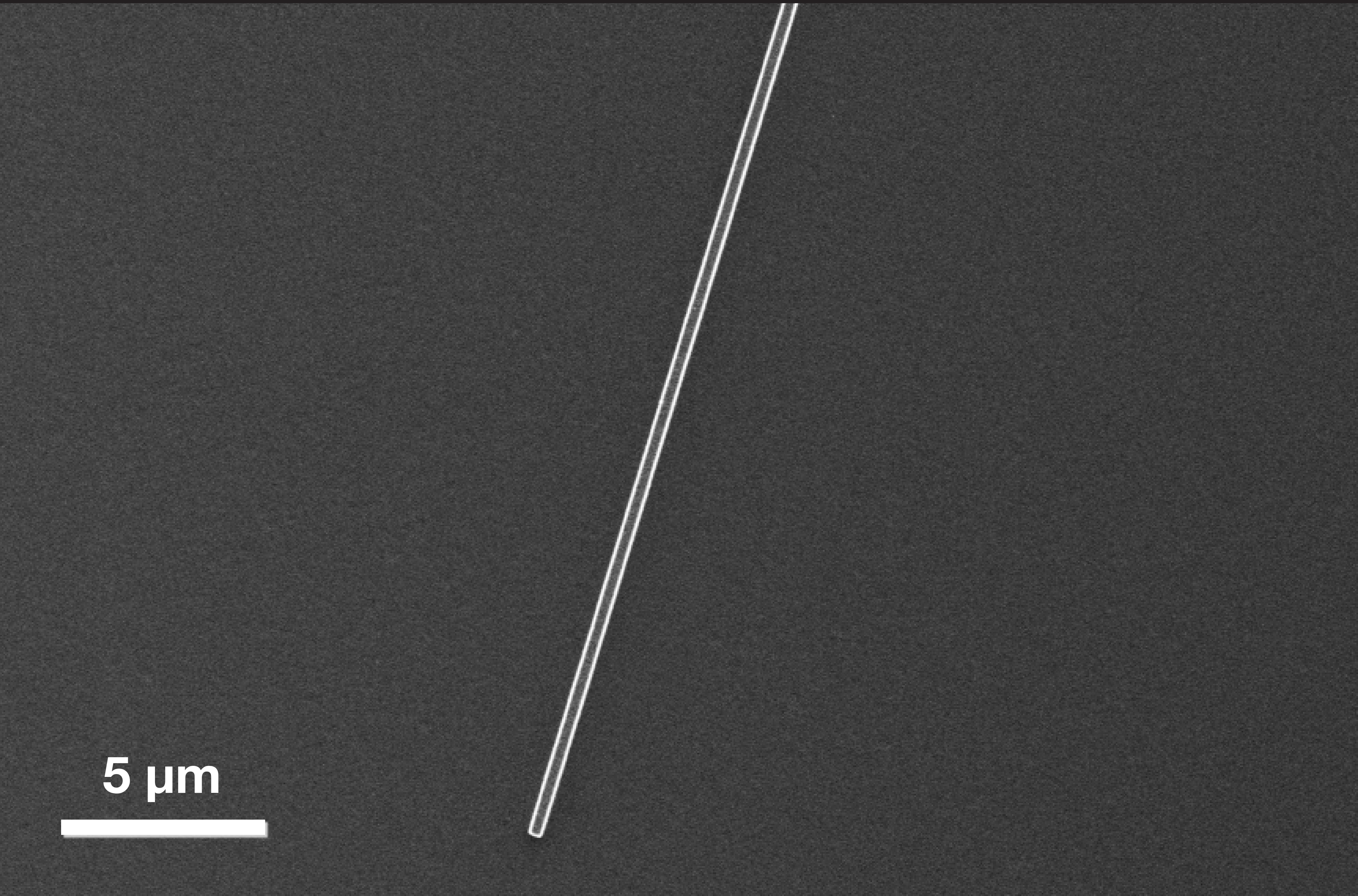


# Waveguiding at the nanoscale



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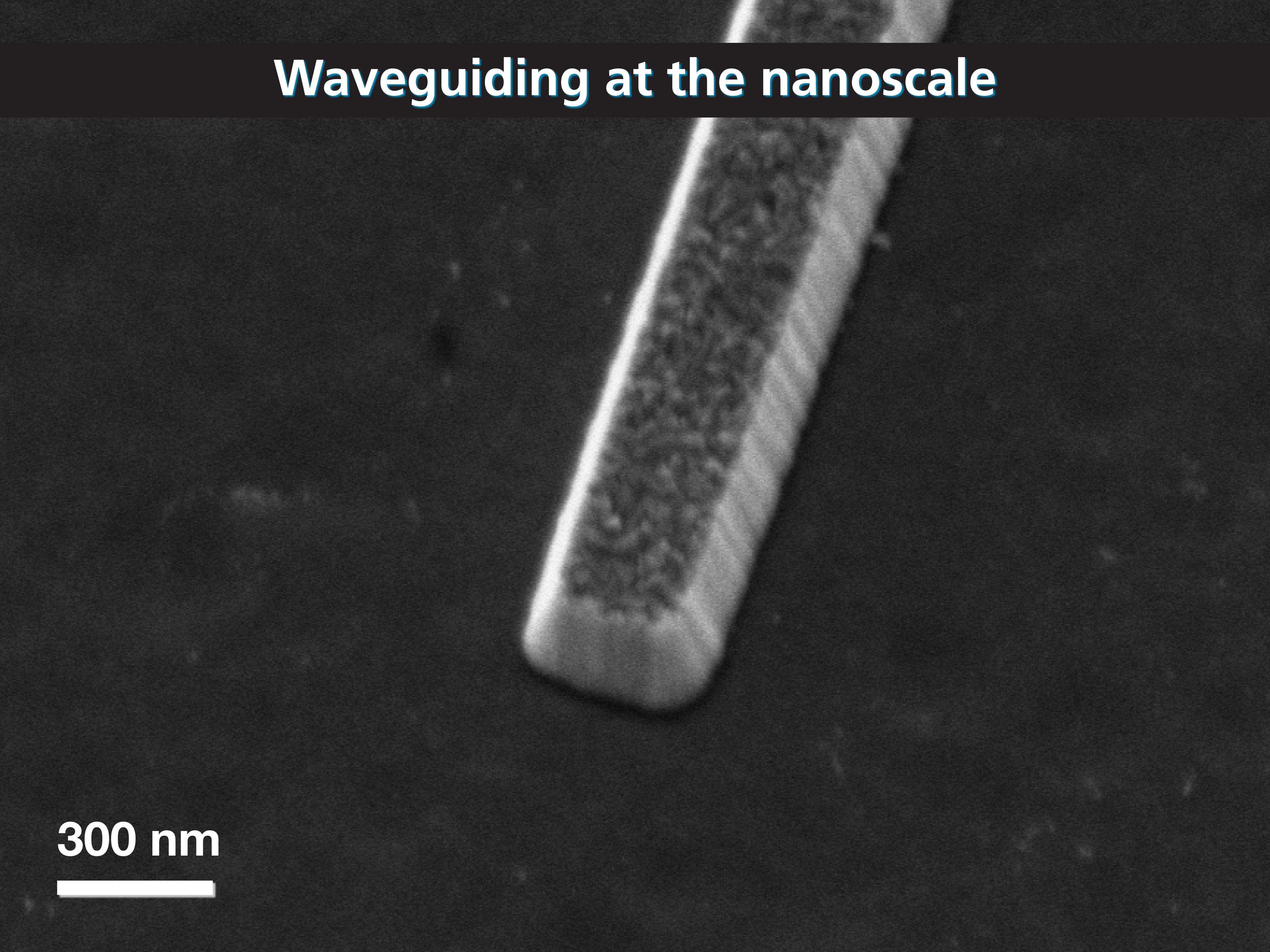
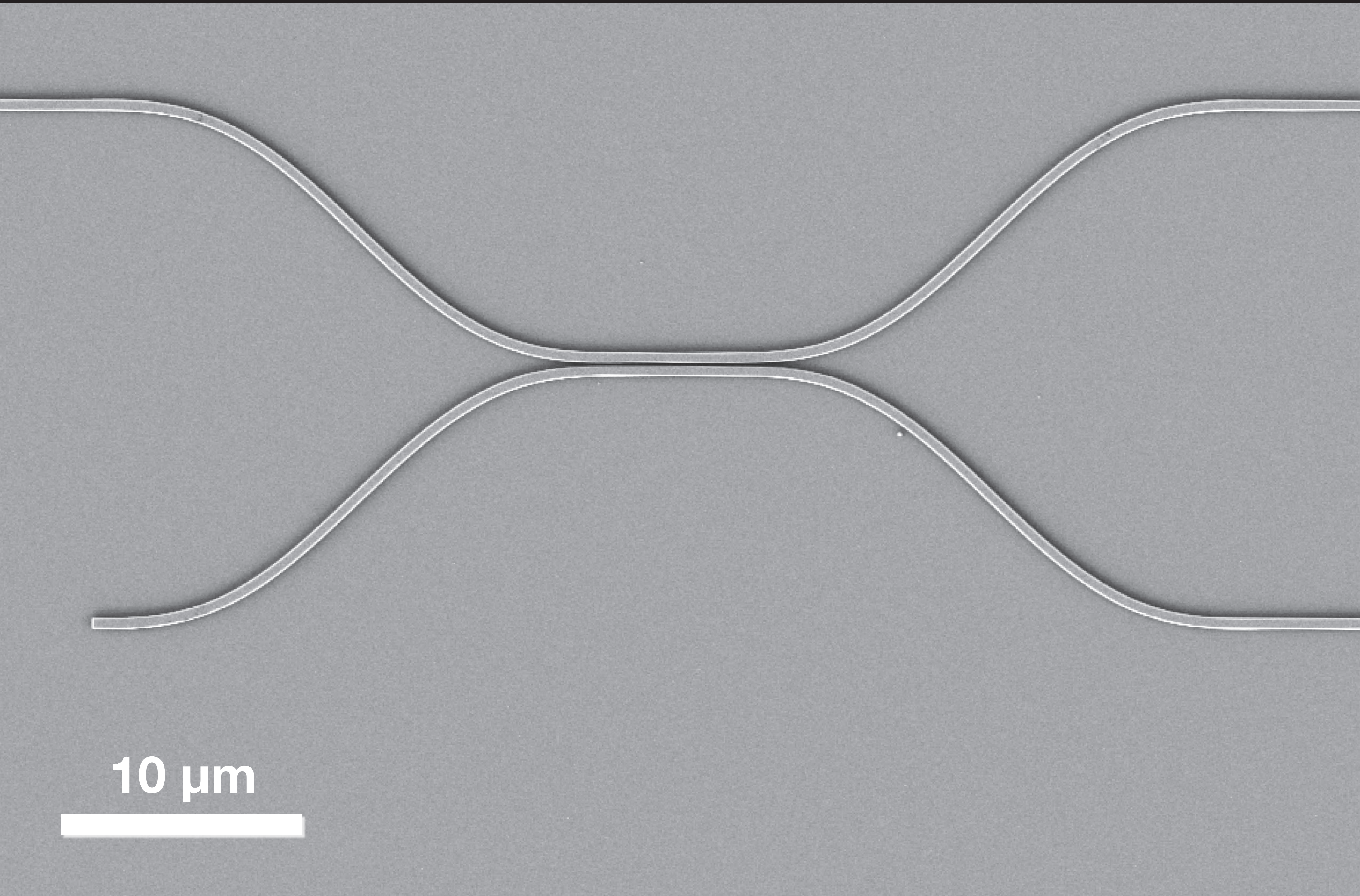
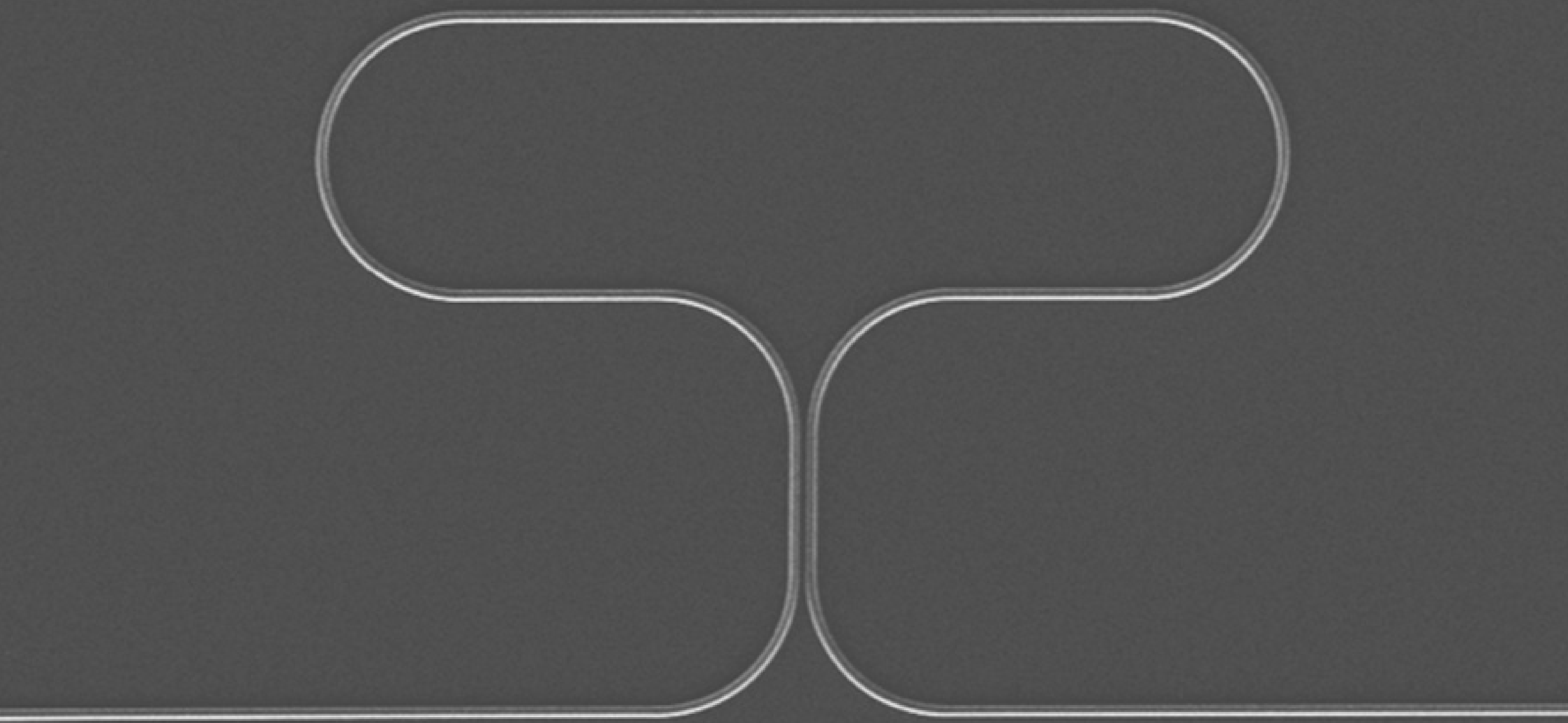


# Waveguiding at the nanoscale



# Optical logic gates



# Zero-index materials

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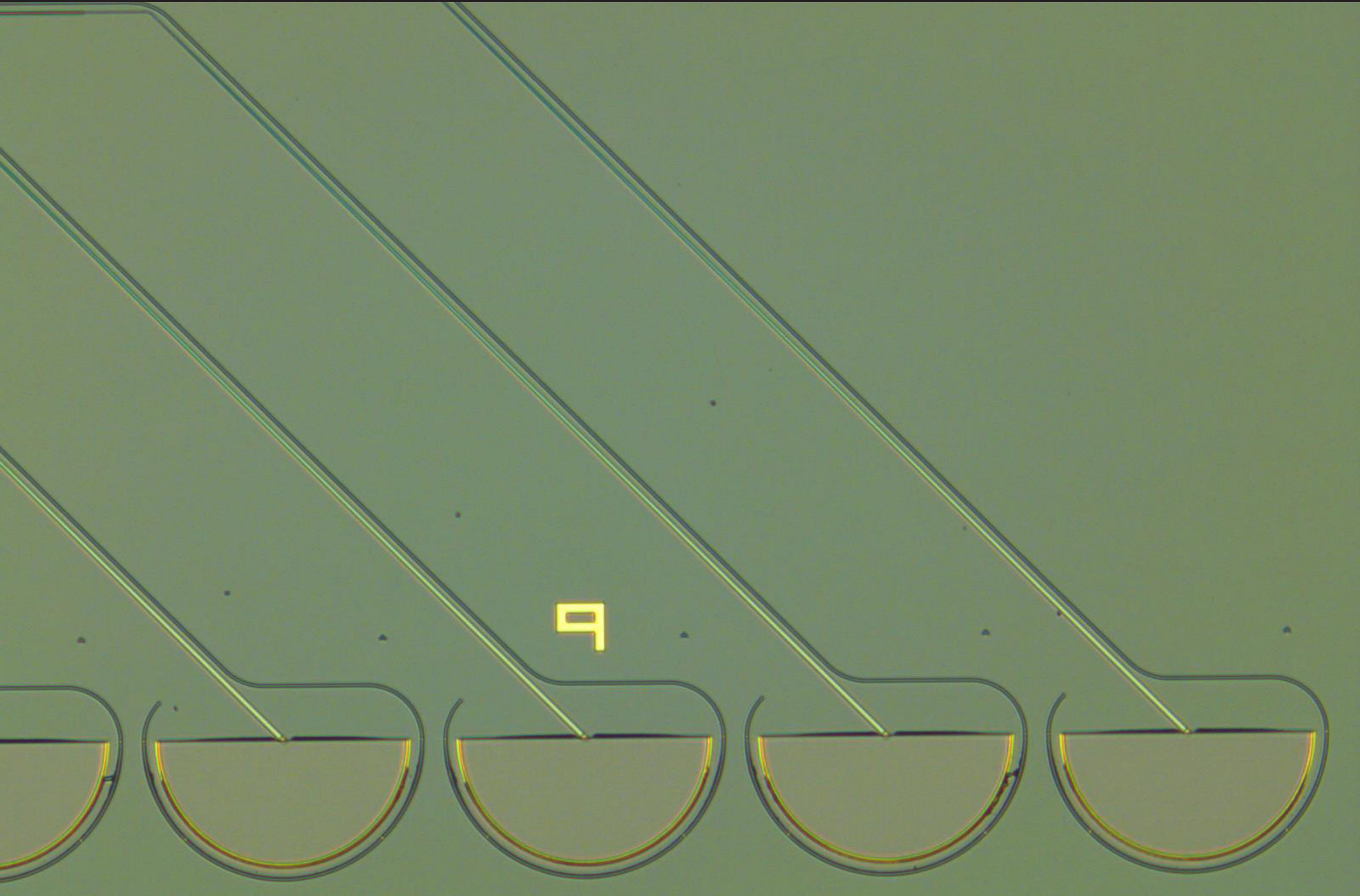

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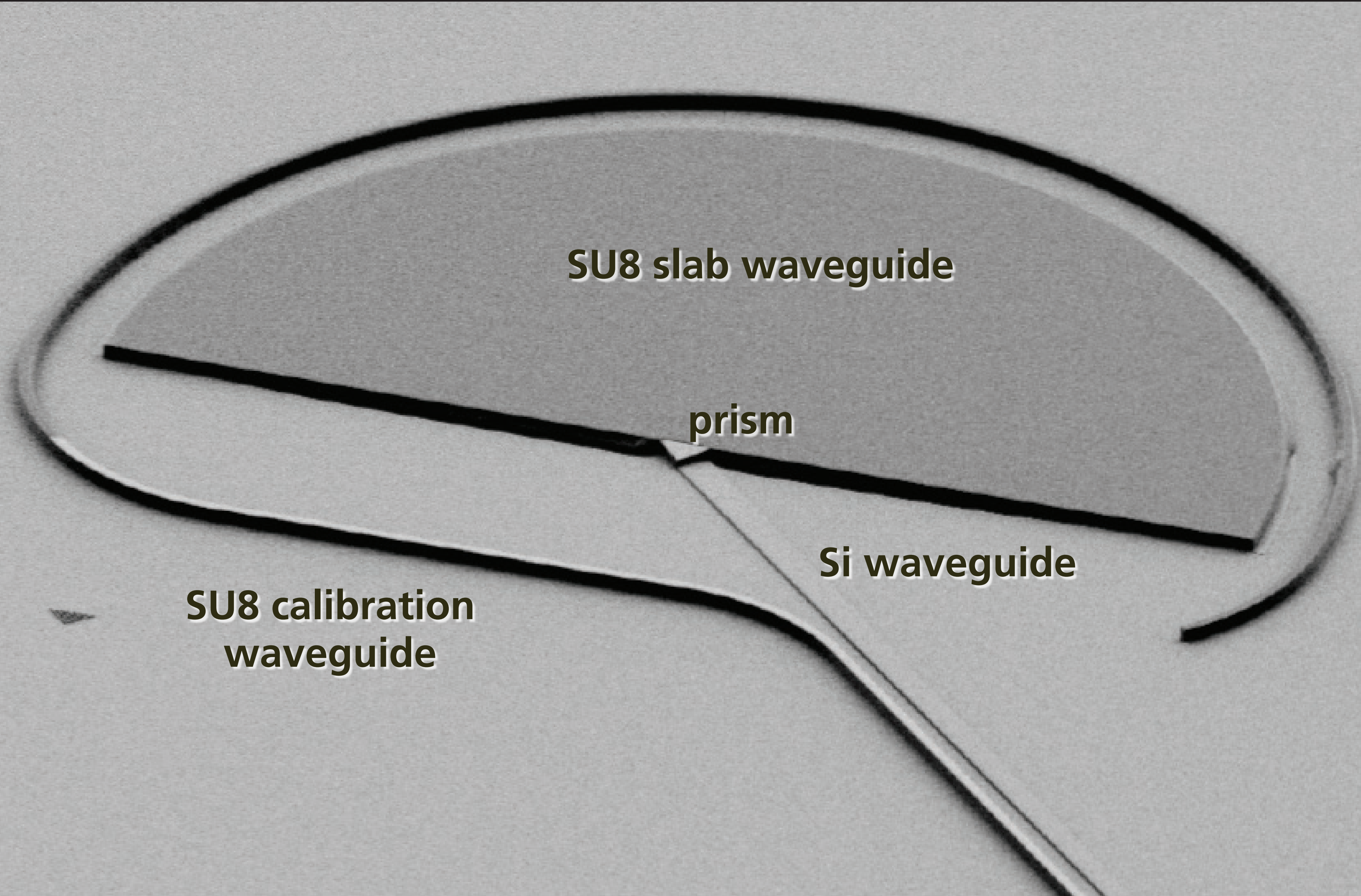

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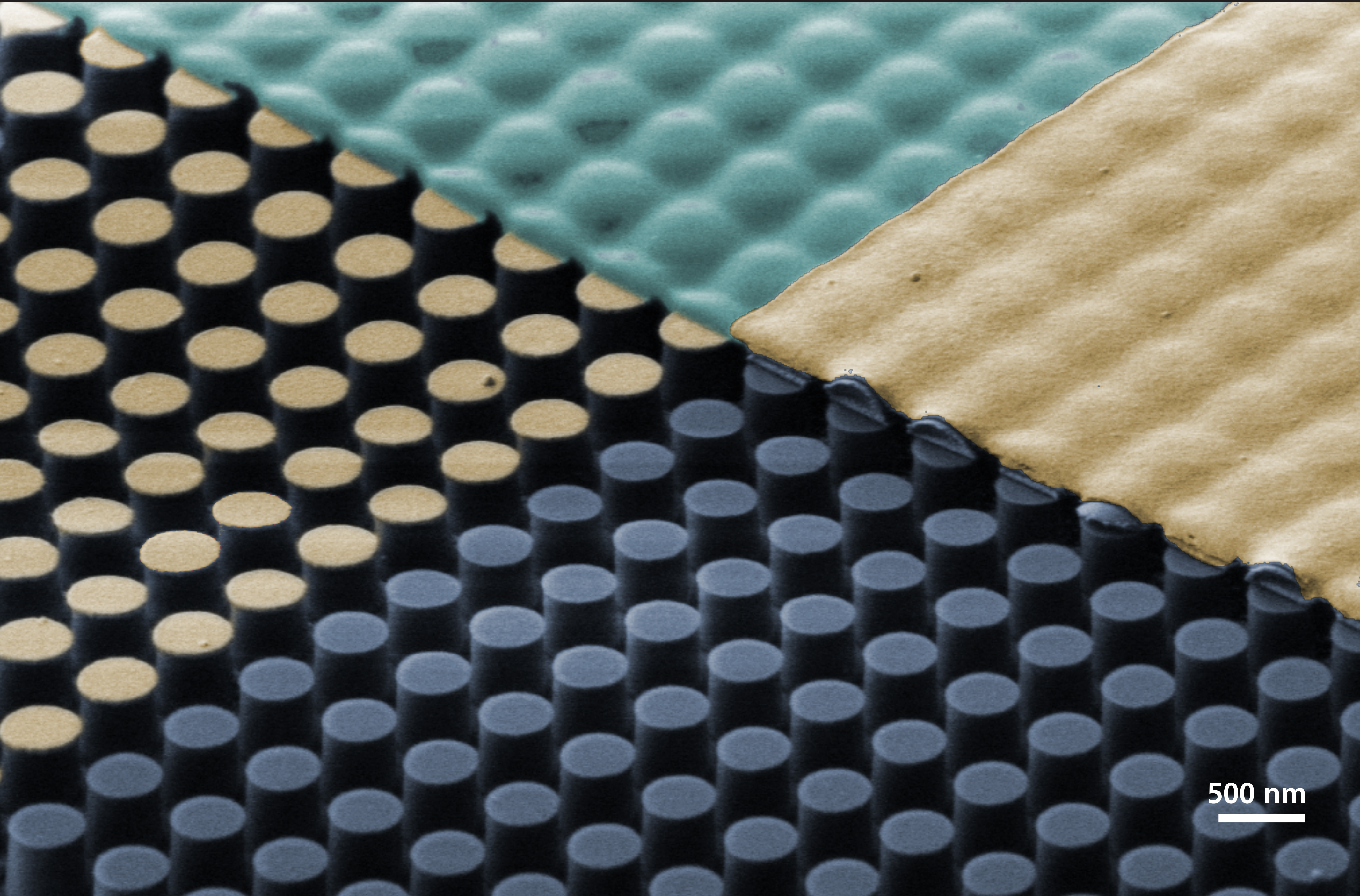
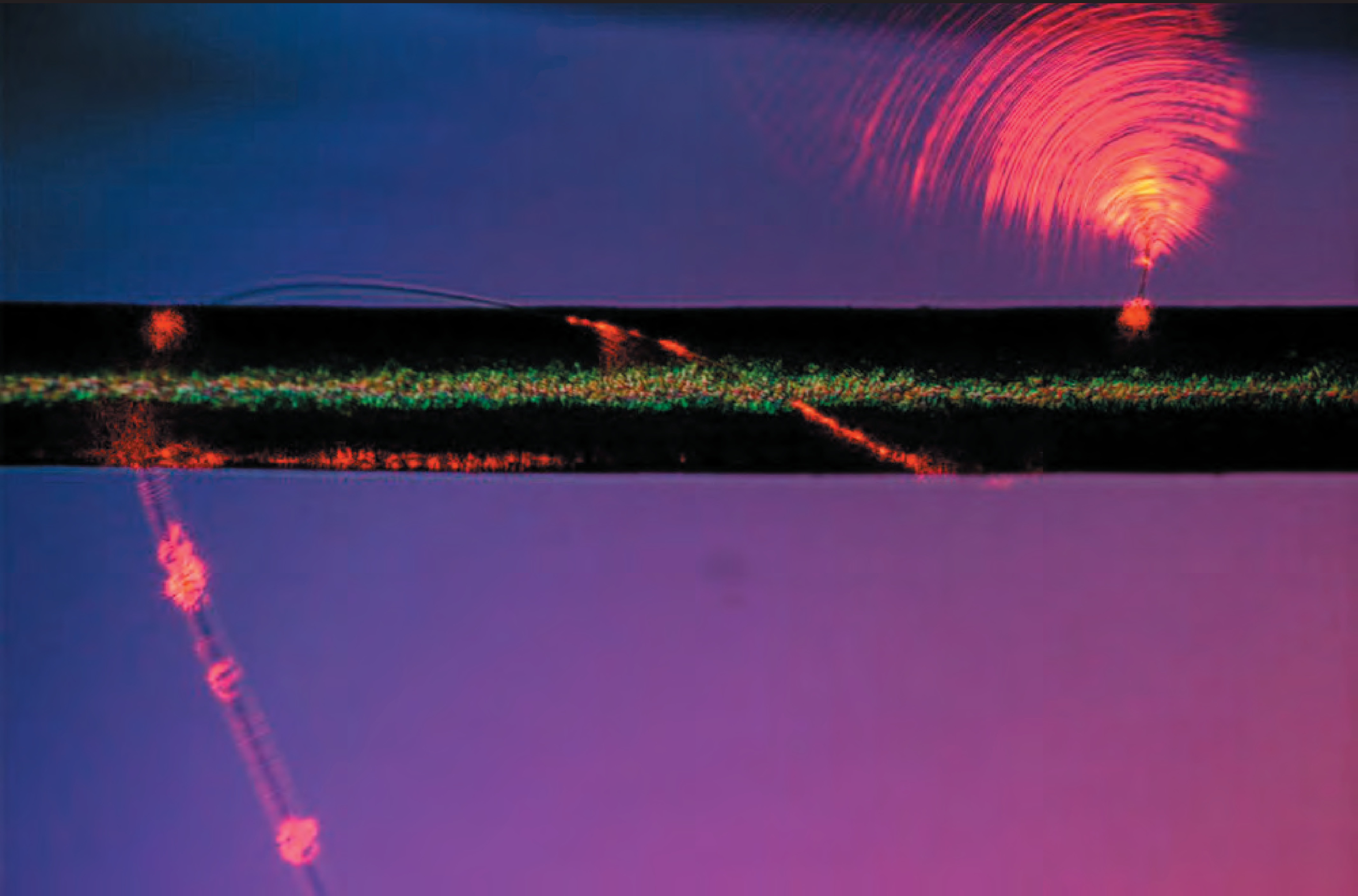


# Summary



# Summary

- easy fabrication
- convenient nanoscale light manipulation
- nanoscale nonlinear optics

Funding:

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