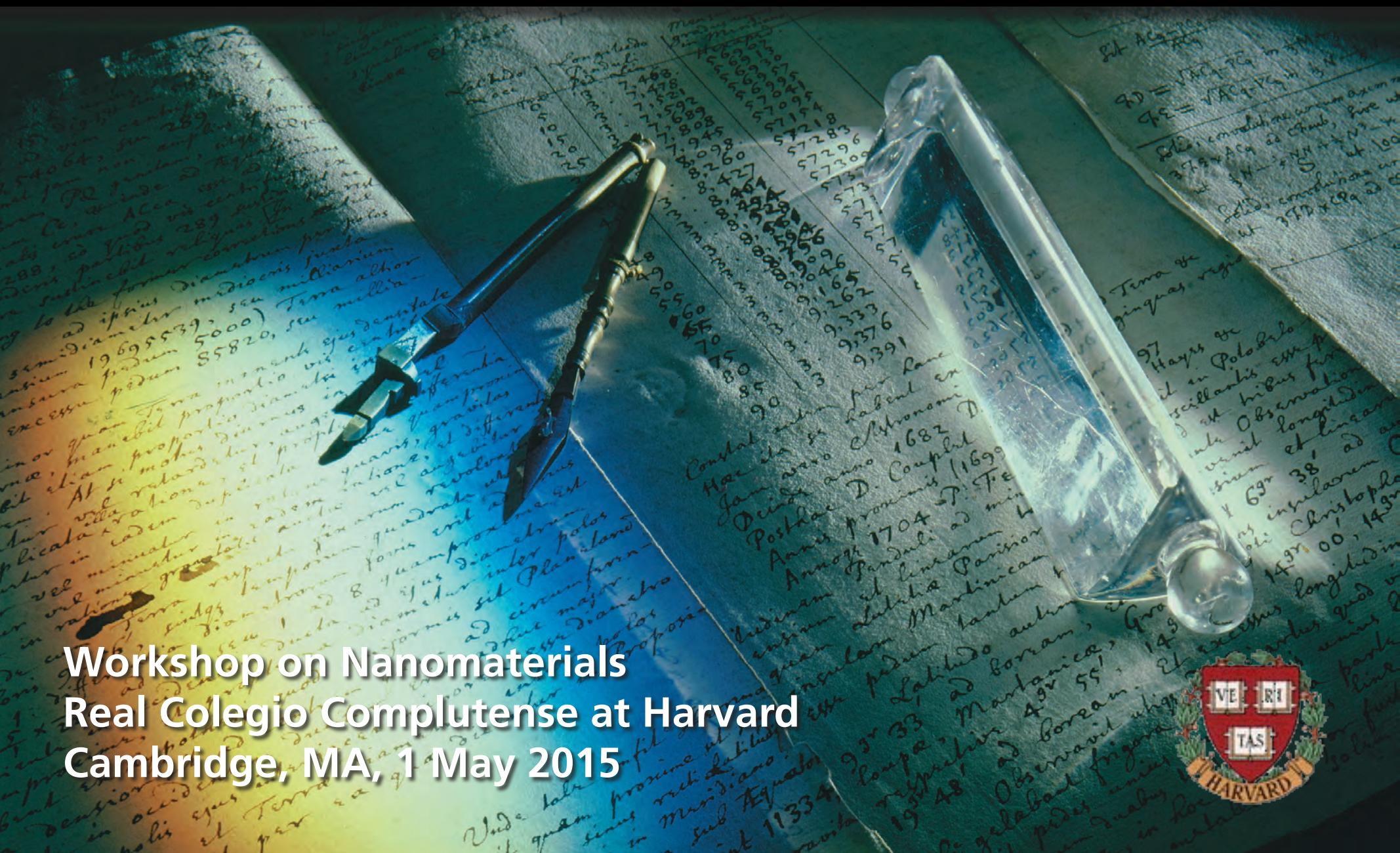


Making light go infinitely fast



**Workshop on Nanomaterials
Real Colegio Complutense at Harvard
Cambridge, MA, 1 May 2015**

Making light go infinitely fast



@eric_mazur

Workshop on Nanomaterials
Real Colegio Complutense at Harvard
Cambridge, MA, 1 May 2015





1 zero index



n

1 zero index

wave equation

$$\nabla^2 \vec{E} - \frac{\mu\epsilon}{c^2} \frac{\partial^2 \vec{E}}{\partial t^2} = 0$$

1 zero index

wave equation

$$\nabla^2 \vec{E} - \frac{\mu\epsilon}{c^2} \frac{\partial^2 \vec{E}}{\partial t^2} = 0$$

solution

$$\vec{E} = \vec{E}_o e^{i(kx - \omega t)}$$

1 zero index

wave equation

$$\nabla^2 \vec{E} - \frac{\mu\epsilon}{c^2} \frac{\partial^2 \vec{E}}{\partial t^2} = 0$$

solution

$$\vec{E} = \vec{E}_o e^{i(kx - \omega t)}$$

where

$$\frac{\omega}{k} = \frac{1}{\sqrt{\epsilon\mu}} c = \frac{1}{n} c$$

1 zero index

wave equation

$$\nabla^2 \vec{E} - \frac{\mu \epsilon_0 c^2 \vec{E}}{c^2 \epsilon_0 \mu_0} = 0$$

solution

$$\vec{E} = \vec{E}_o e^{i(kx - \omega t)}$$

where

$$\frac{\omega}{k} = \frac{1}{\sqrt{\epsilon\mu}} c = \frac{1}{n} c$$

1 zero index

wave equation

$$\nabla^2 \vec{E} - \frac{\mu \epsilon_0}{c^2} \vec{E} = 0$$

solution

$$\vec{E} = \vec{E}_o e^{i(kx - \omega t)} \longrightarrow \vec{E} = \vec{E}_o e^{-i\omega t}$$

where

$$\frac{\omega}{k} = \frac{1}{\sqrt{\epsilon\mu}} c = \frac{1}{n} c$$

1 zero index

wave equation

$$\nabla^2 \vec{E} - \frac{\mu \epsilon_0 \omega^2}{c^2} \vec{E} = 0$$

solution

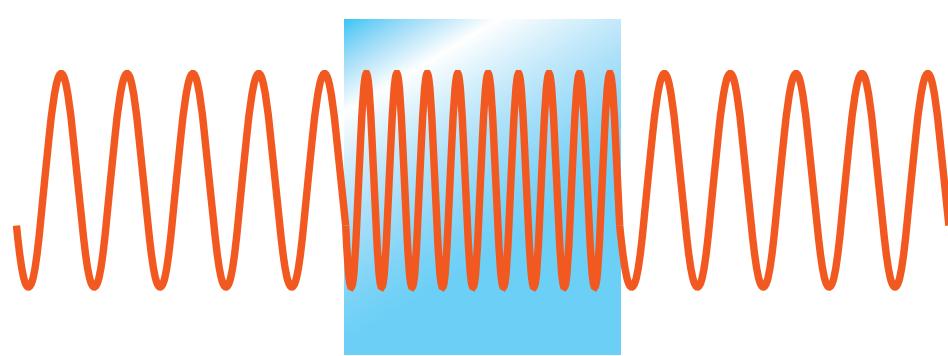
$$\vec{E} = \vec{E}_o e^{i(kx - \omega t)} \longrightarrow \vec{E} = \vec{E}_o e^{-i\omega t}$$

where

$$\frac{\omega}{k} = \frac{1}{\sqrt{\epsilon\mu}} c = \frac{1}{n} c \longrightarrow \infty$$

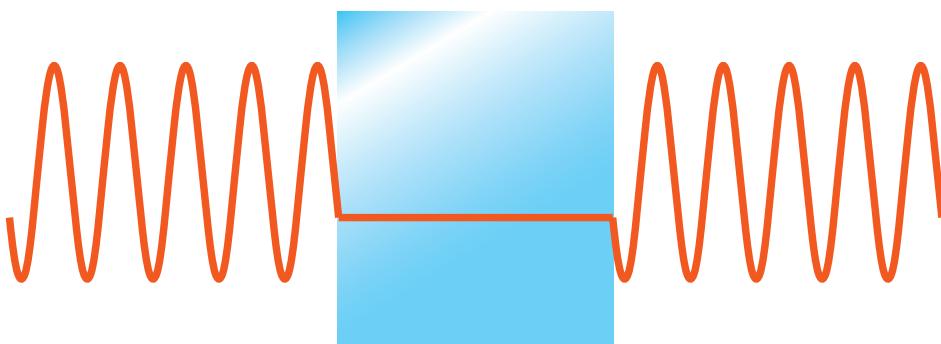
1 zero index

$n > 0$



1 zero index

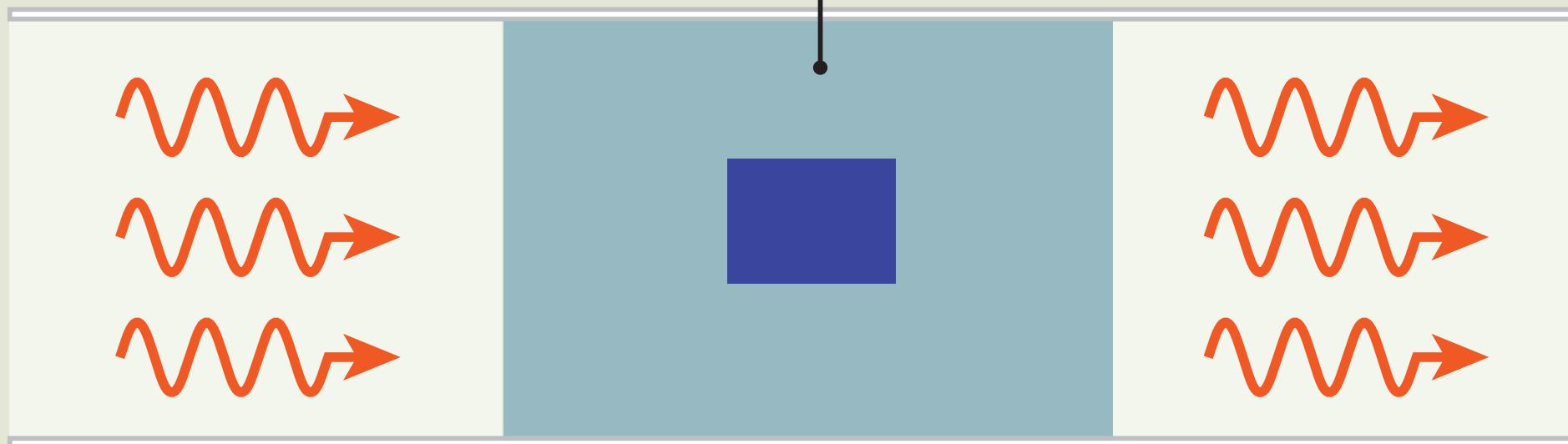
$n = 0$



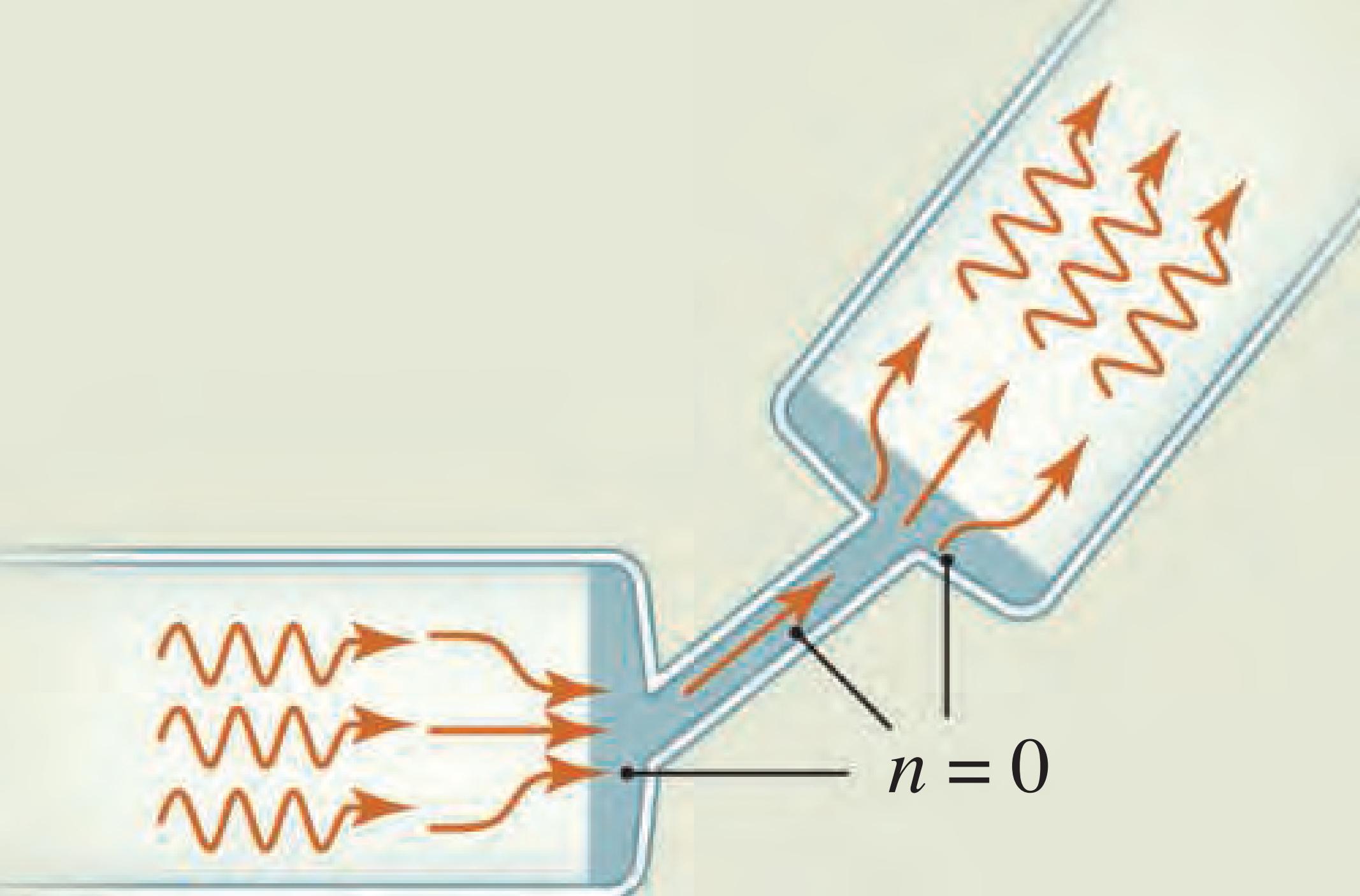
1 zero index

$n = 0$ 

1 zero index

$n = 0$ 

1 zero index



1 zero index

how?

1 zero index

how?

$$n = \sqrt{\epsilon\mu}$$

how?

$$n = \sqrt{\varepsilon\mu}$$

$$Z = \sqrt{\frac{\mu}{\varepsilon}}$$

how?

$$\mu \rightarrow 0$$

$$n = \sqrt{\varepsilon\mu} \rightarrow 0$$

$$Z = \sqrt{\frac{\mu}{\varepsilon}}$$

how?

$$\mu \rightarrow 0$$

$$n = \sqrt{\varepsilon\mu} \rightarrow 0$$

$$Z = \sqrt{\frac{\mu}{\varepsilon}} \rightarrow 0$$

how?

$$\varepsilon \rightarrow 0$$

$$n = \sqrt{\varepsilon\mu} \rightarrow 0$$

$$Z = \sqrt{\frac{\mu}{\varepsilon}} \rightarrow \infty$$

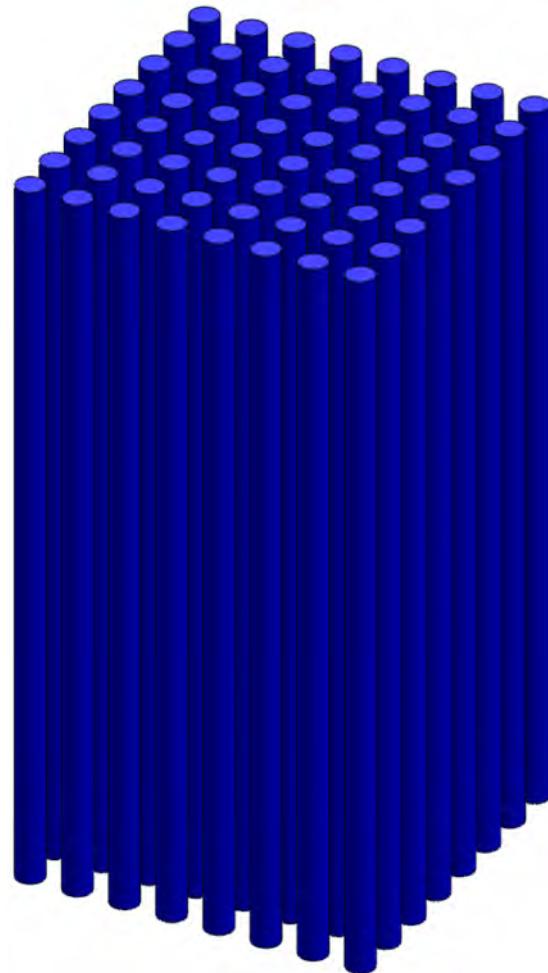
how?

$$\varepsilon, \mu \rightarrow 0$$

$$n = \sqrt{\varepsilon\mu} \rightarrow 0$$

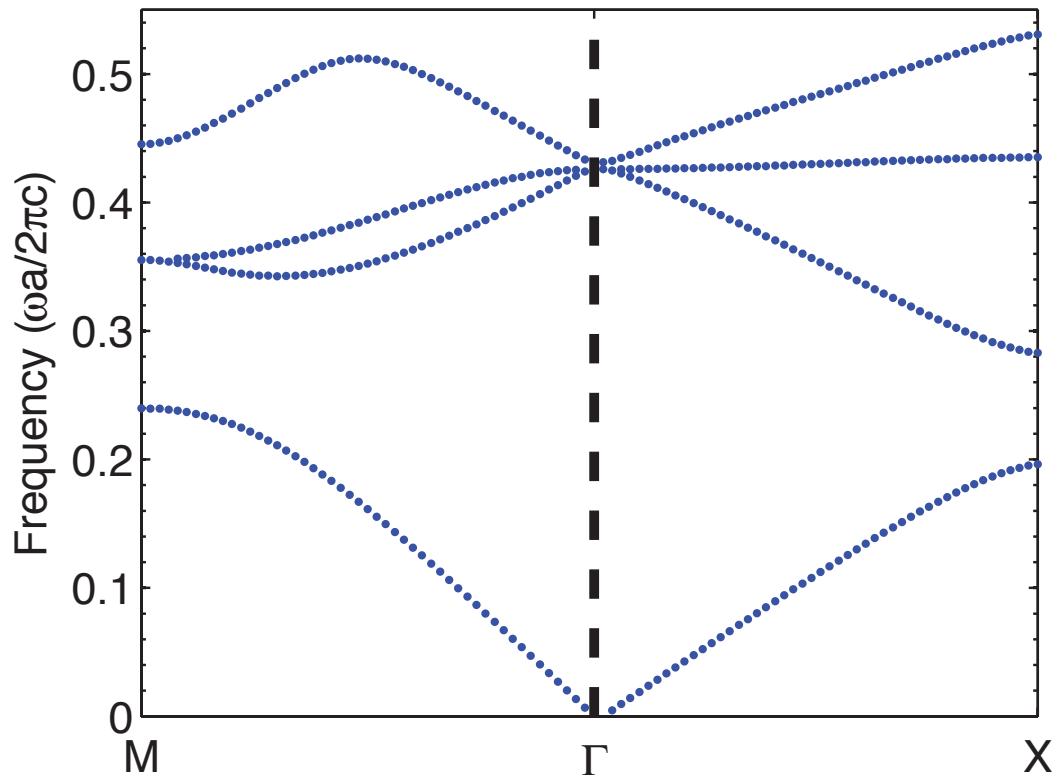
$$Z = \sqrt{\frac{\mu}{\varepsilon}} \quad \text{finite!}$$

how?



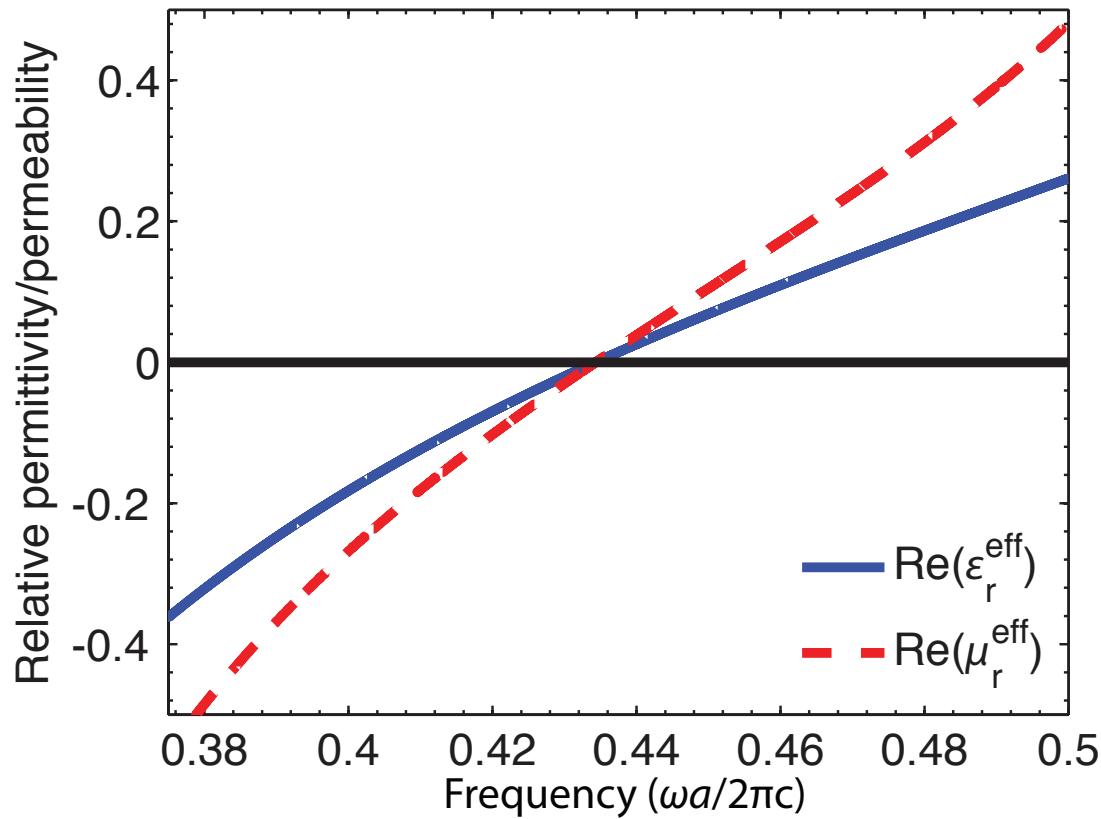
1 zero index

how?



1 zero index

how?



1 zero index

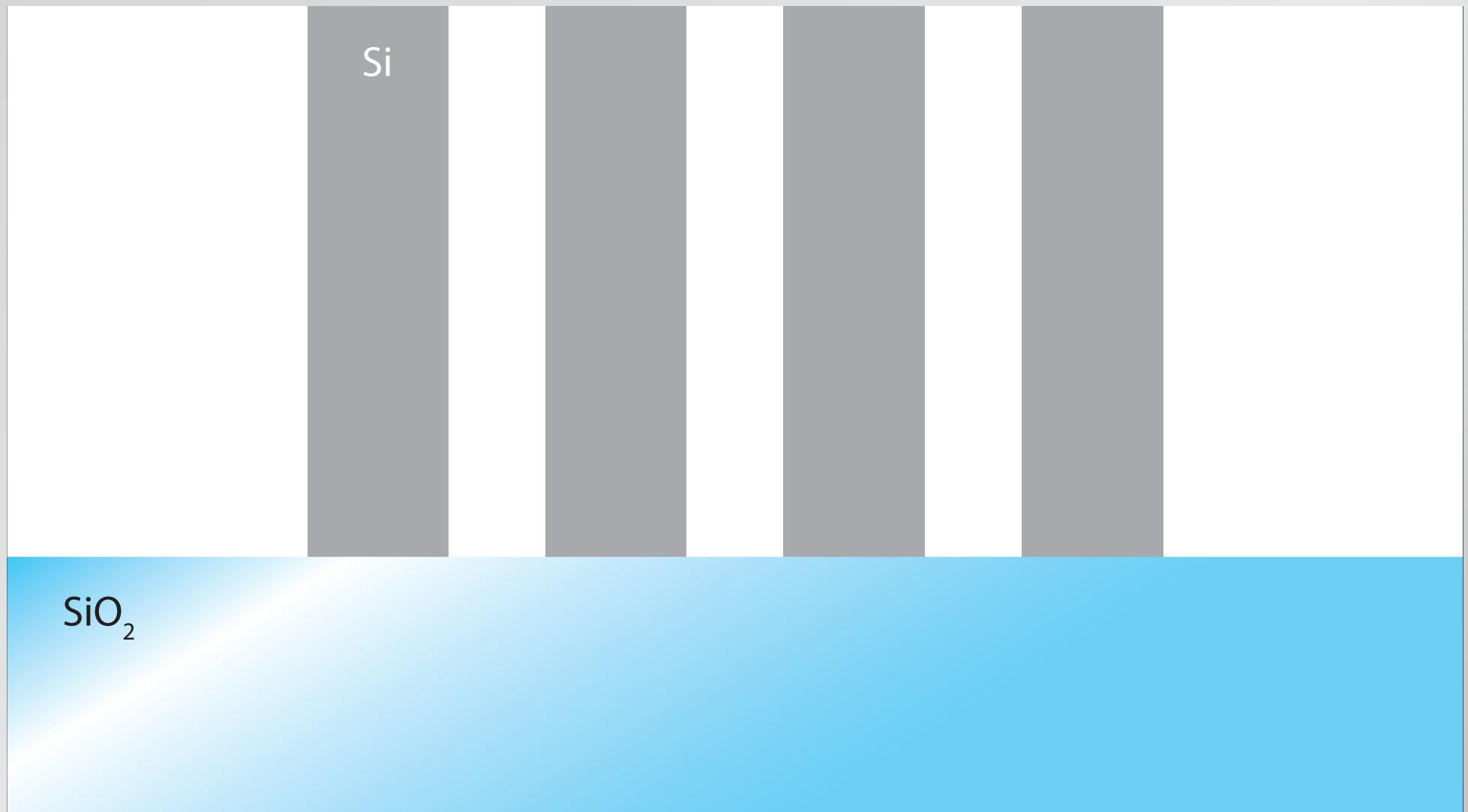
On-chip zero-index fabrication



1 zero index

2 fabrication

On-chip zero-index fabrication



1 zero index

2 fabrication

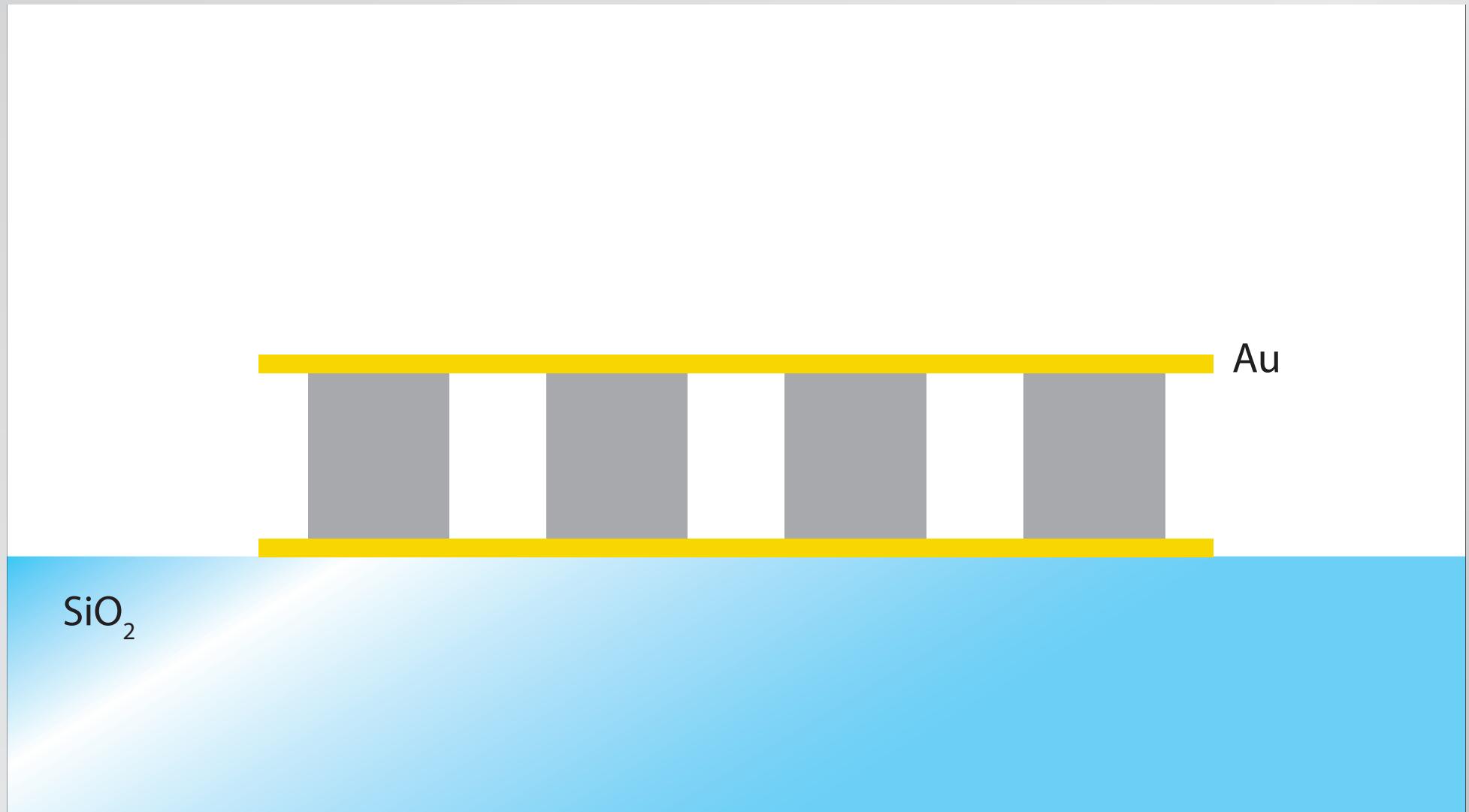
On-chip zero-index fabrication



1 zero index

2 fabrication

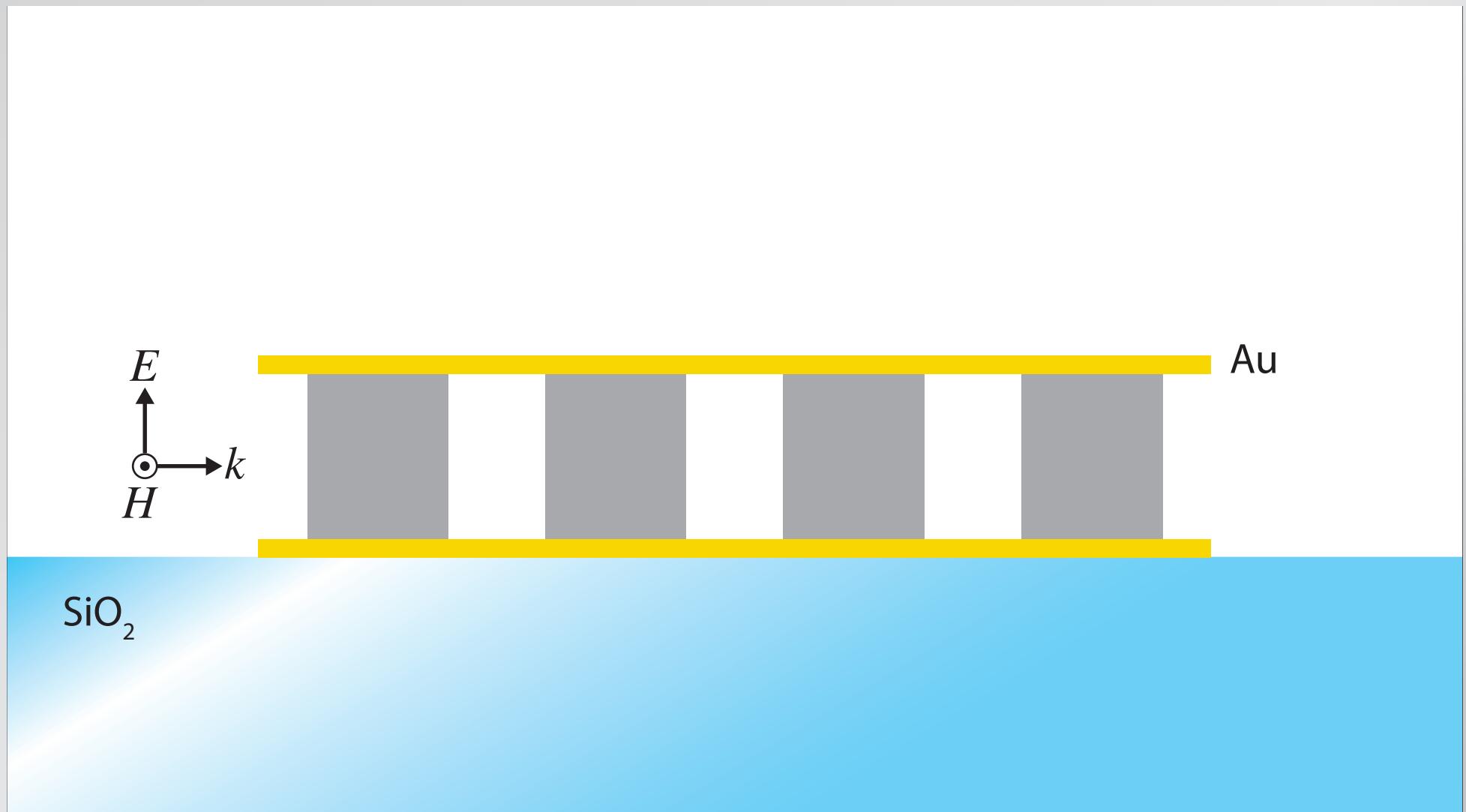
On-chip zero-index fabrication



1 zero index

2 fabrication

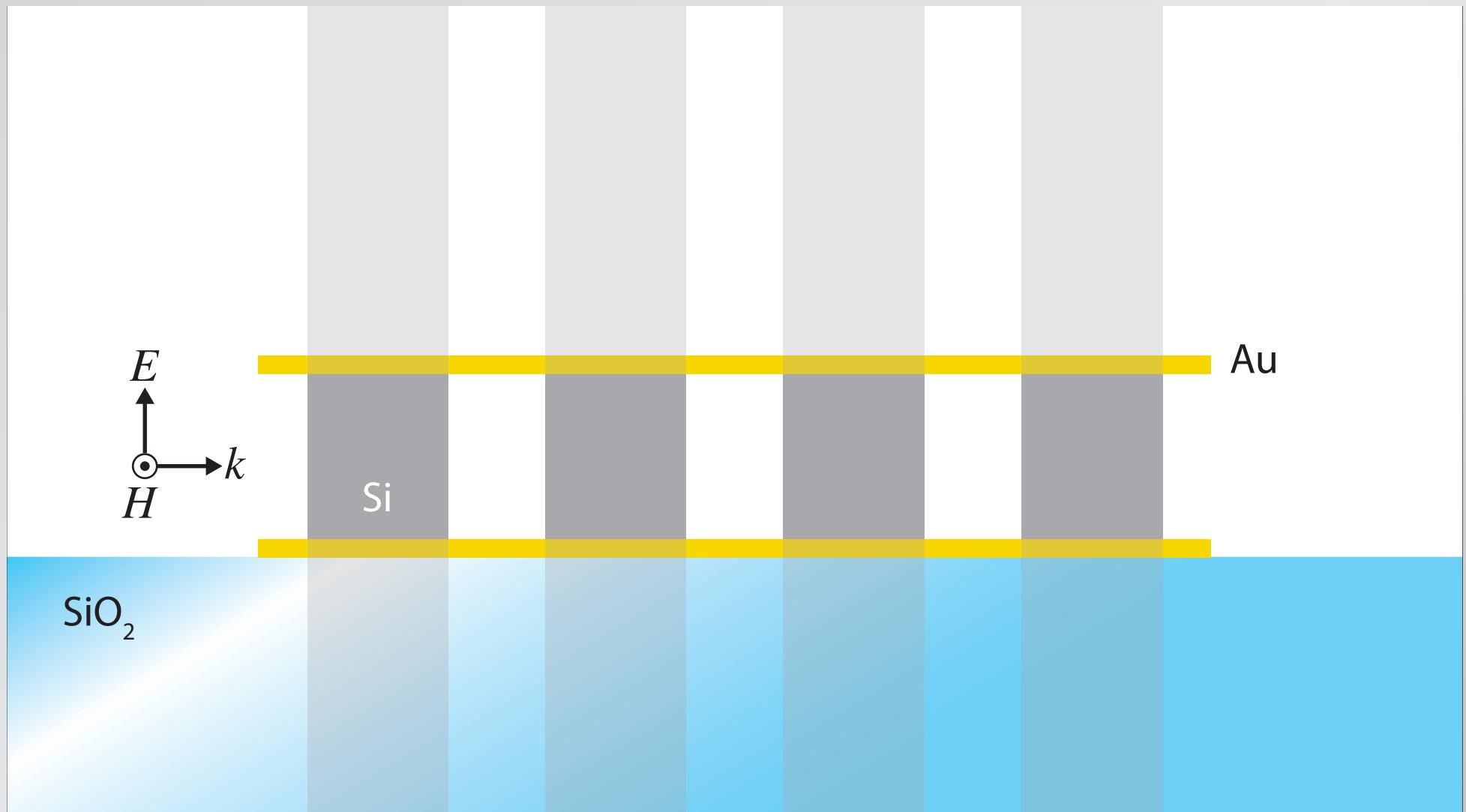
On-chip zero-index fabrication



1 zero index

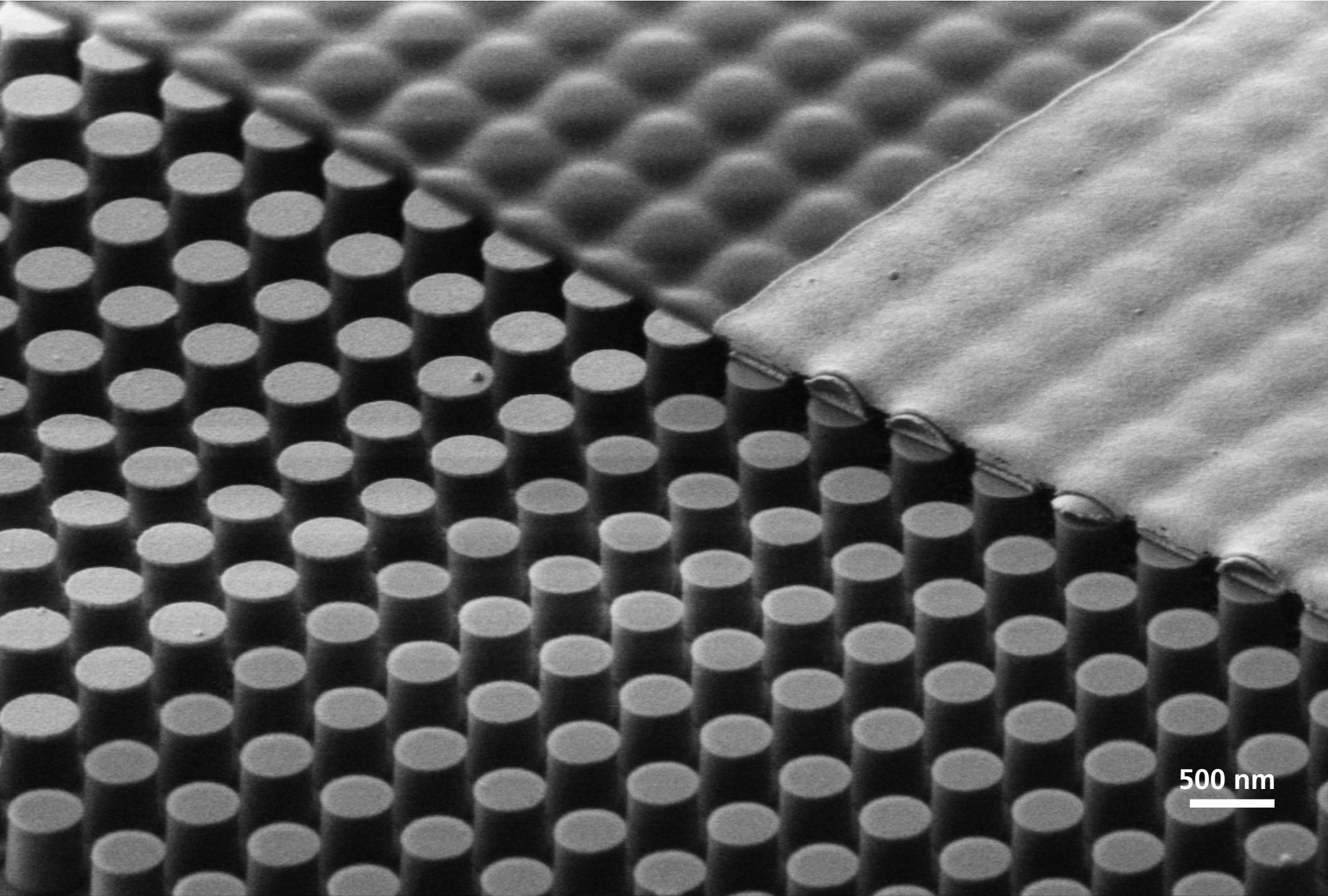
2 fabrication

On-chip zero-index fabrication



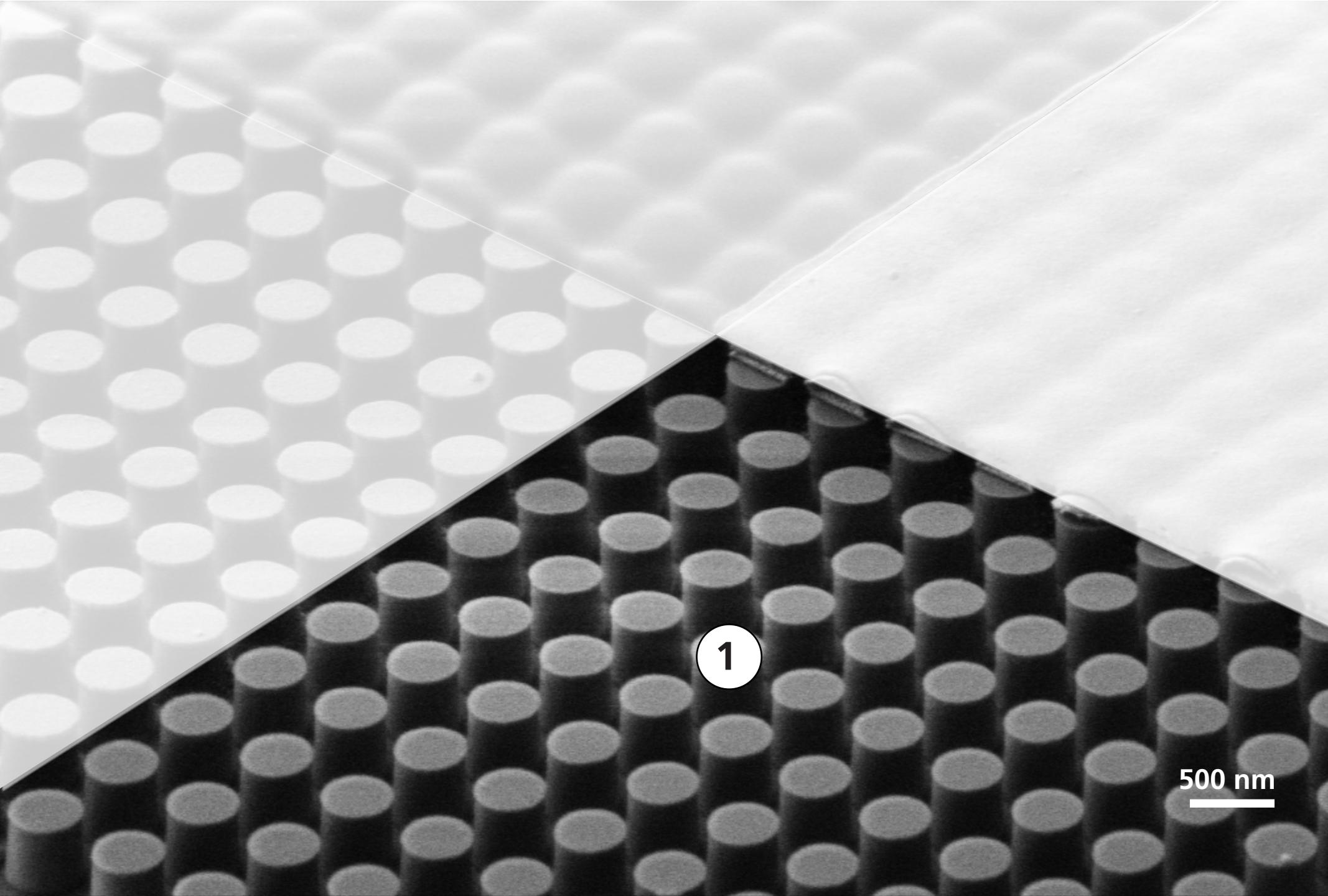
1 zero index

2 fabrication



1 zero index

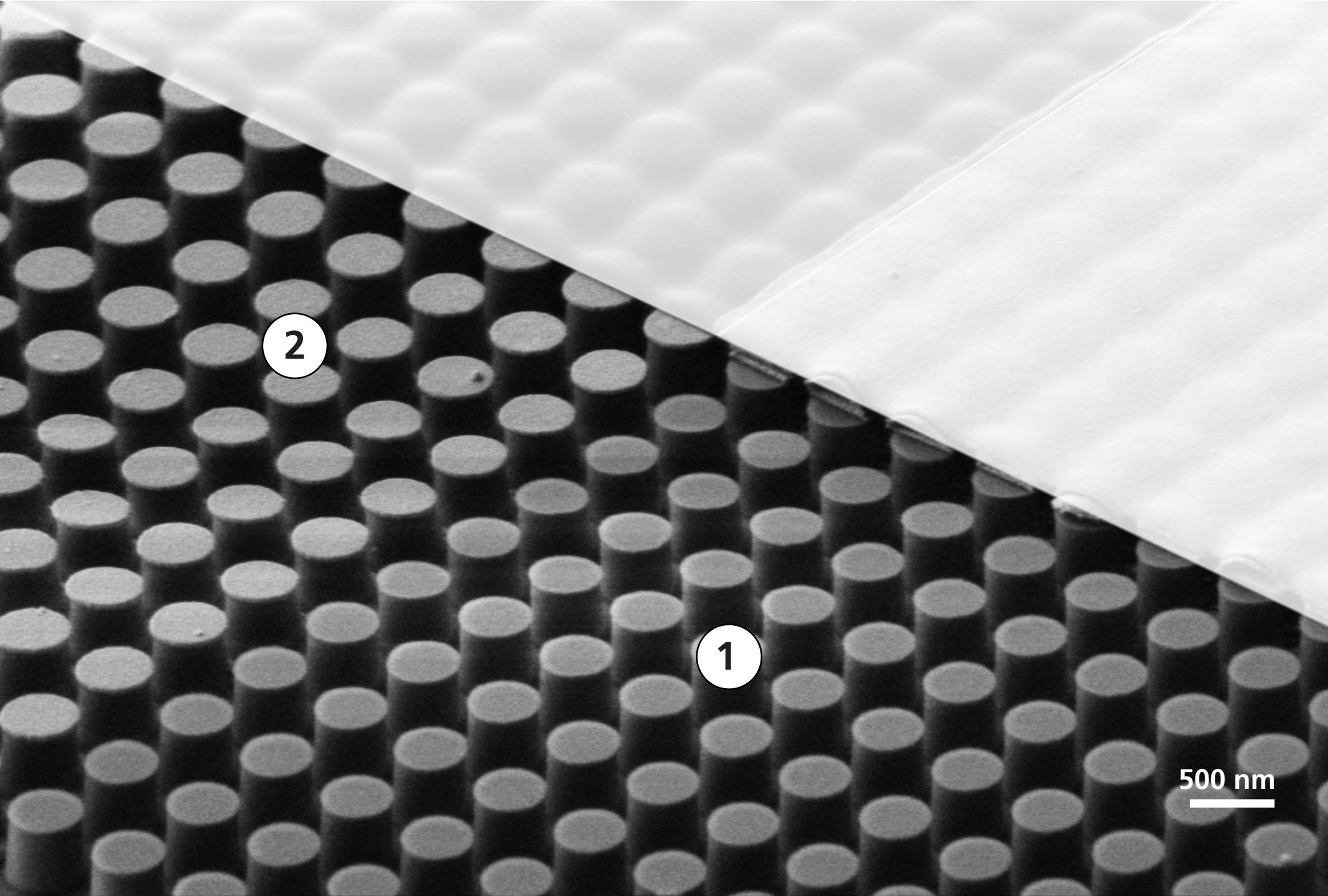
2 fabrication



1 zero index

2 fabrication

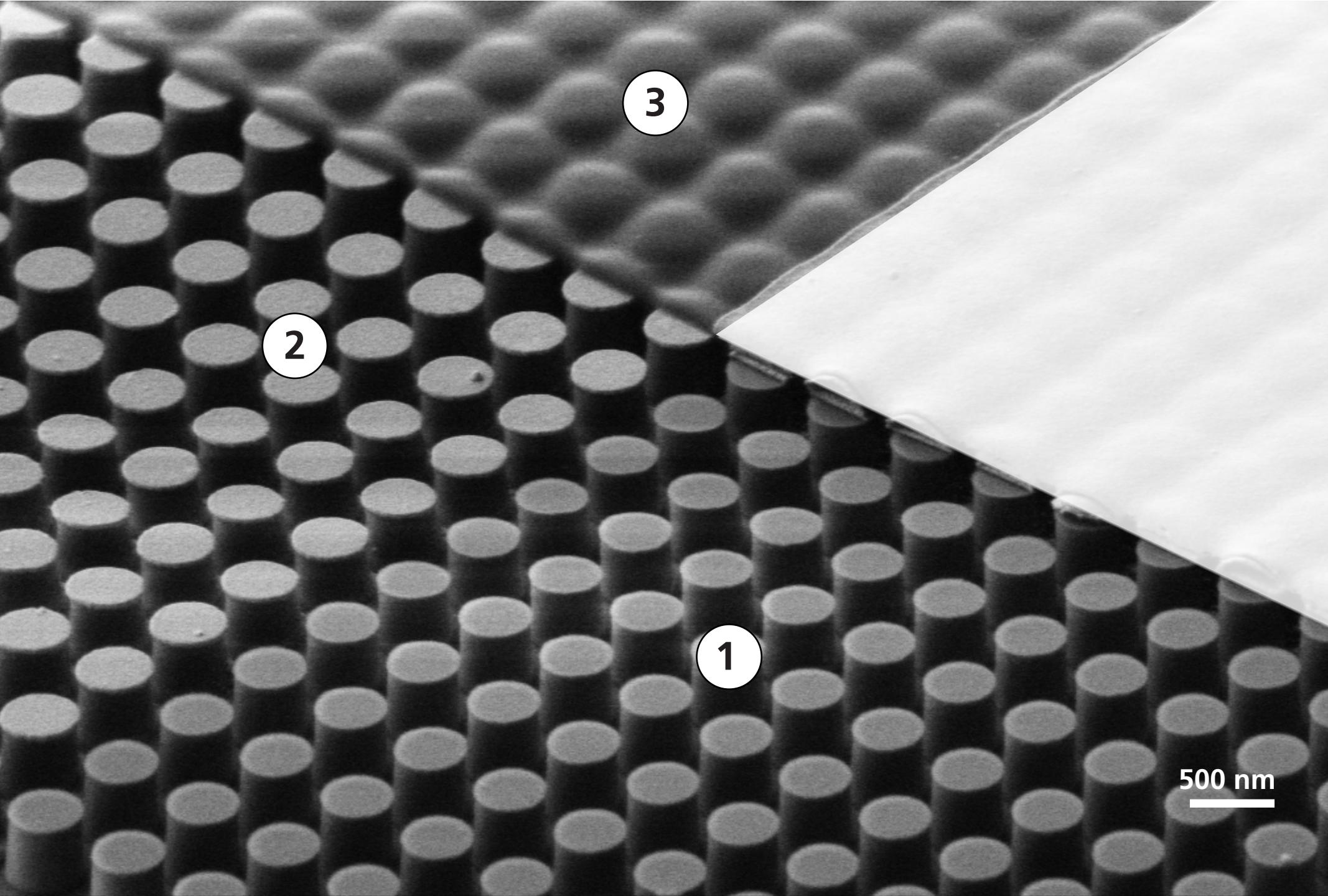
500 nm



1 zero index

2 fabrication

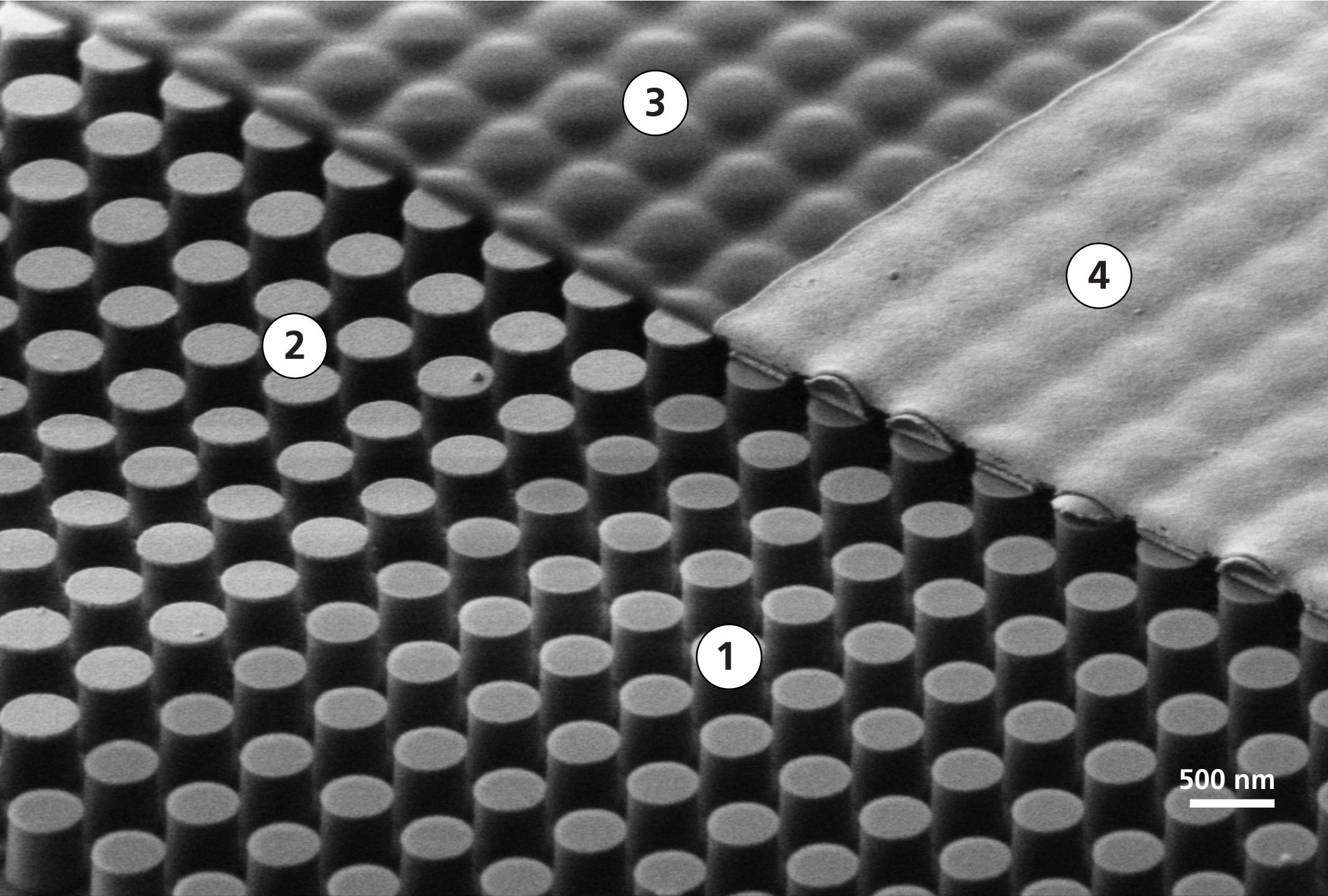
500 nm



1 zero index

2 fabrication

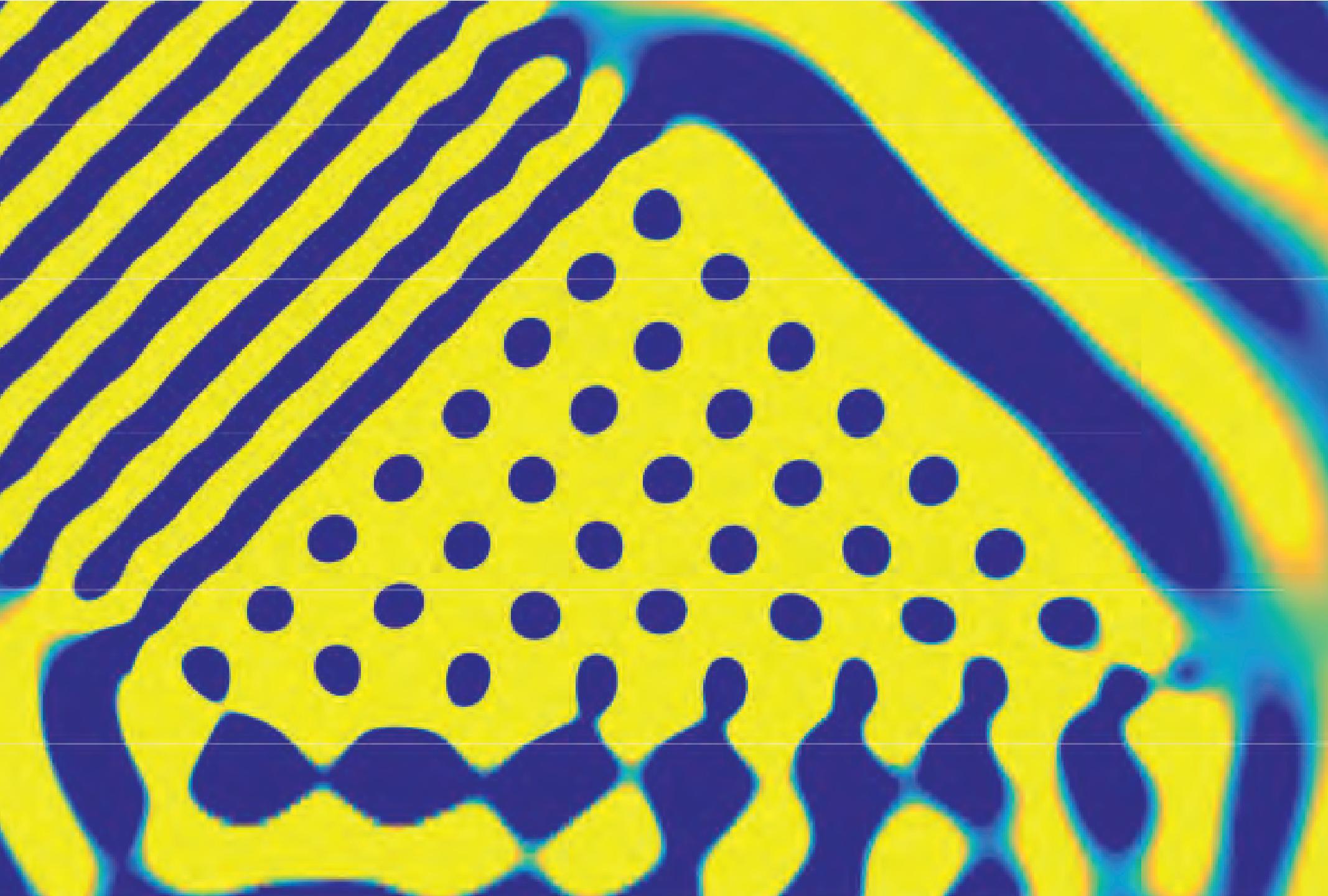
500 nm



1 zero index

2 fabrication

500 nm



1 zero index

2 fabrication

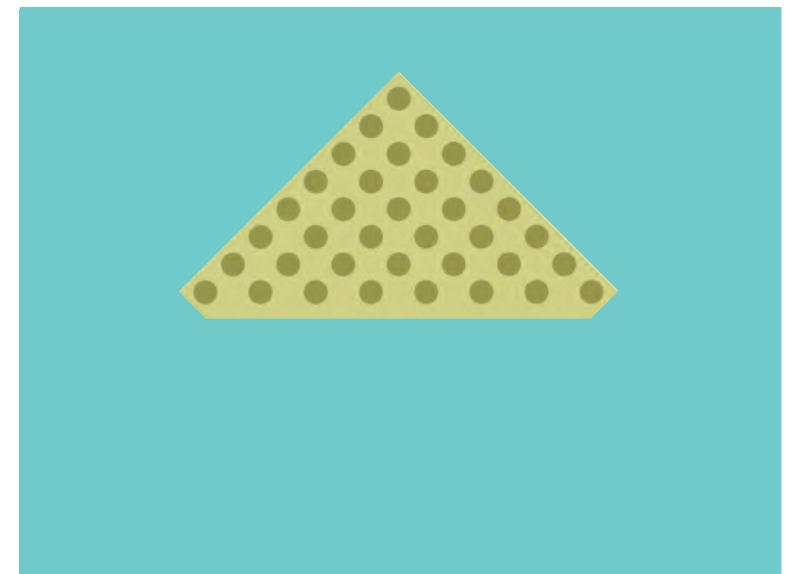
On-chip zero-index prism



1 zero index

2 fabrication

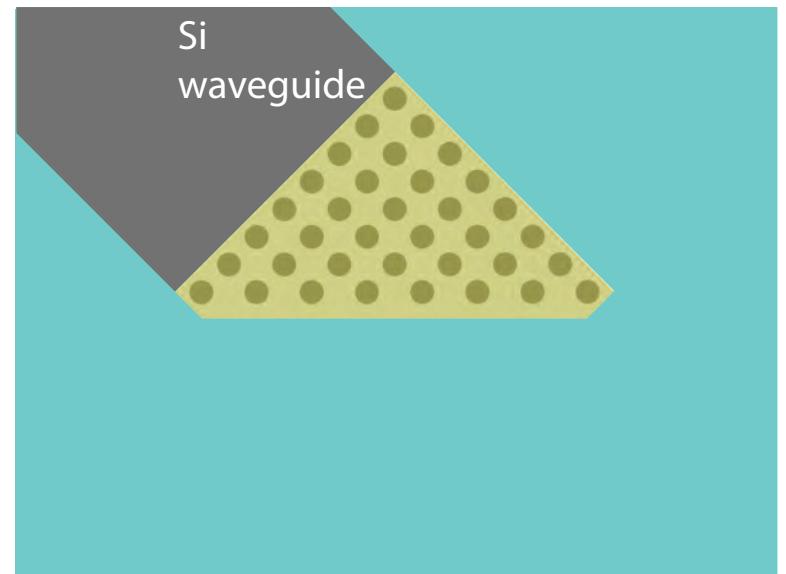
On-chip zero-index prism



1 zero index

2 fabrication

On-chip zero-index prism

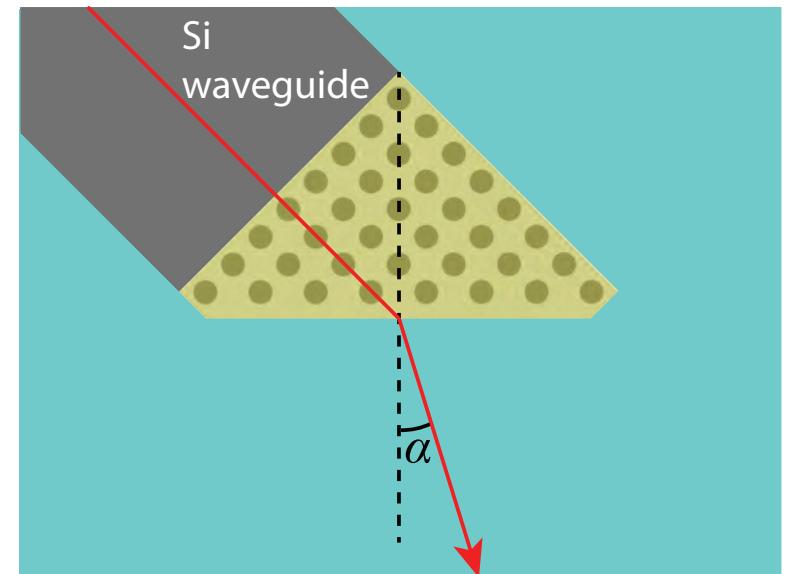


1 zero index

2 fabrication

3 results

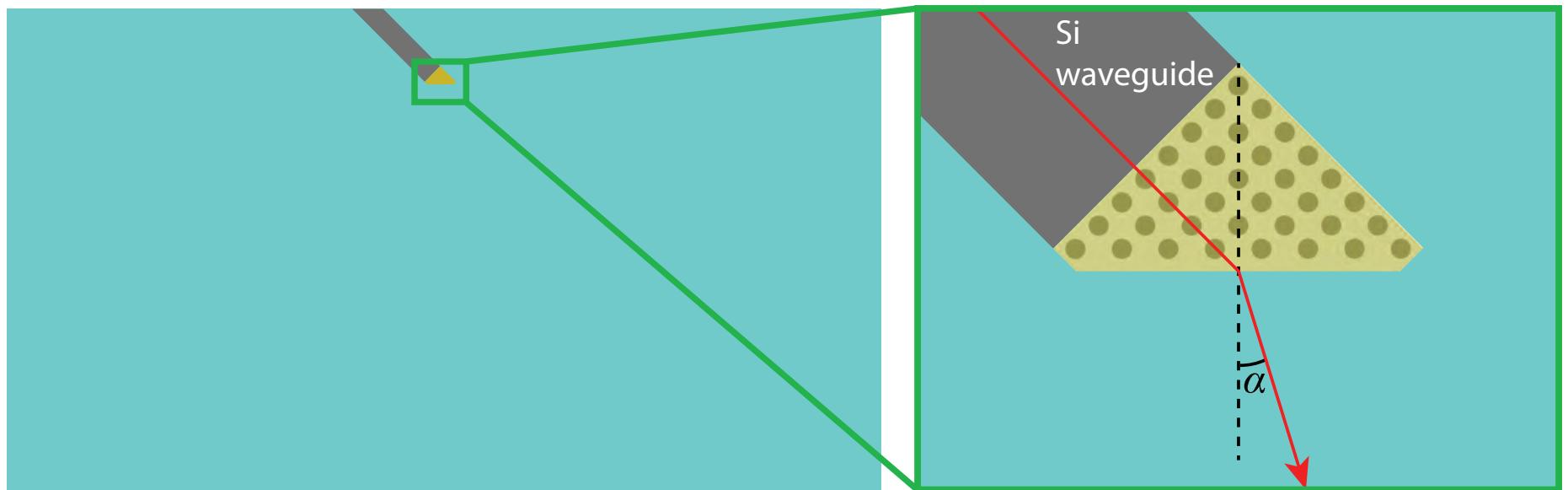
On-chip zero-index prism



1 zero index

2 fabrication

On-chip zero-index prism

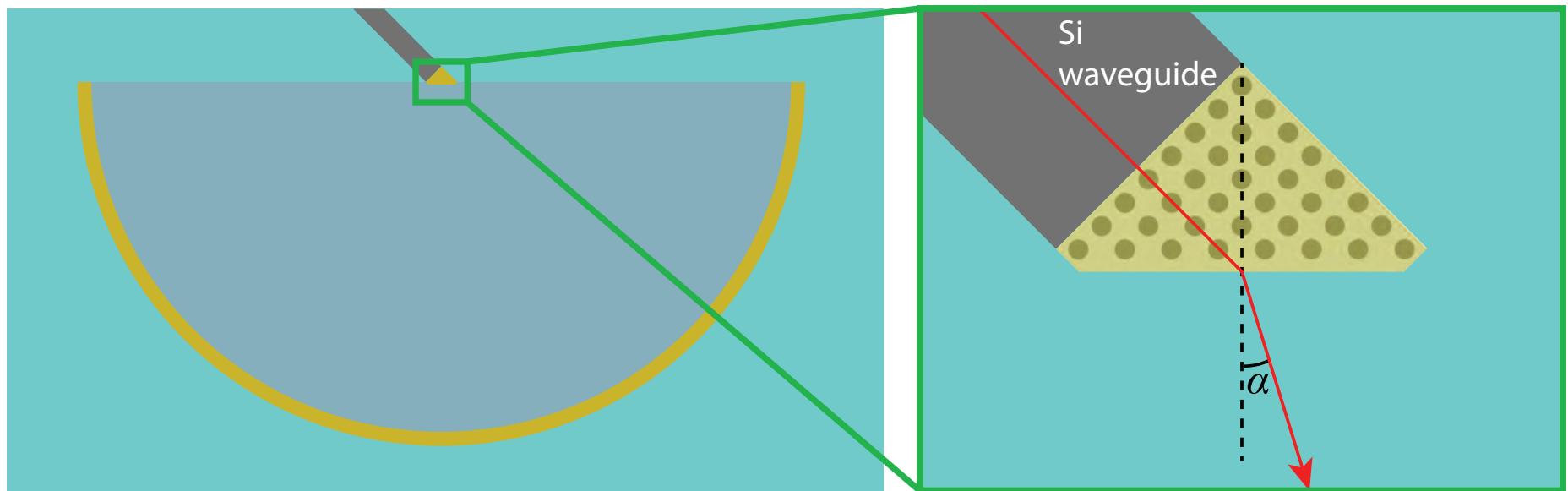


1 zero index

2 fabrication

3 results

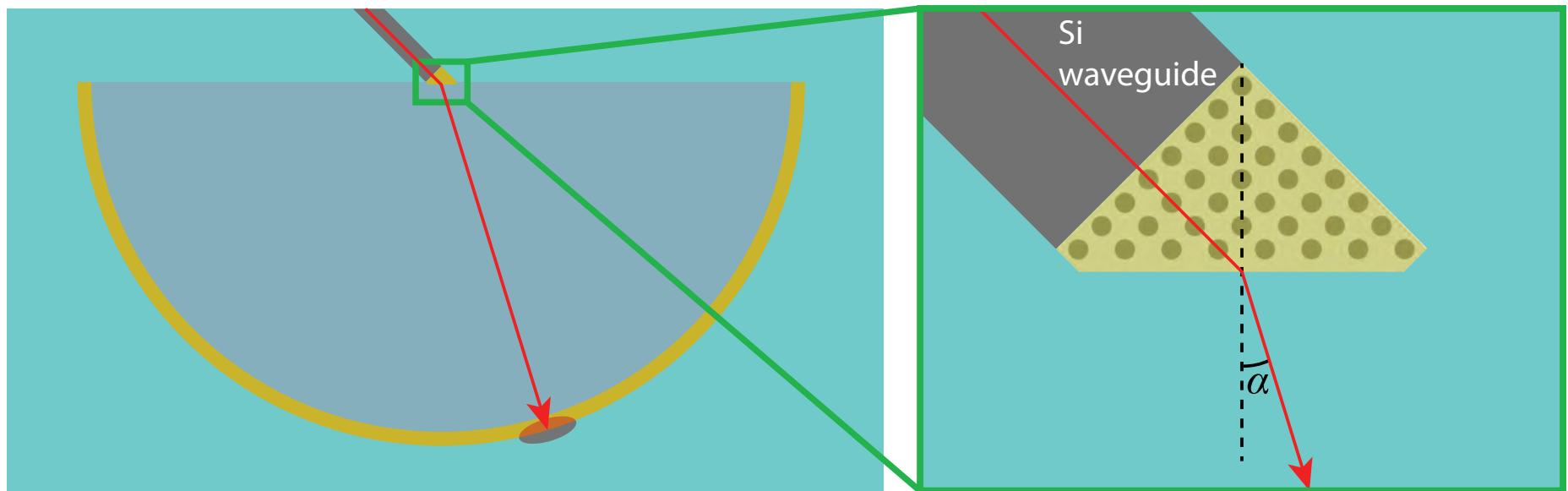
On-chip zero-index prism



1 zero index

2 fabrication

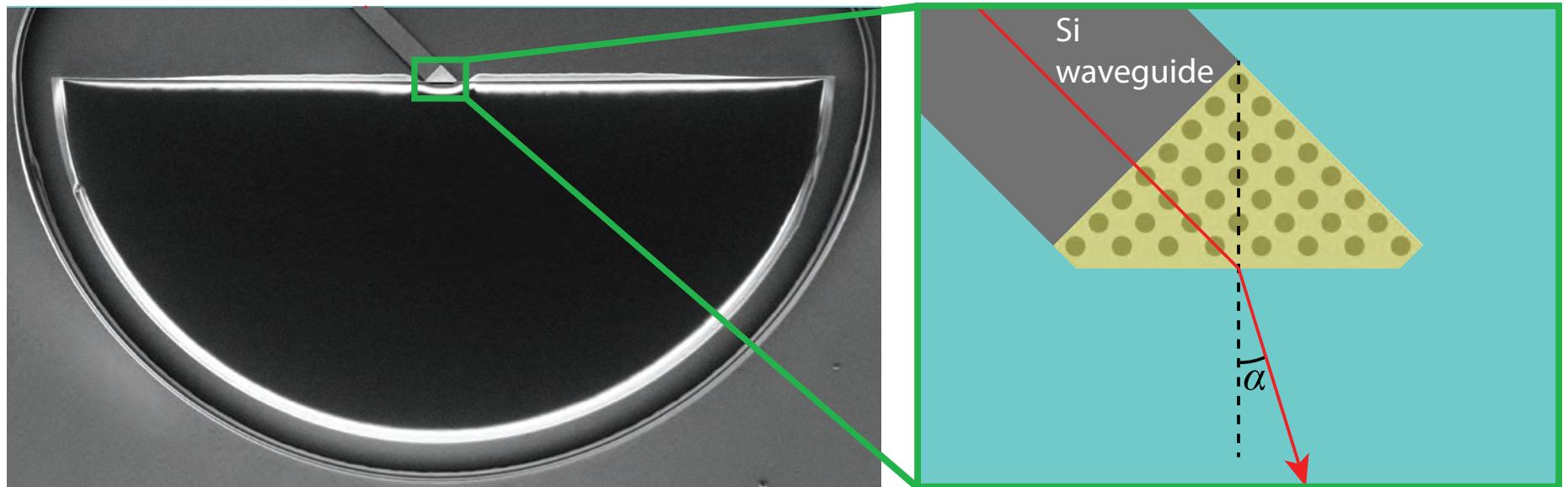
On-chip zero-index prism



1 zero index

2 fabrication

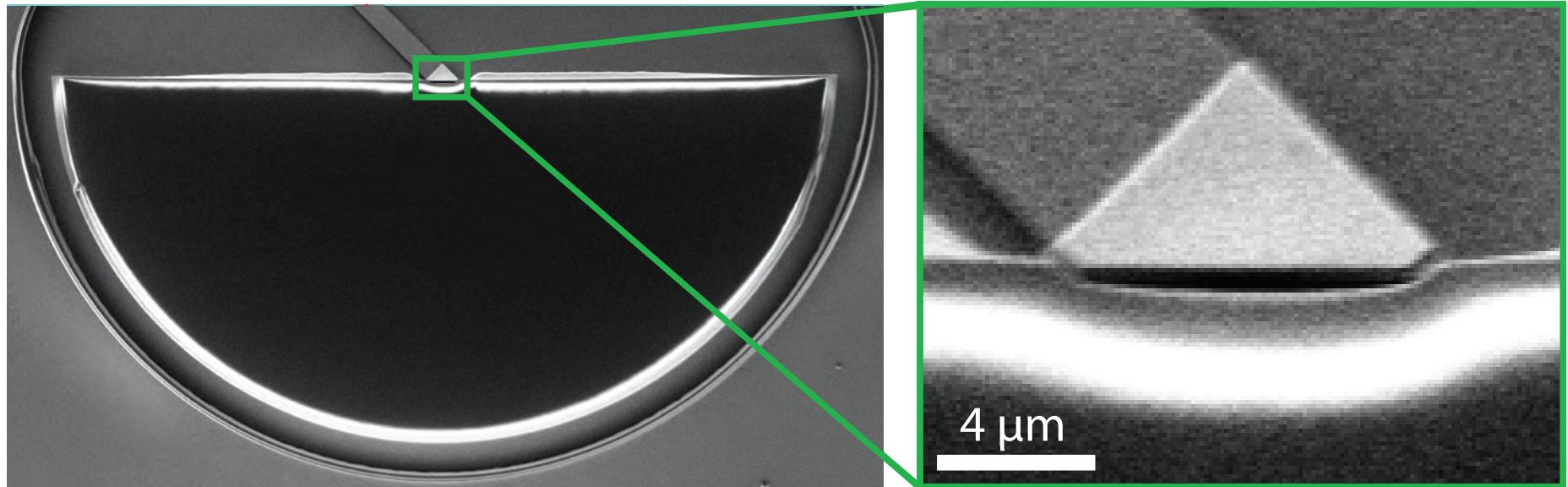
On-chip zero-index prism



1 zero index

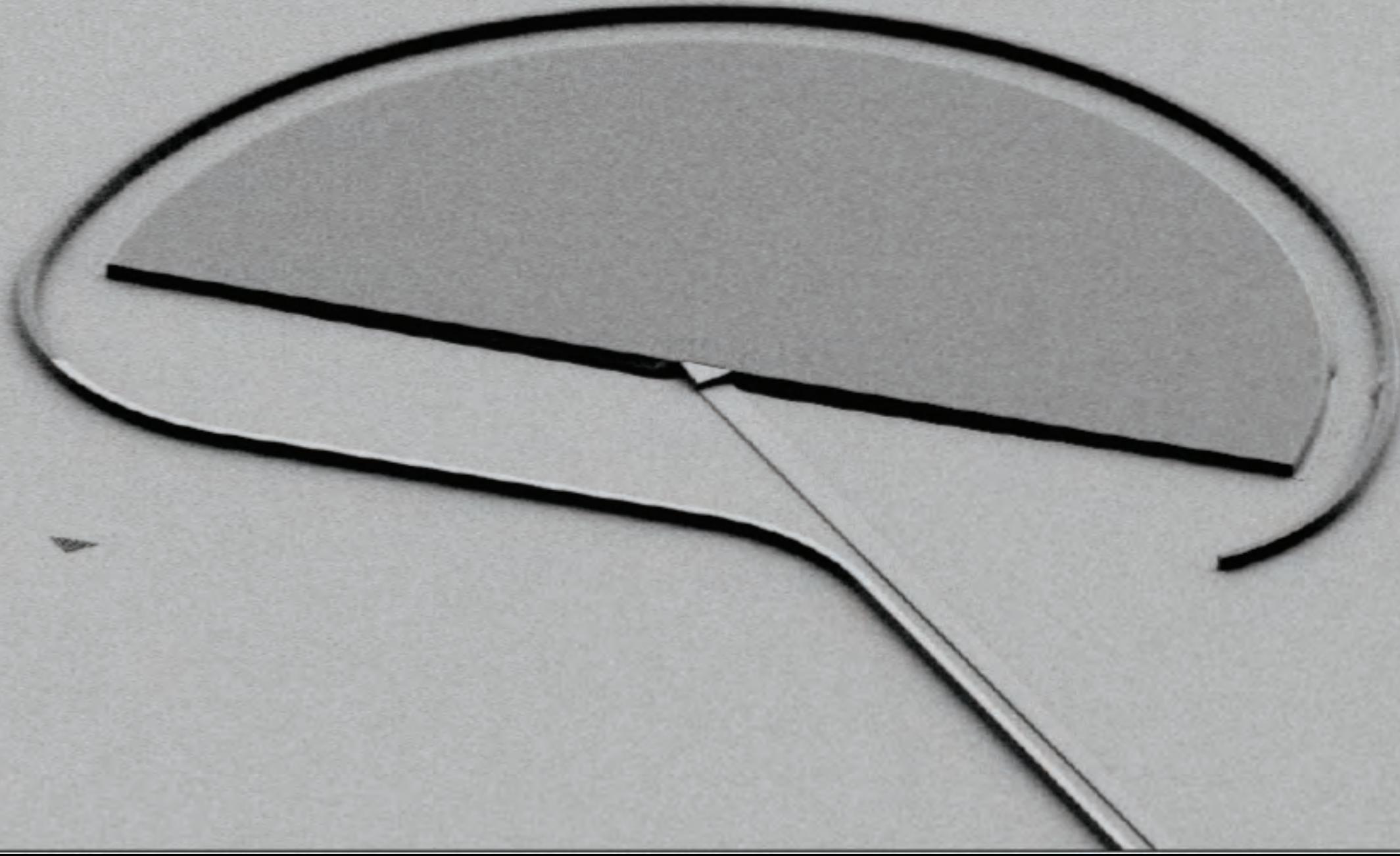
2 fabrication

On-chip zero-index prism



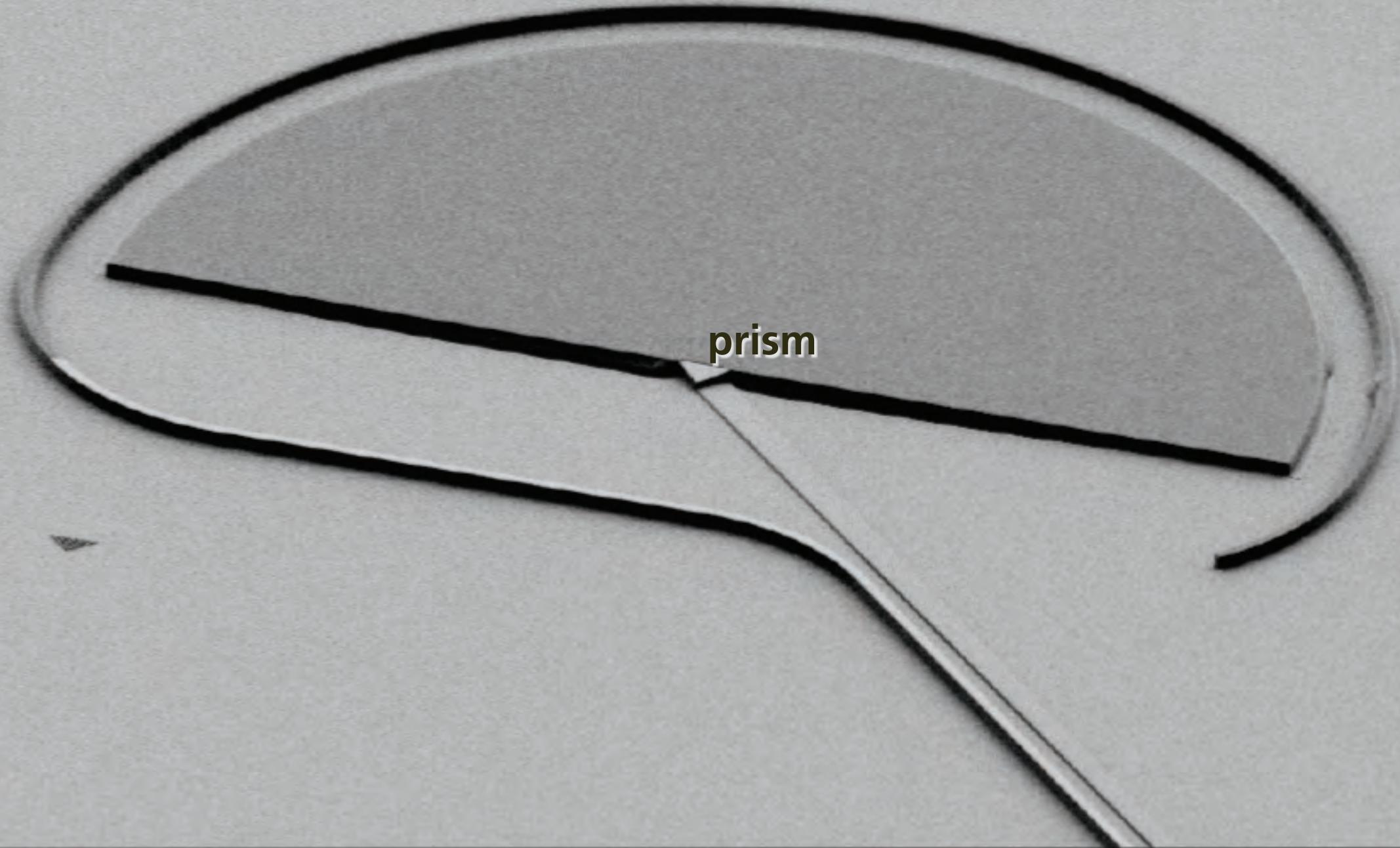
1 zero index

2 fabrication



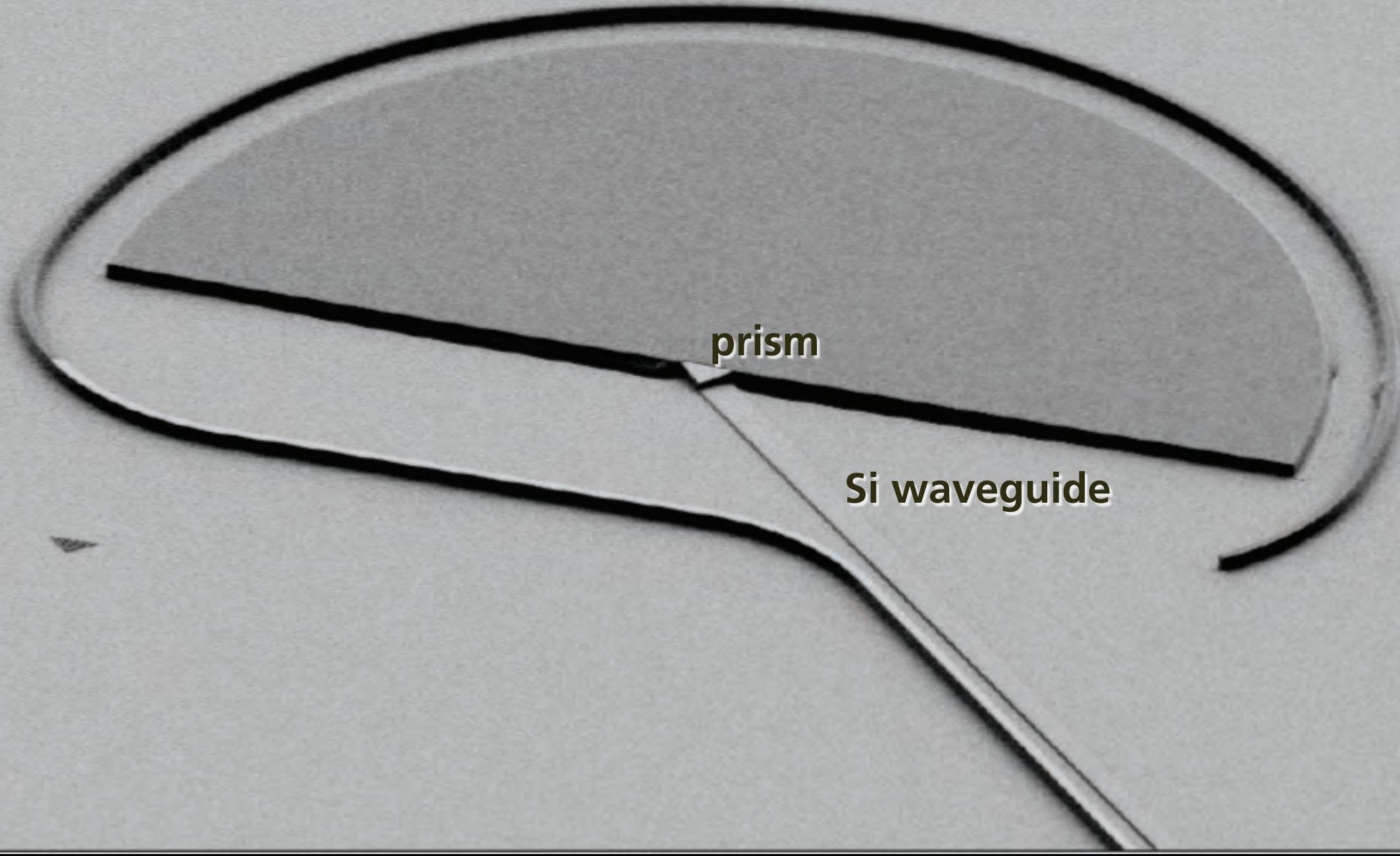
1 zero index

2 fabrication



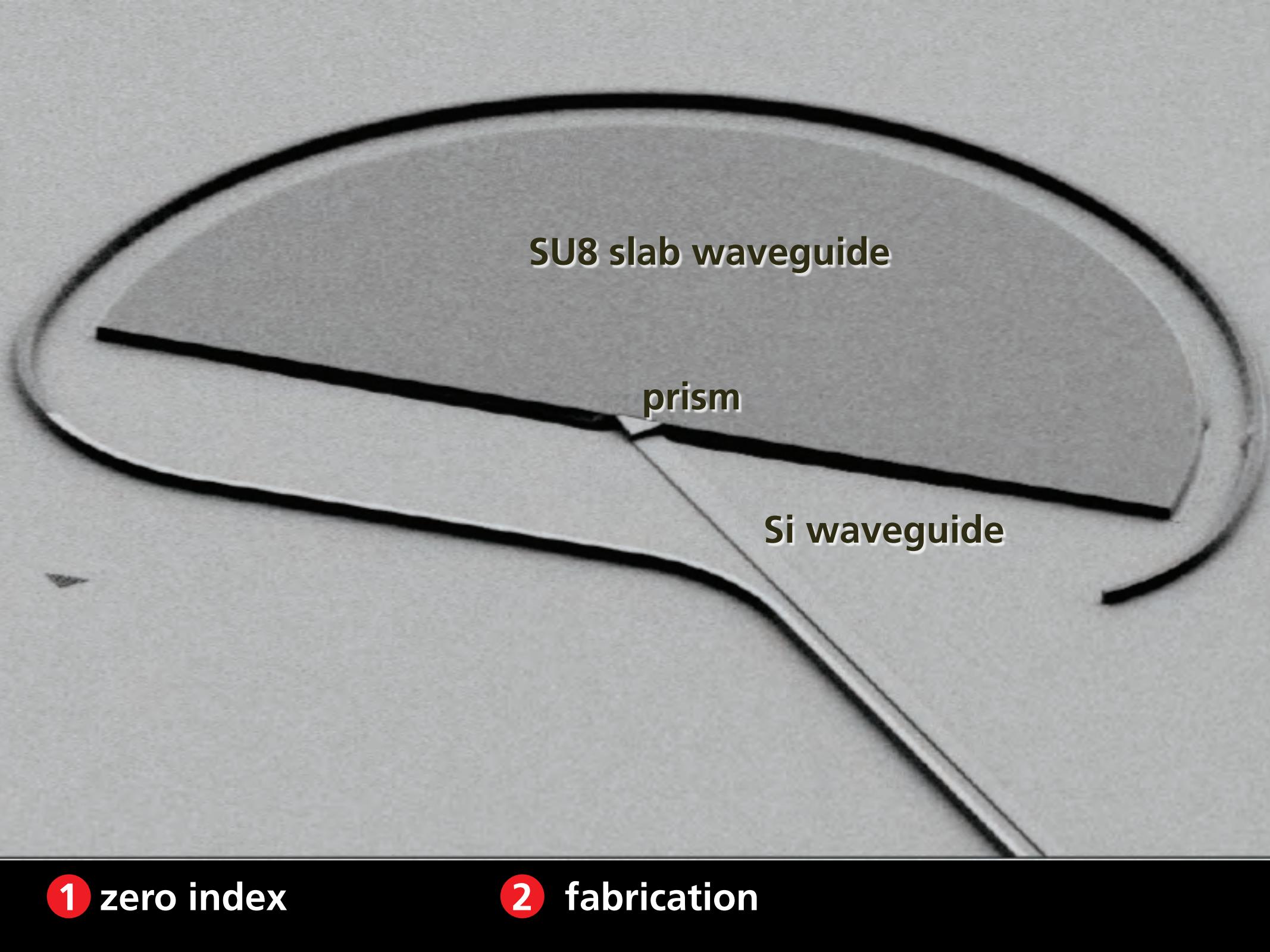
1 zero index

2 fabrication



1 zero index

2 fabrication



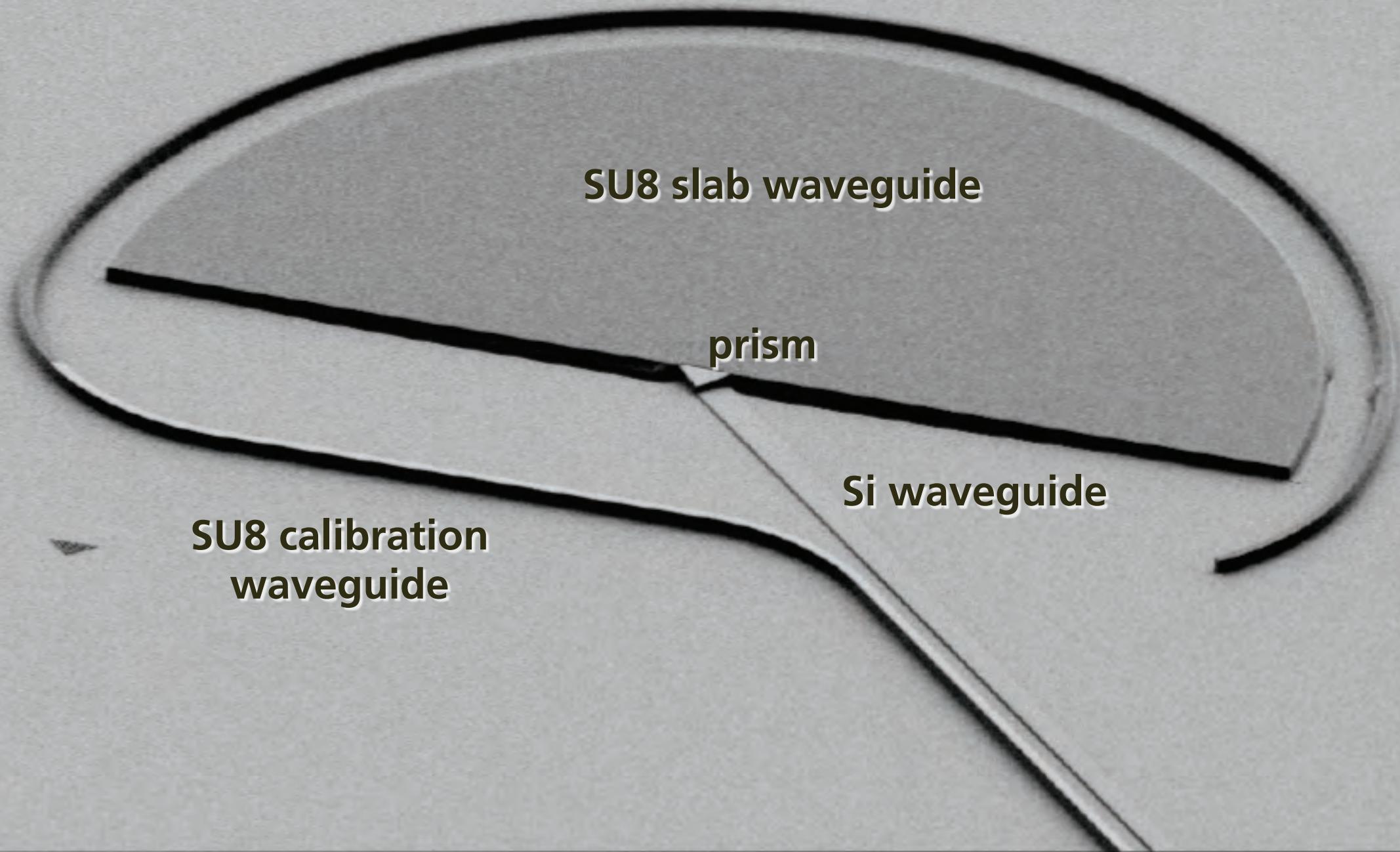
SU8 slab waveguide

prism

Si waveguide

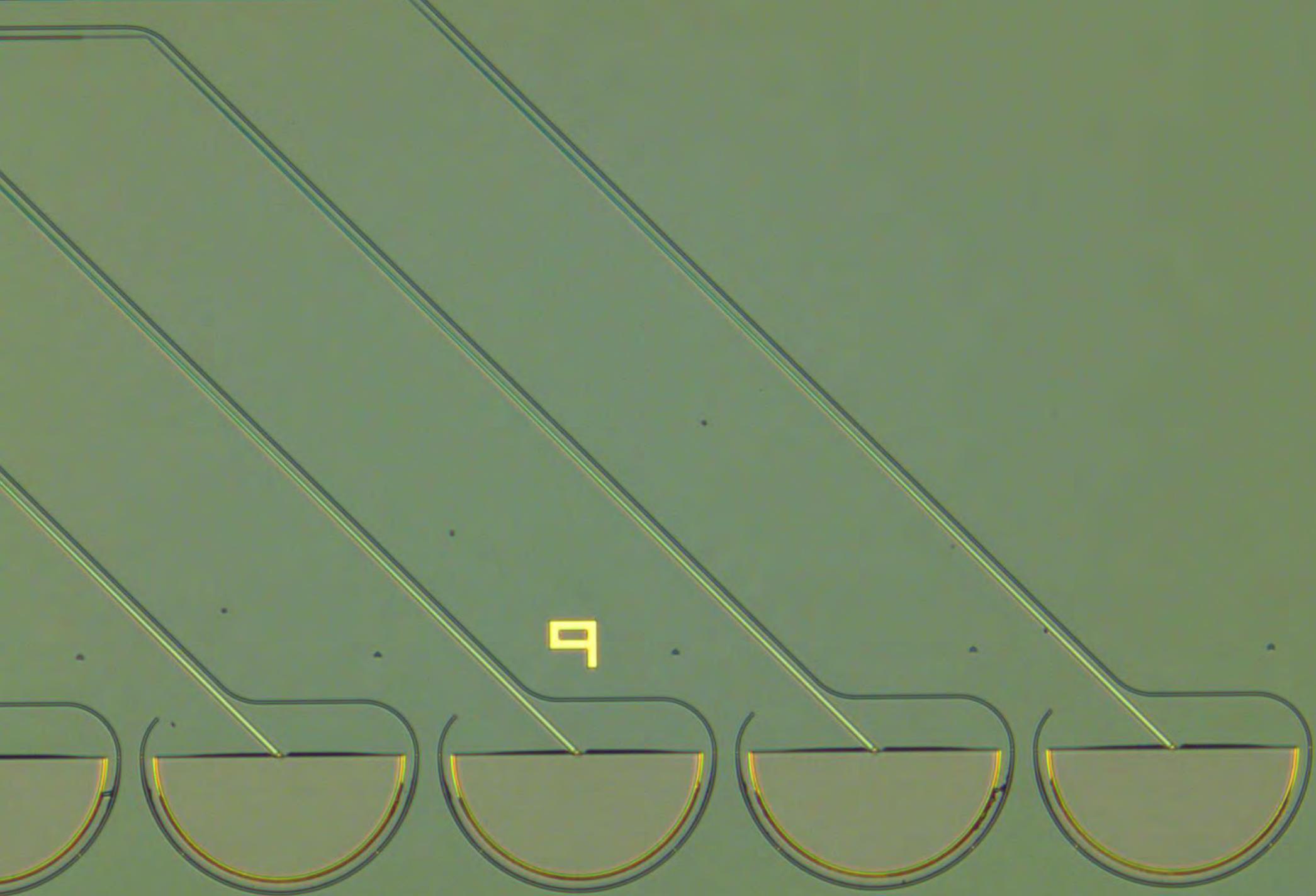
1 zero index

2 fabrication



1 zero index

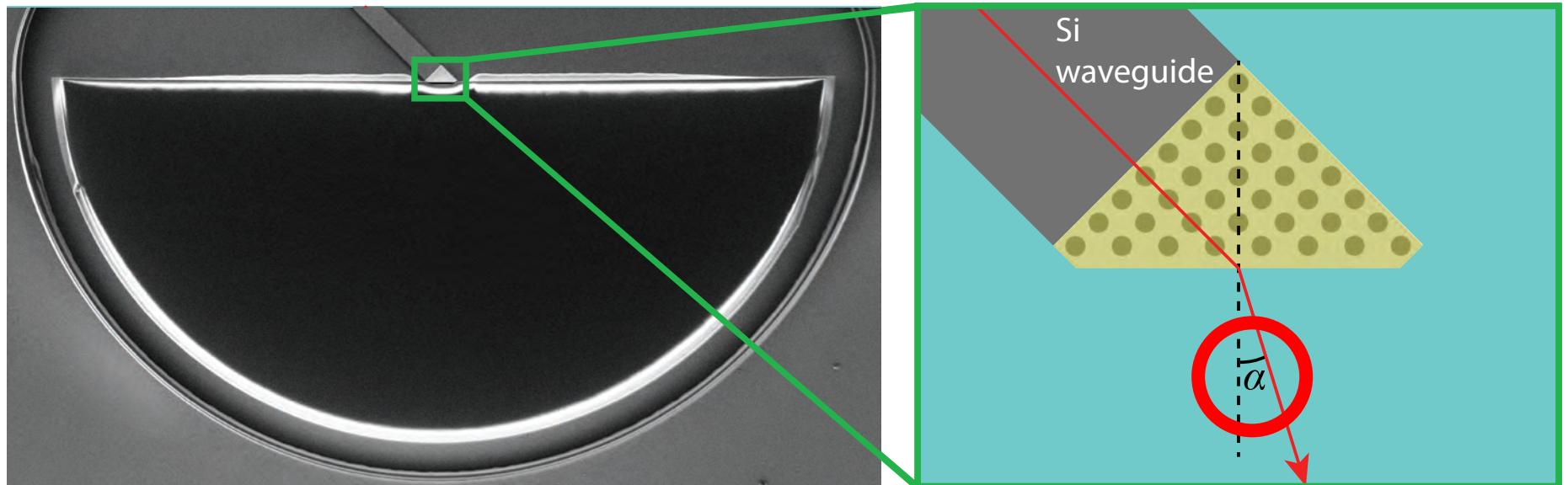
2 fabrication



1 zero index

2 fabrication

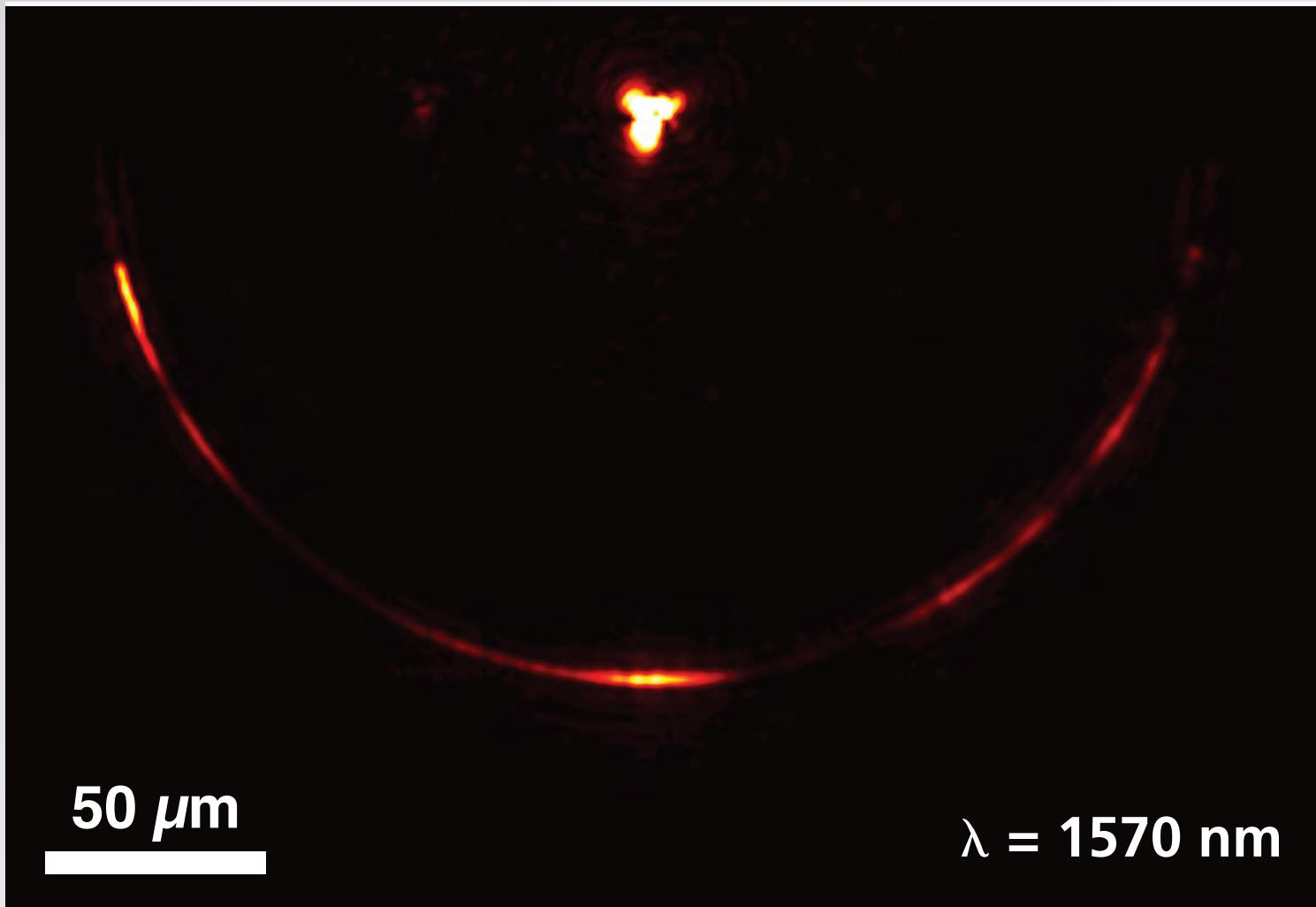
On-chip zero-index prism



1 zero index

2 fabrication

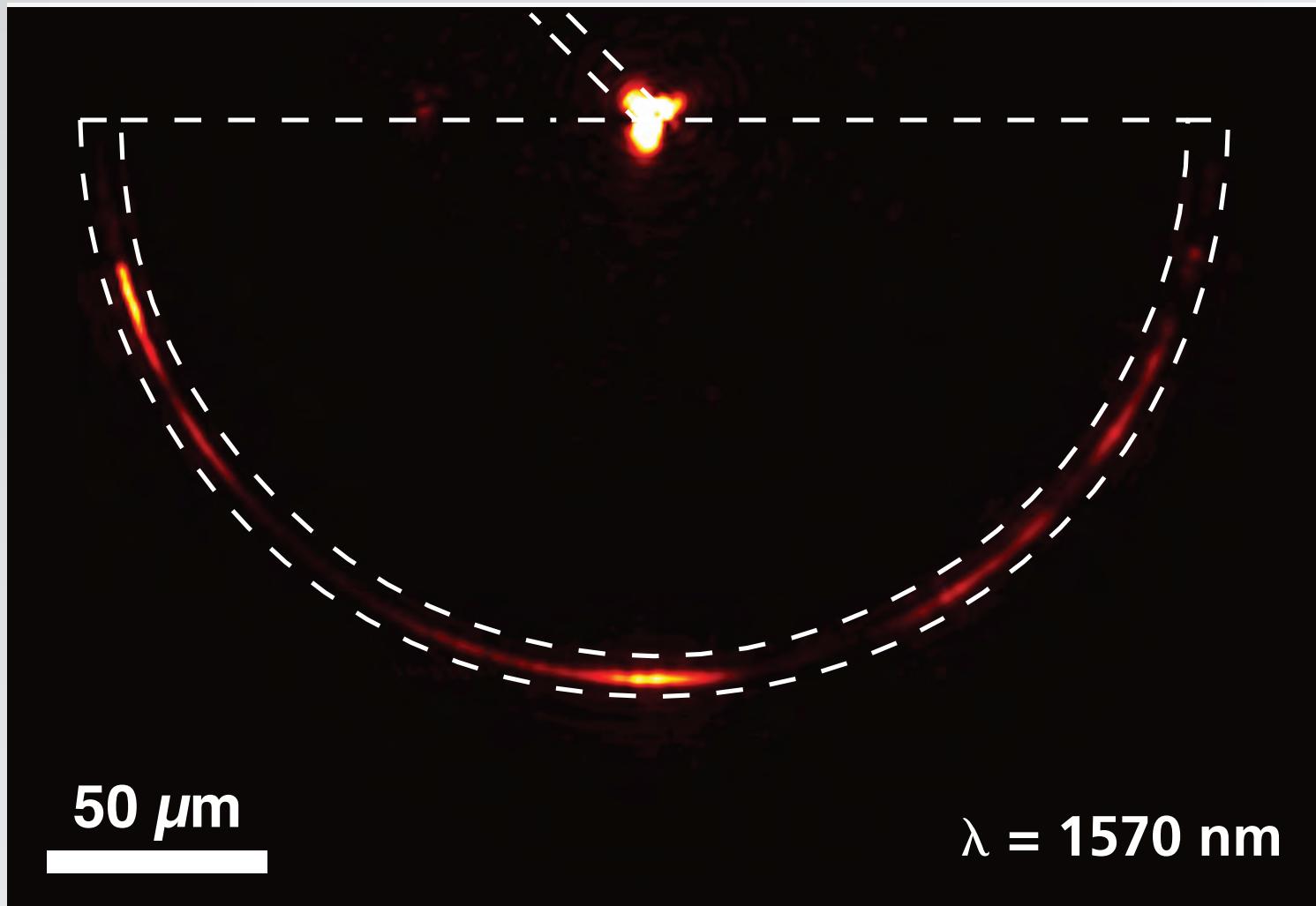
3 results



1 zero index

2 fabrication

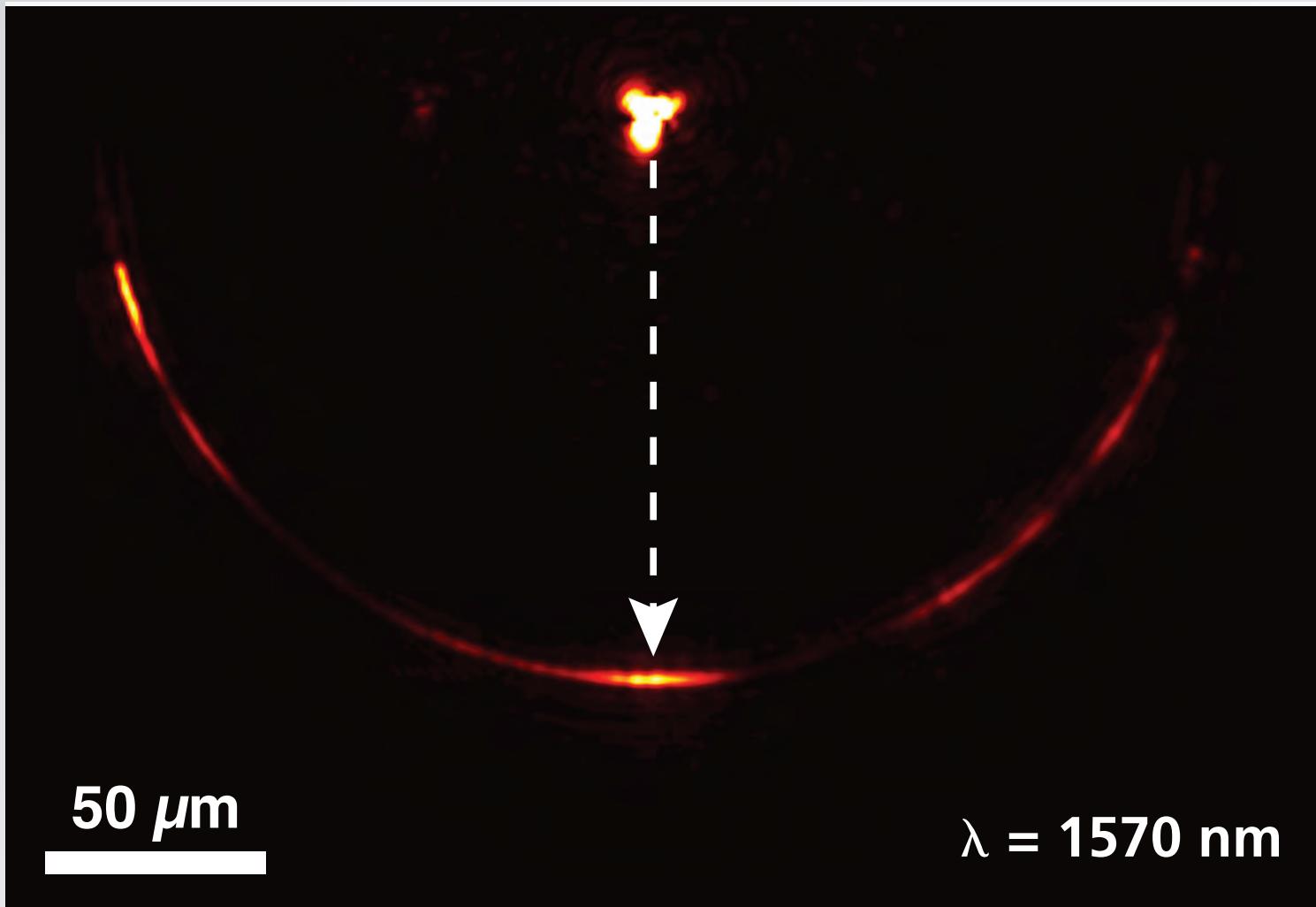
3 results



1 zero index

2 fabrication

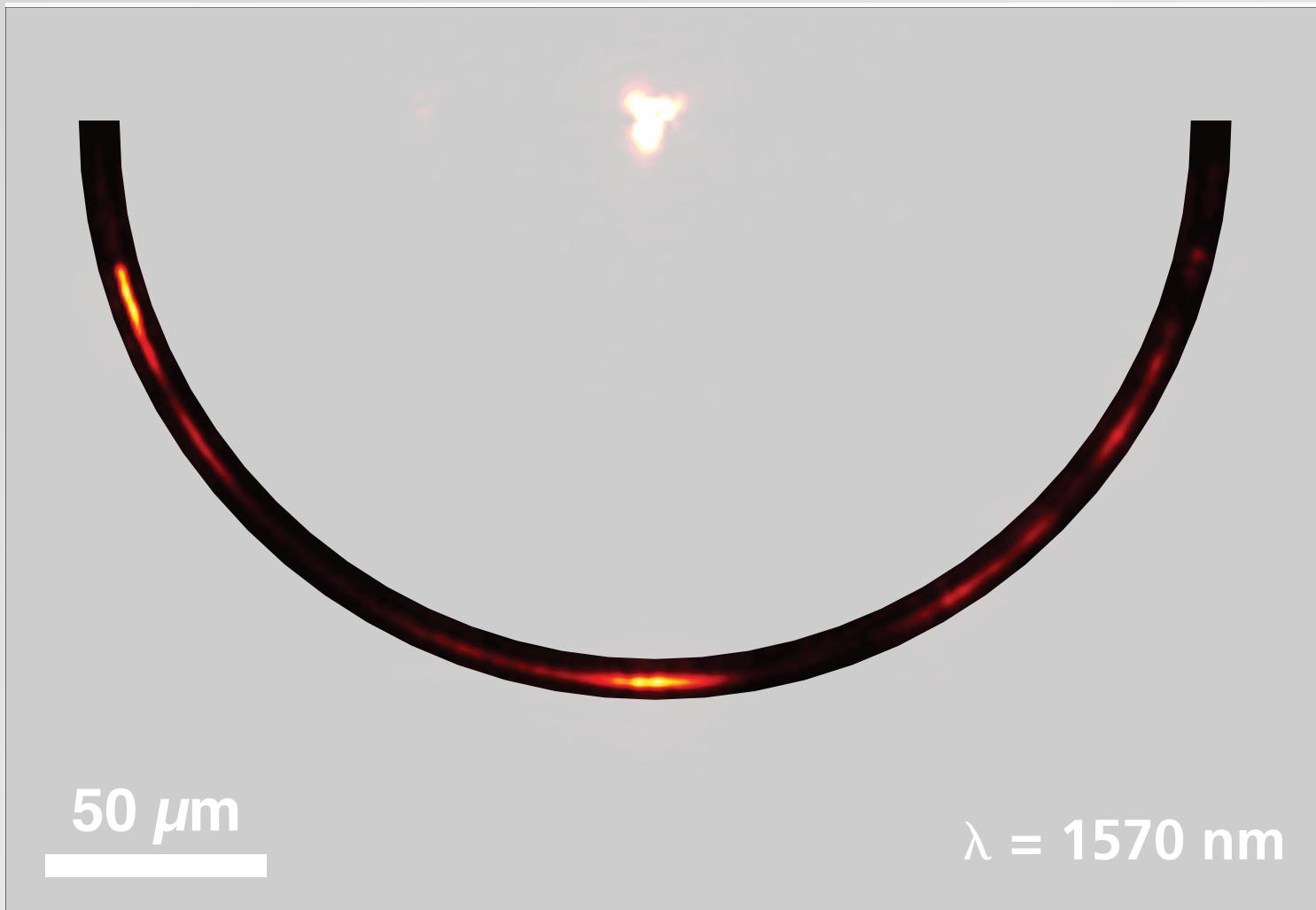
3 results



1 zero index

2 fabrication

3 results

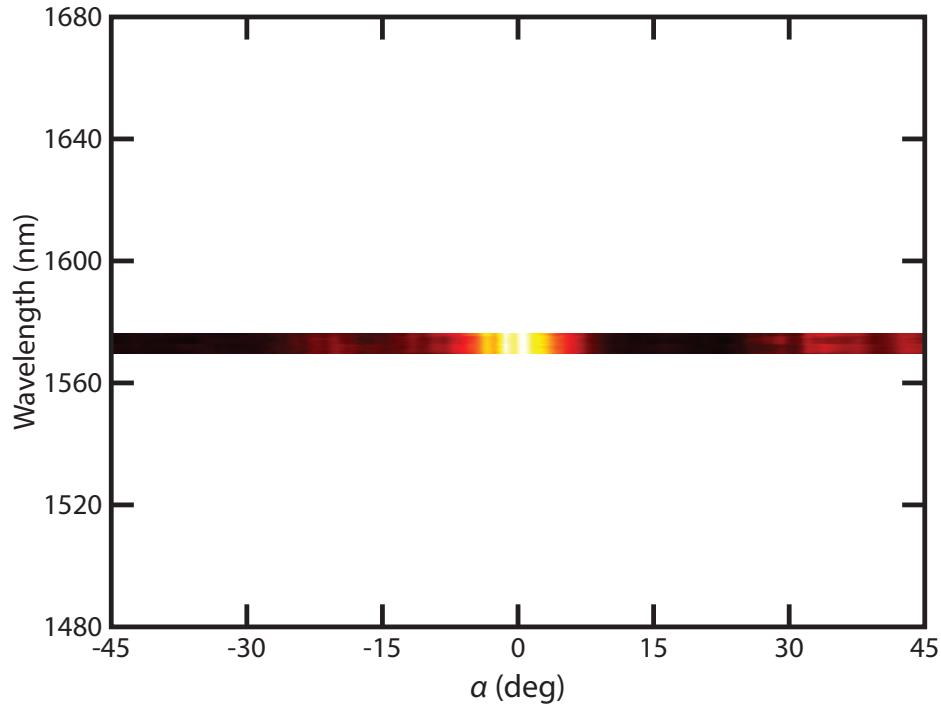


1 zero index

2 fabrication

3 results

Wavelength dependence of refraction angle

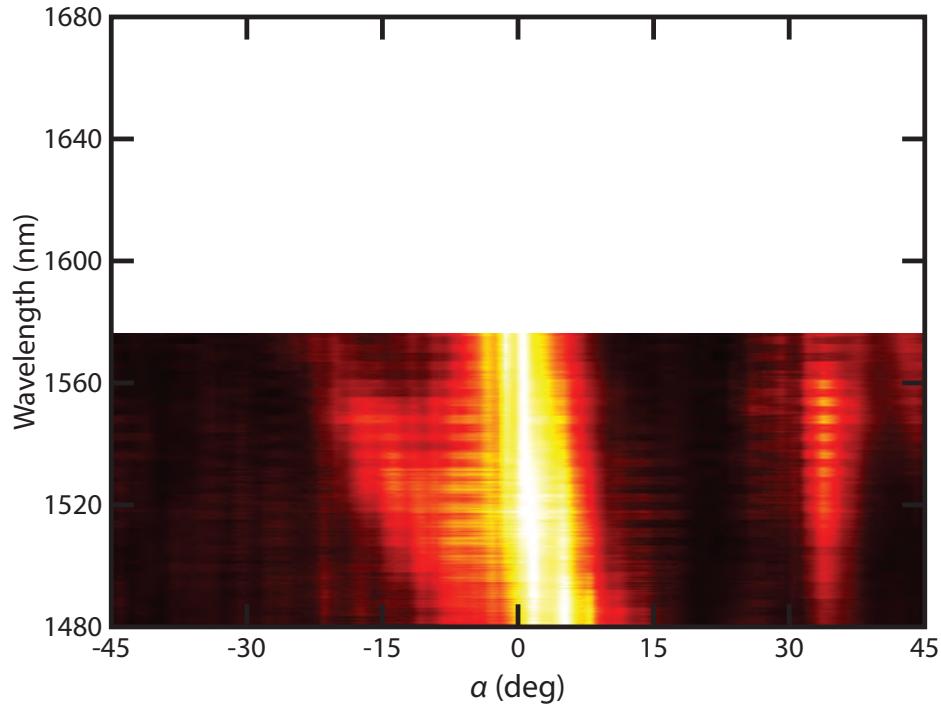


1 zero index

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Wavelength dependence of refraction angle

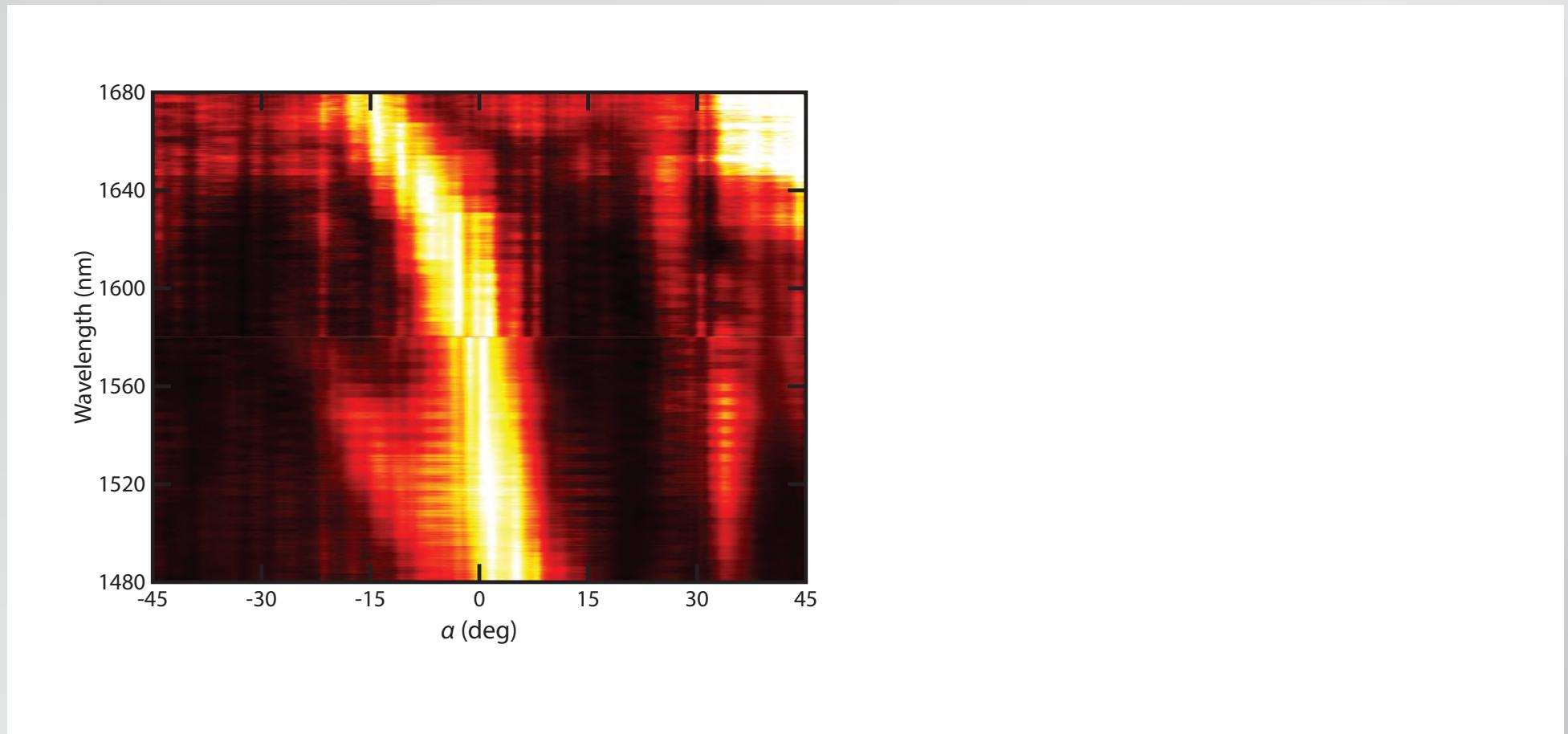


1 zero index

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3 results

Wavelength dependence of refraction angle

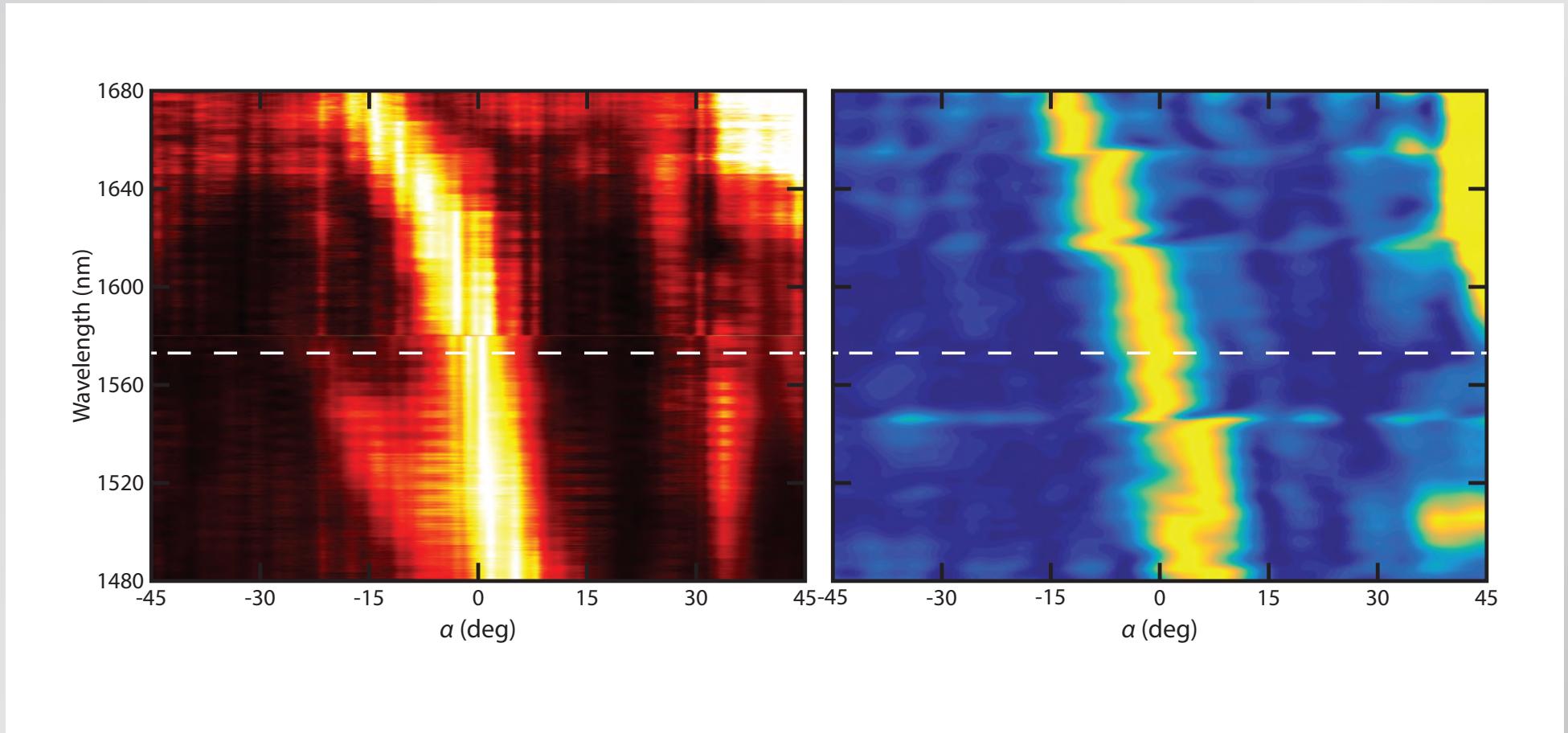


1 zero index

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Wavelength dependence of refraction angle

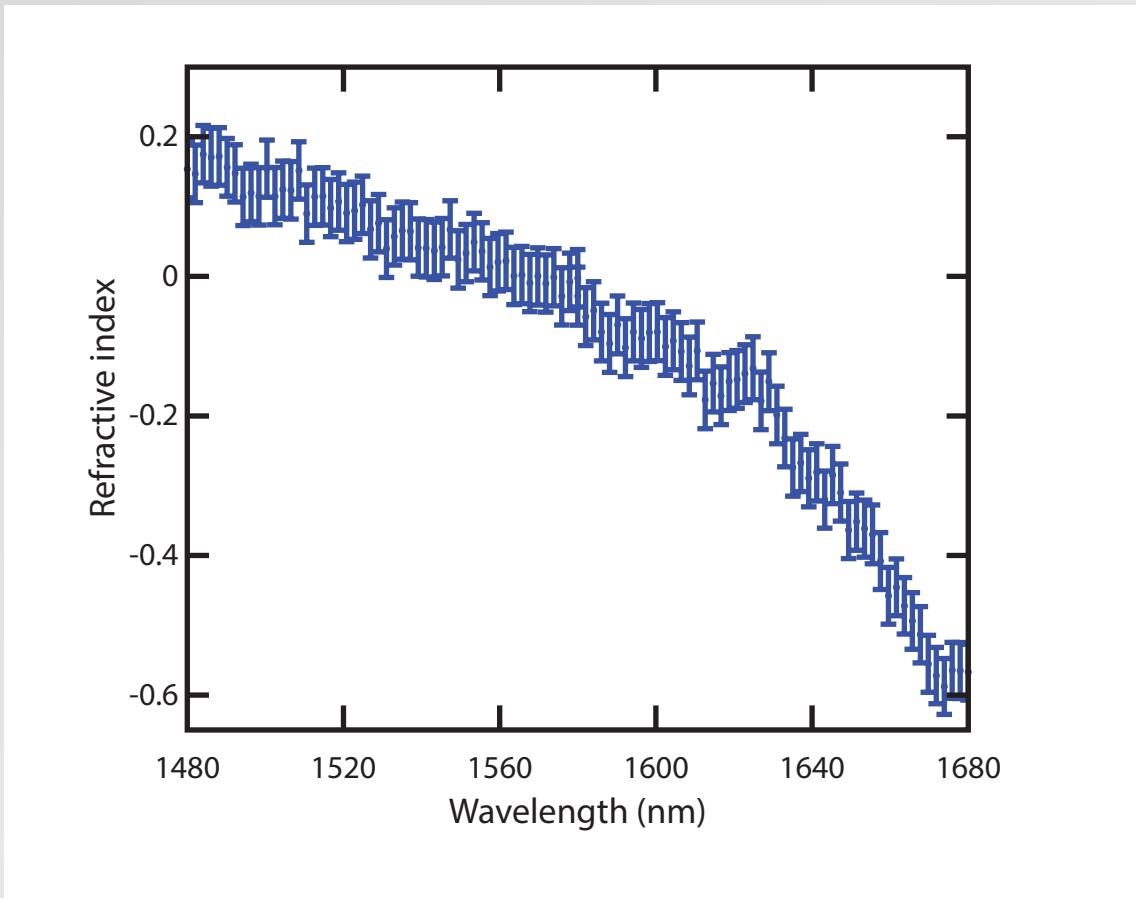


1 zero index

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3 results

Wavelength dependence of index

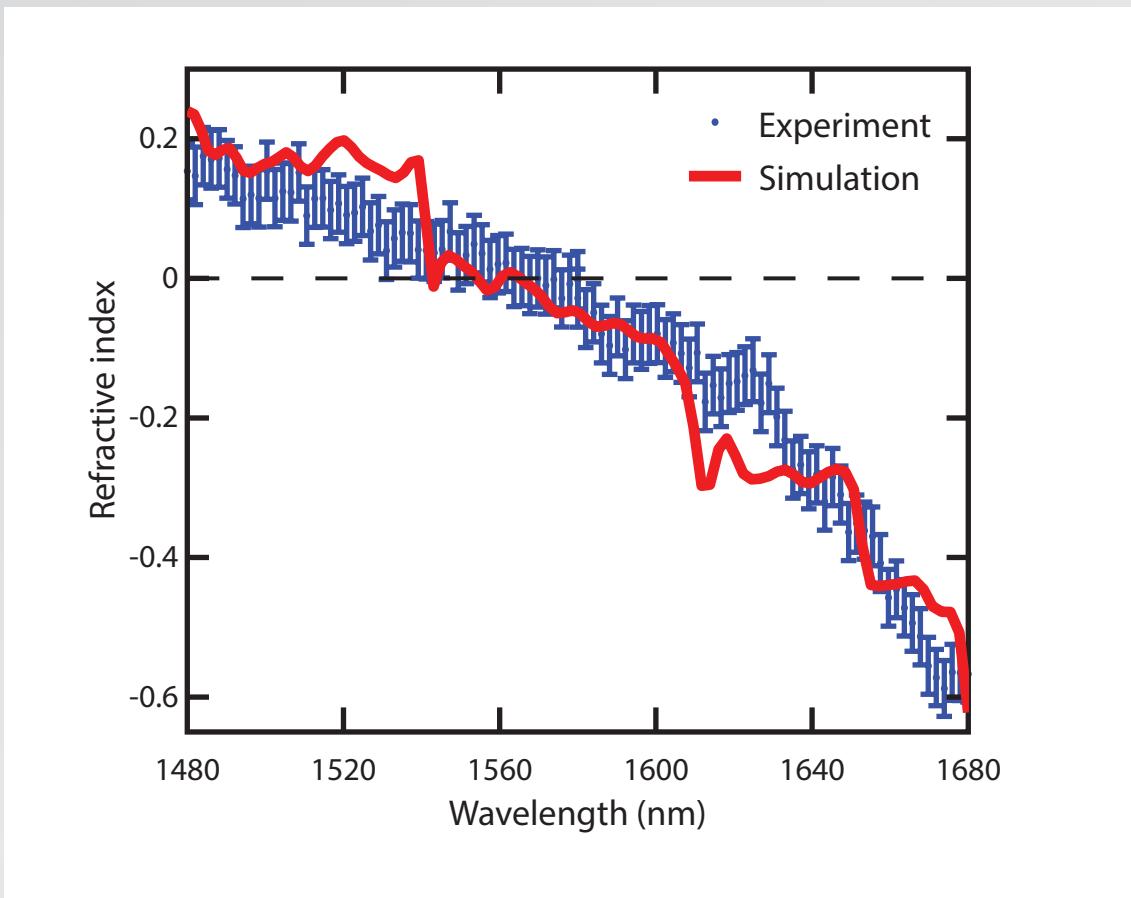


1 zero index

2 fabrication

3 results

Wavelength dependence of index



1 zero index

2 fabrication

3 results

unambiguous demonstration of on-chip zero-index material!

1 zero index

2 fabrication

3 results



1 zero index

2 fabrication

3 results

**The Team: Yang Li, Shota Kita,
Orad Reshef, Philip Muñoz, Daryl Vulis, Marko Lončar**

Funding: National Science Foundation

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3 results