

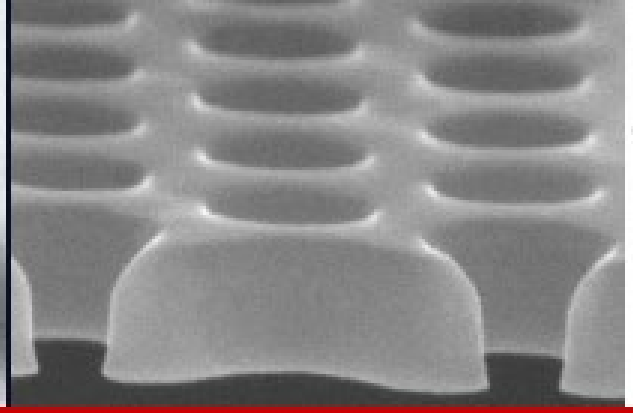
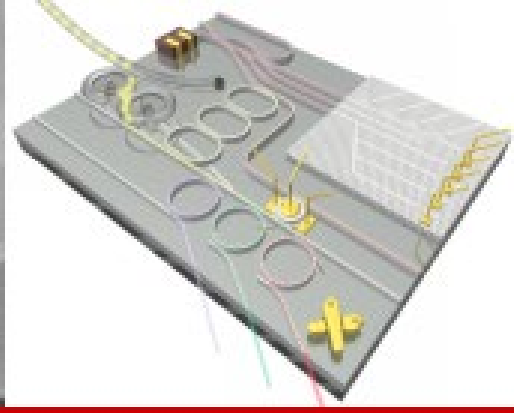

CLEO/Europe-EQEC 2019
June 24, 2019, 14:30-14:45 PM

# Efficient coupling of silica toroid microresonator to silicon chip with photonic crystal waveguide

Yuyang Zhuang[1,2], Hajime Kumazaki[1], Shun Fujii[1], and Takasumi Tanabe[1]

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[2] Nanjing University of Posts and Telecommunications

# Outline

**Part 1**. Background

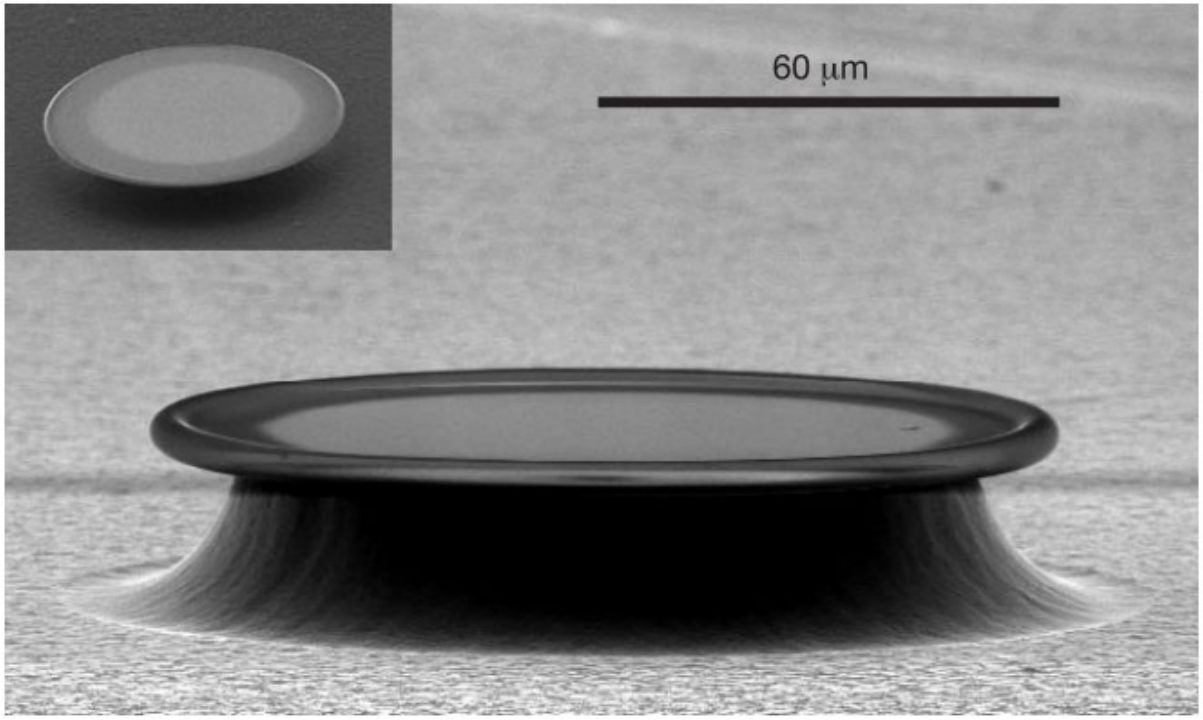
**Part 2**. Motivation

**Part 3**. Experiments/Resuls

**Part 4**. Conclusion

# Background

## ☐ Whispering gallery mode (WGM) microcavity




D. K. Armani et al, Nature **421**, 925 (2003)

Silica toroid microcavity

### Ultra-high quality factor (Q)

- $Q \sim 10^8$
- $V \sim 100\ (\lambda/n)^3$

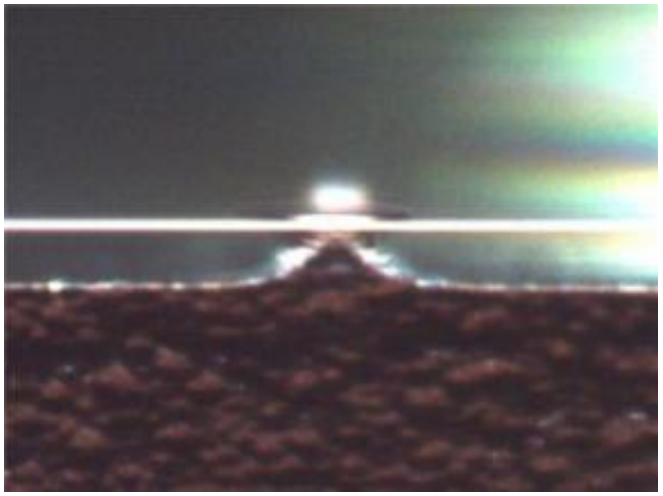
### Applications

- **Frequency Kerr comb**
- **Optical buffer**
- **Low power optical switch**

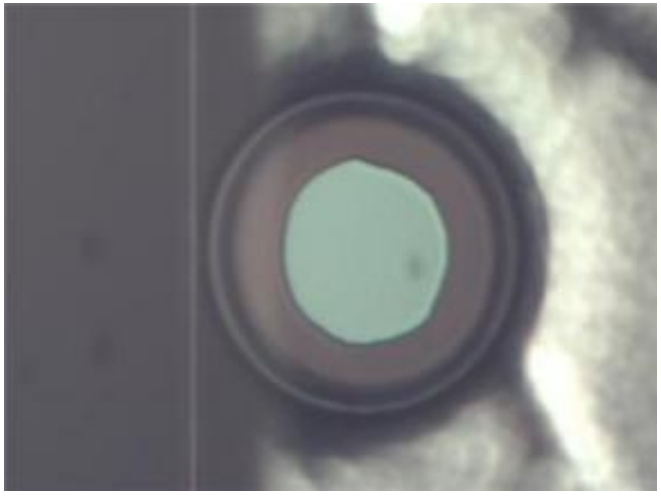
# Background

## ☐ Coupling structures

Side view



Top view



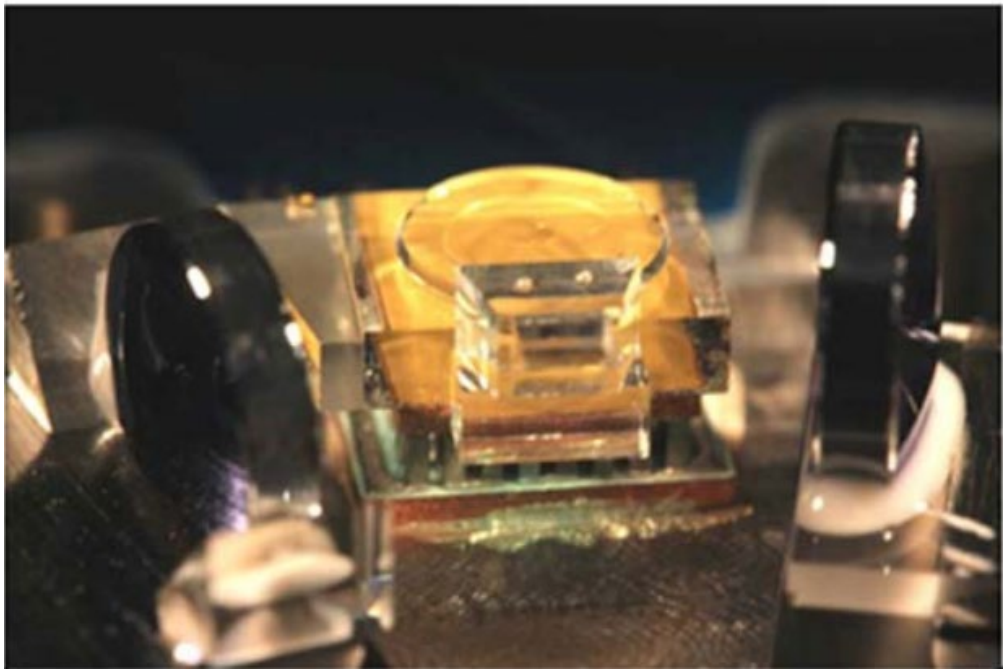
Tapered fiber

- **High coupling efficiency**
  **>99.97%** [1]
- **Low insertion loss**
  **~99.4%** [2]
- **Tunable**
- **Sensitive**
- **Fragile**

[1] S. M. Spillane, et al , Phys. Rev. Lett., **91**, 043902, (2003).
[2] T. Aoki, et al, Jpn. J. Appl. Phys. **49**, 118001 (2010).

# Background

## ☐ Coupling structures



A. A. Savchenkov et al, Opt. Lett. **15**, 3468 (2015)

Prism

- **Coupling efficiency**

  **~80 %** [3]

- **Materials: silica, diamond, rutile, and sapphire, etc.**

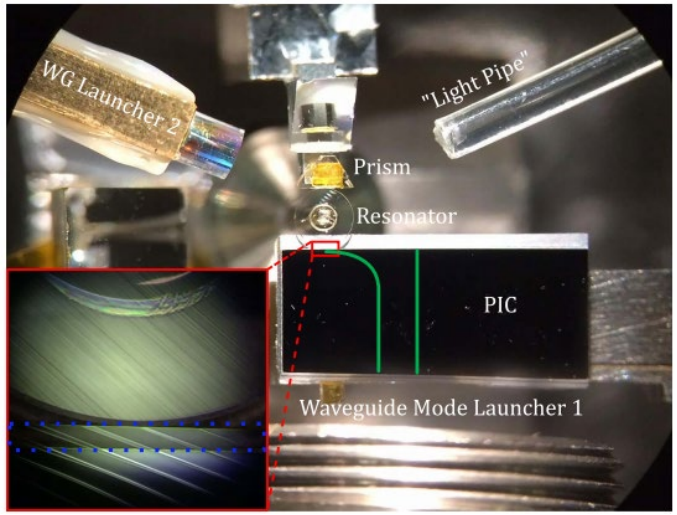
- **Relatively robust and simple**

- **Critical alignment angle**

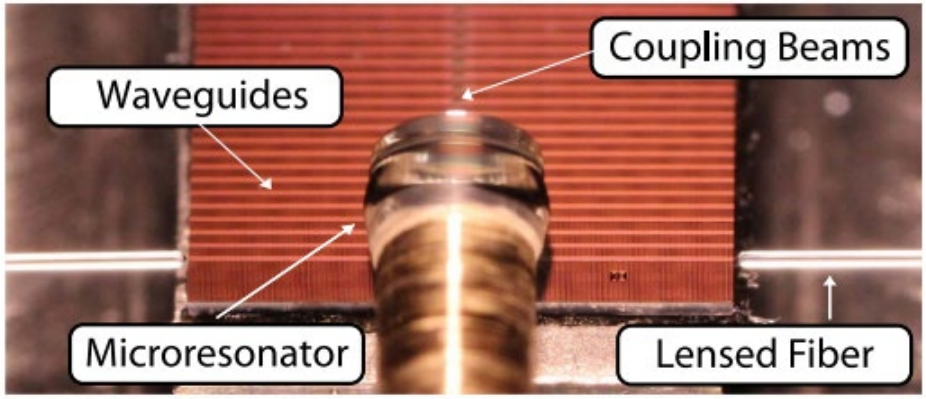
[3] M. L. Gorodetsky and V. S. Ilchenko, J. Opt. Soc. Am. B, **16**,147 (1999).

# Background

## Coupling structures




G. Liu et al, Optica **5**, 219 (2018)




M. Anderson et al, Opt. Lett. **43**, 2107 (2018)

**Plannar waveguide**

- **Coupling efficiency**

  **95.7% for $BaF_2$, 98.1% for $CaF_2$** [6]

- **Relatively robust and simple**

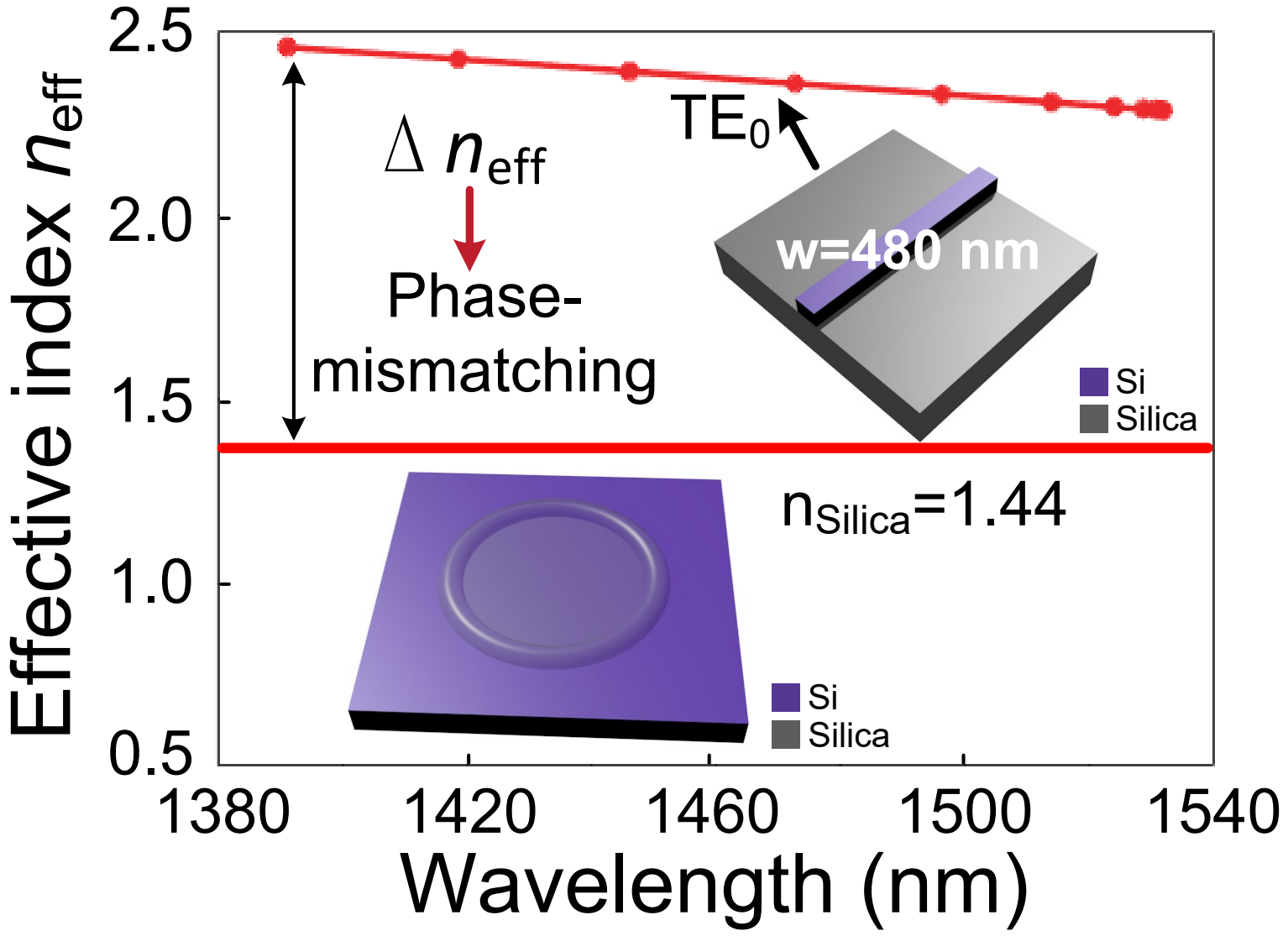
- **Fabrication difficulty**

- **Small index difference coupling**

  - **Si waveguide w/ $LiNbO_3$ cavity (3.48 w/ 2.21)**
    [4] M. Soltani et al, Opt. Lett. **41**, 4375 (2016)
  - **$Si_3N_4$ waveguide w/ $MgF_2$ cavity (2.00 w/ 1.37)**
    [5] G. Liu et al, Optica. **5**, 219 (2018)
  - **$SiO_2$ waveguide w/ $CaF_2$ cavity (1.44 w/ 1.43)**
    [6] M. Anderson et al, Opt. Lett. **43**, 2106 (2018)

# Motivation

## ☐ Large index difference coupling?



# Motivation

- Couple light into Si-based PhC-WG

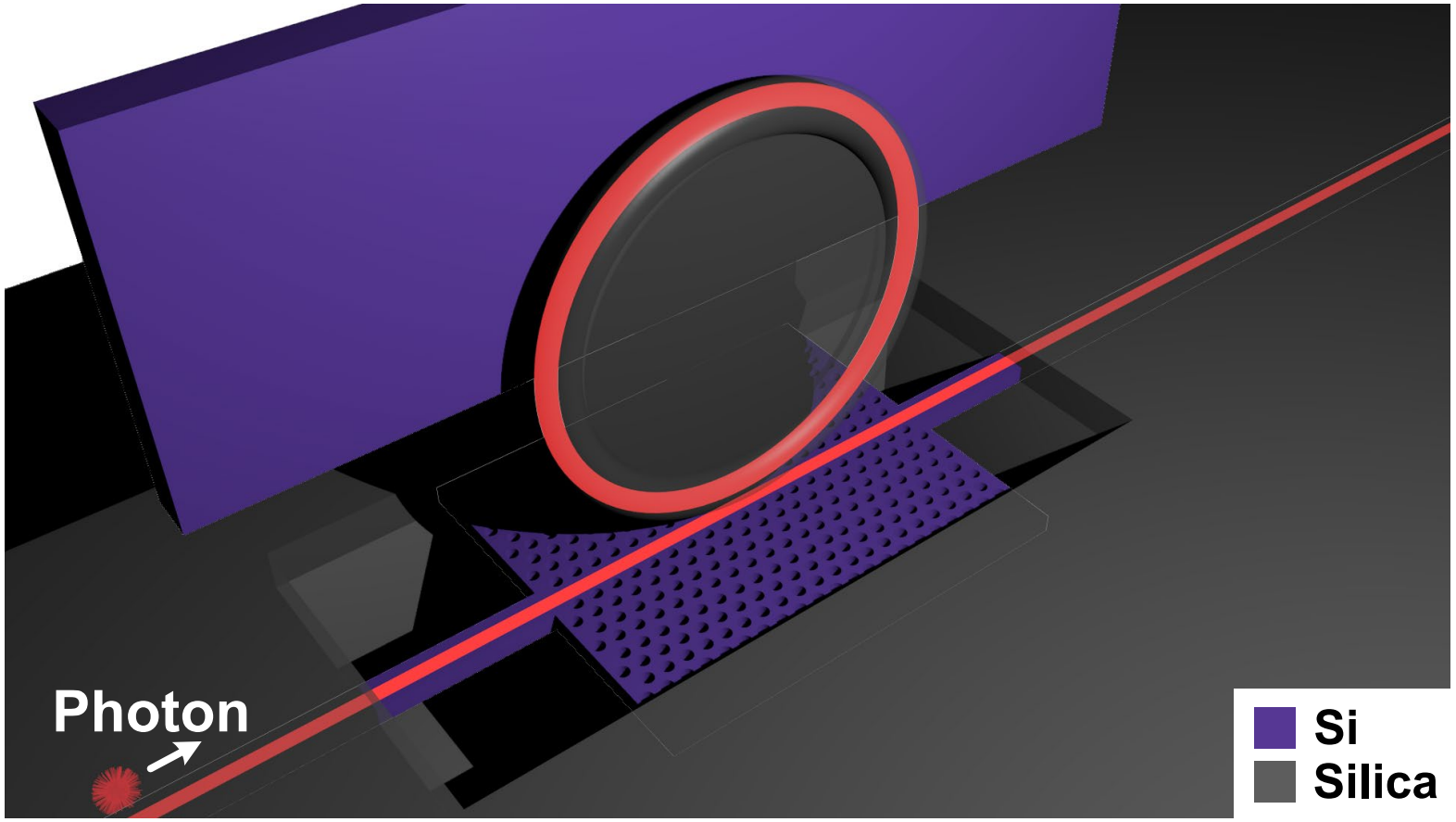
Our work

**Low n cavity**

**Silica**
**(n=1.44)**

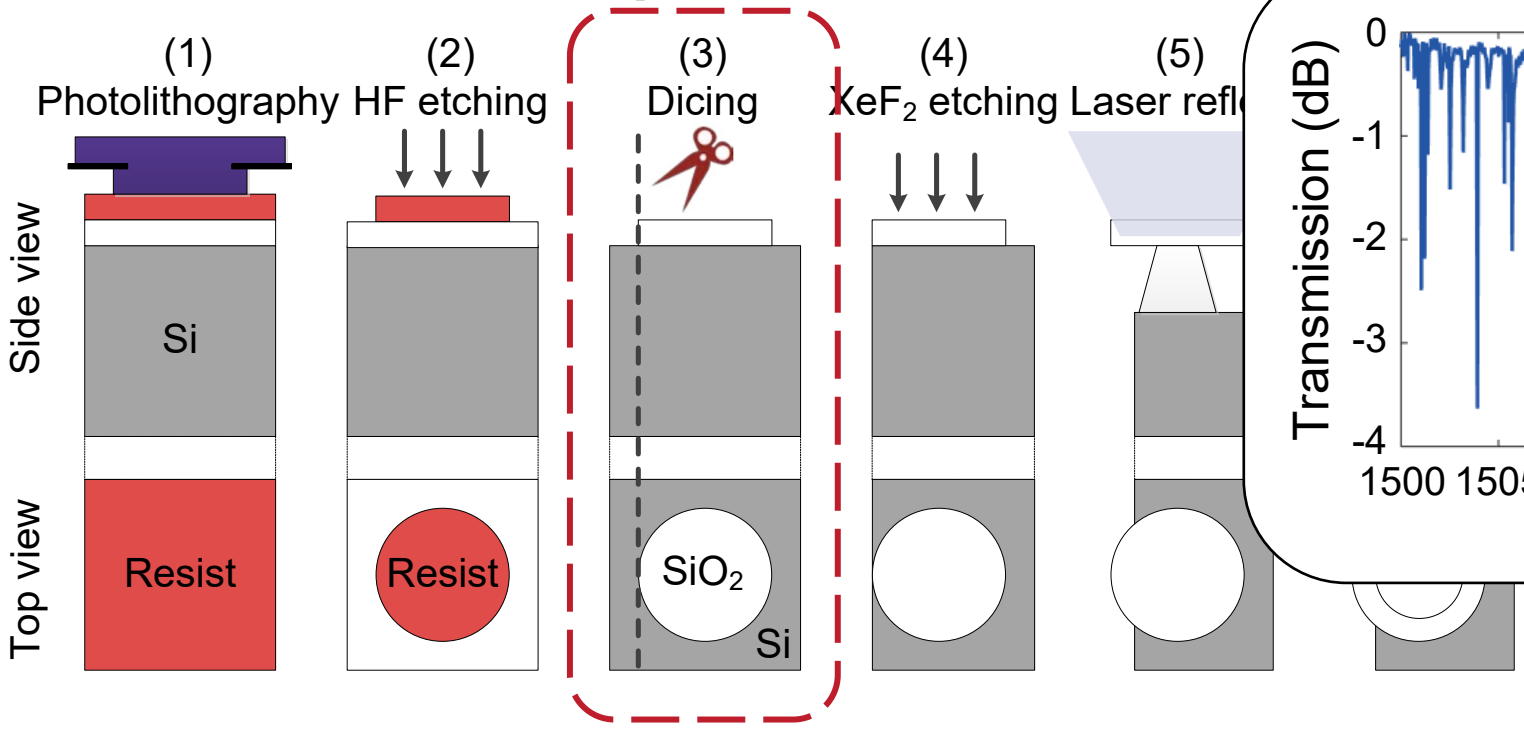
**High n waveguide**

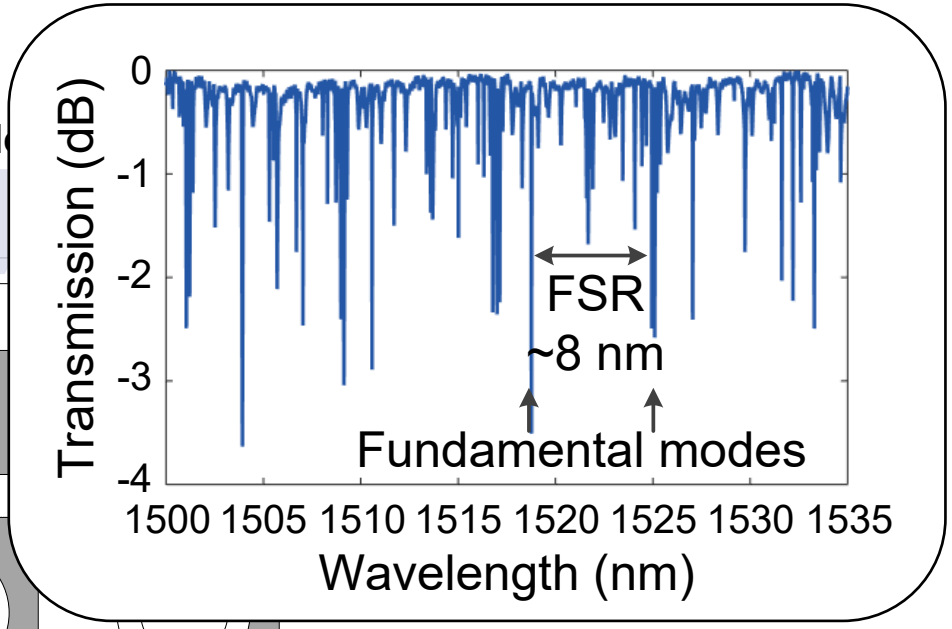
**Si**
**(n=3.48)**



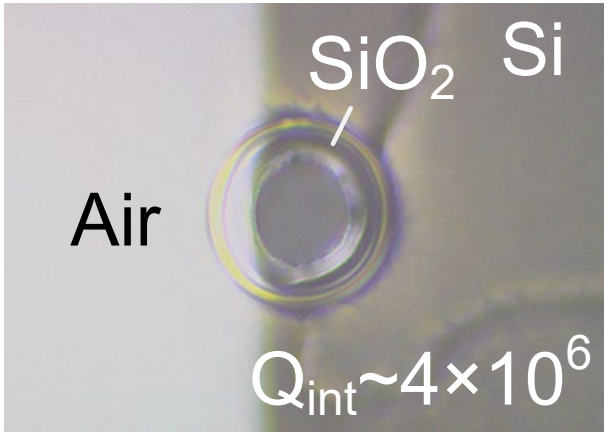
# Fabrication of WGM cavity

## Fabrication process




Top View

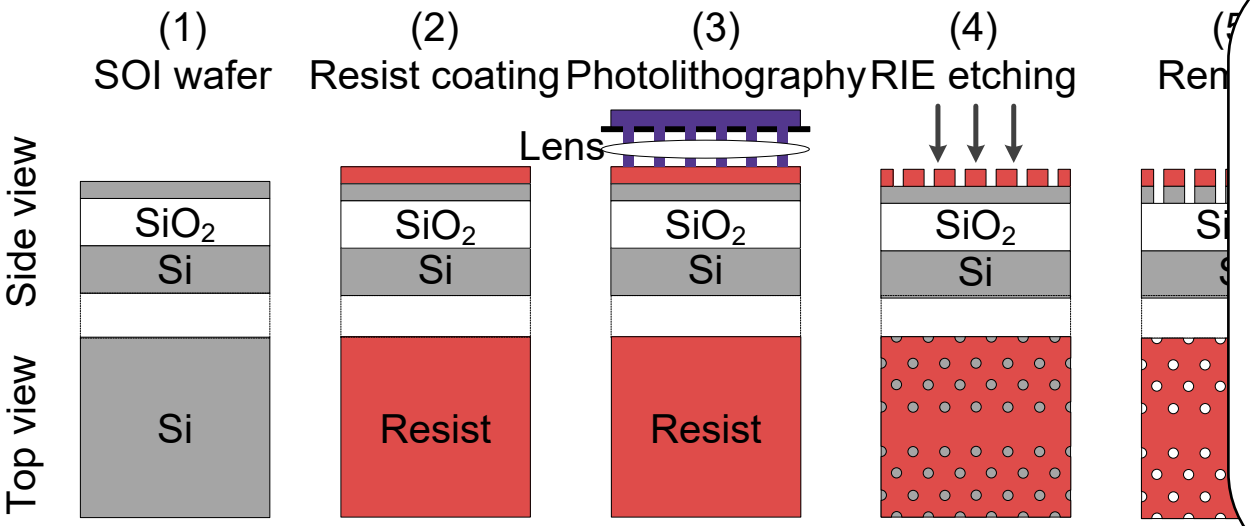


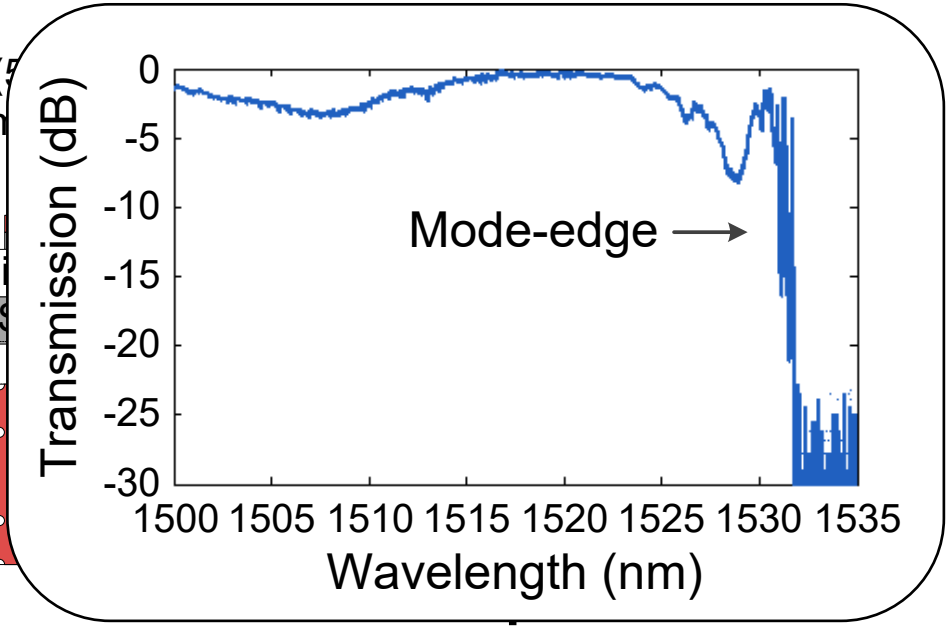

Important fabrication process.

- Make coupling easier.

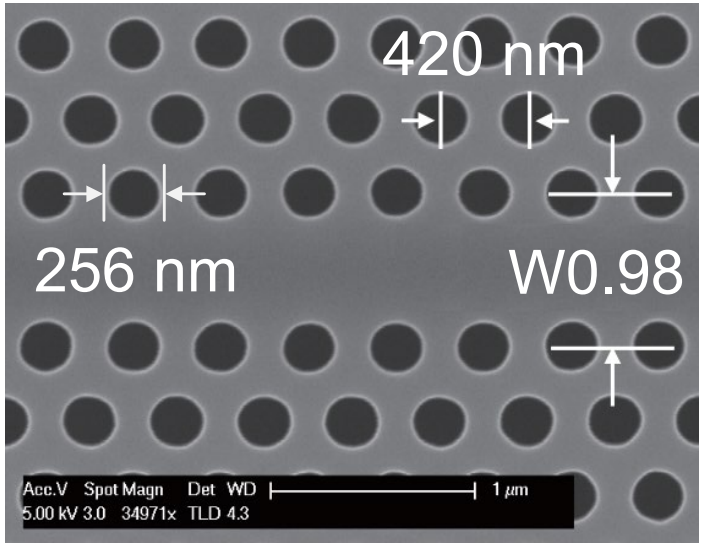
# Fabrication of PhC-WG

## Fabrication process



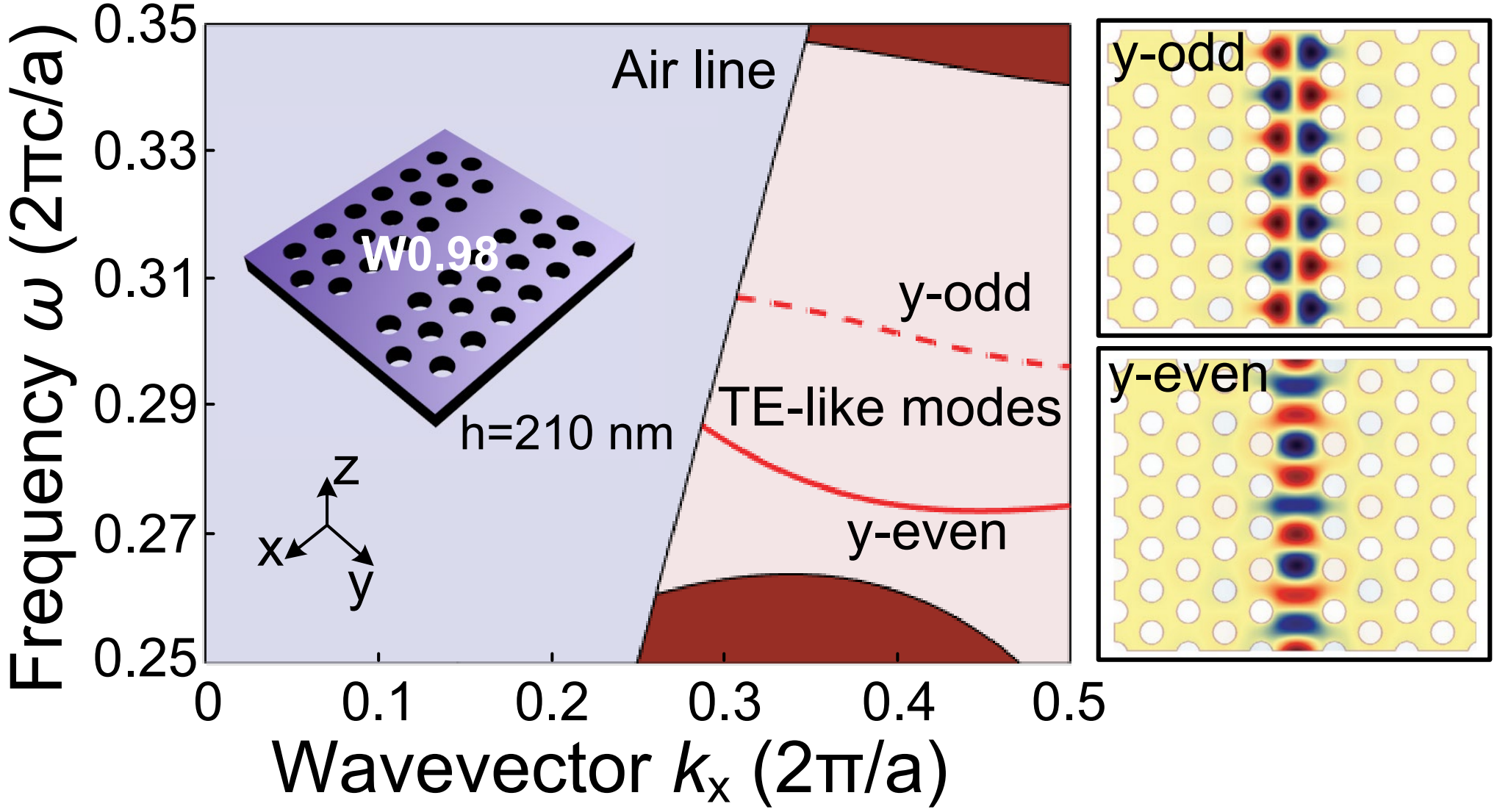




- CMOS compatible.
- Silica cladding is removed to form an air-bridge type structure.



# Dispersion of PhC-WG

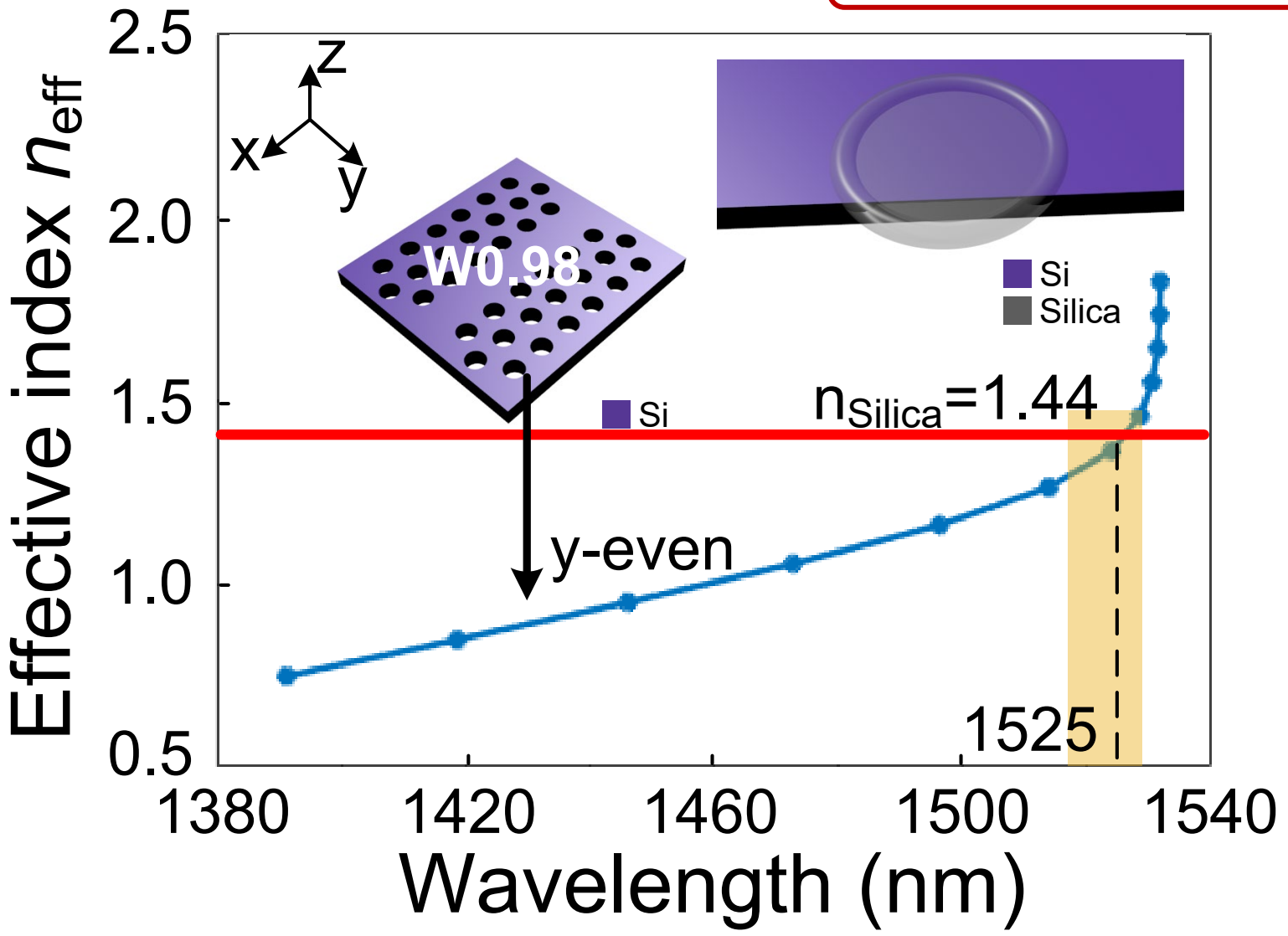
## Dispersion line map



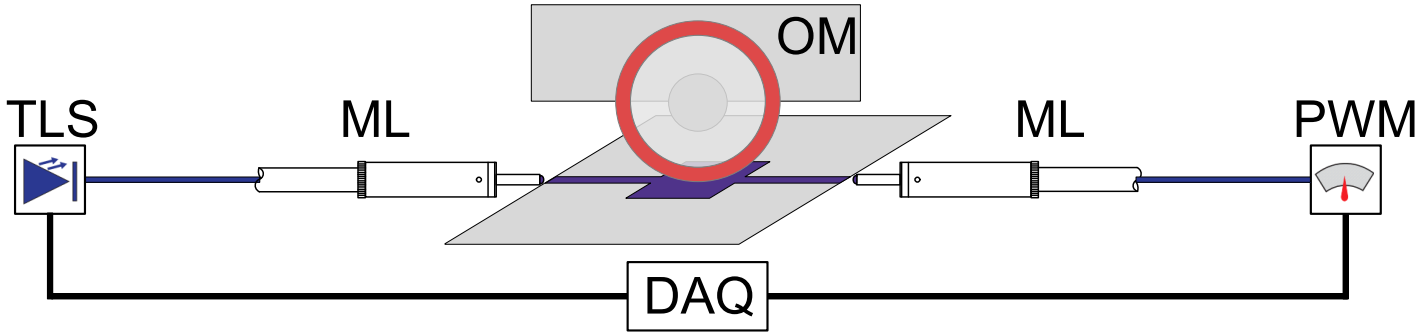
# Phase-matching

- Effective index map

$$k_x = 2\pi n_{eff} / \lambda$$

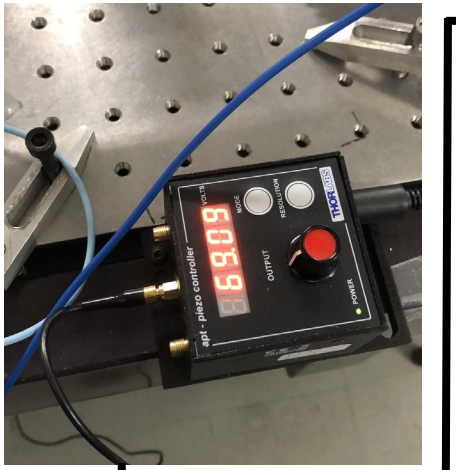


# Experimental setup

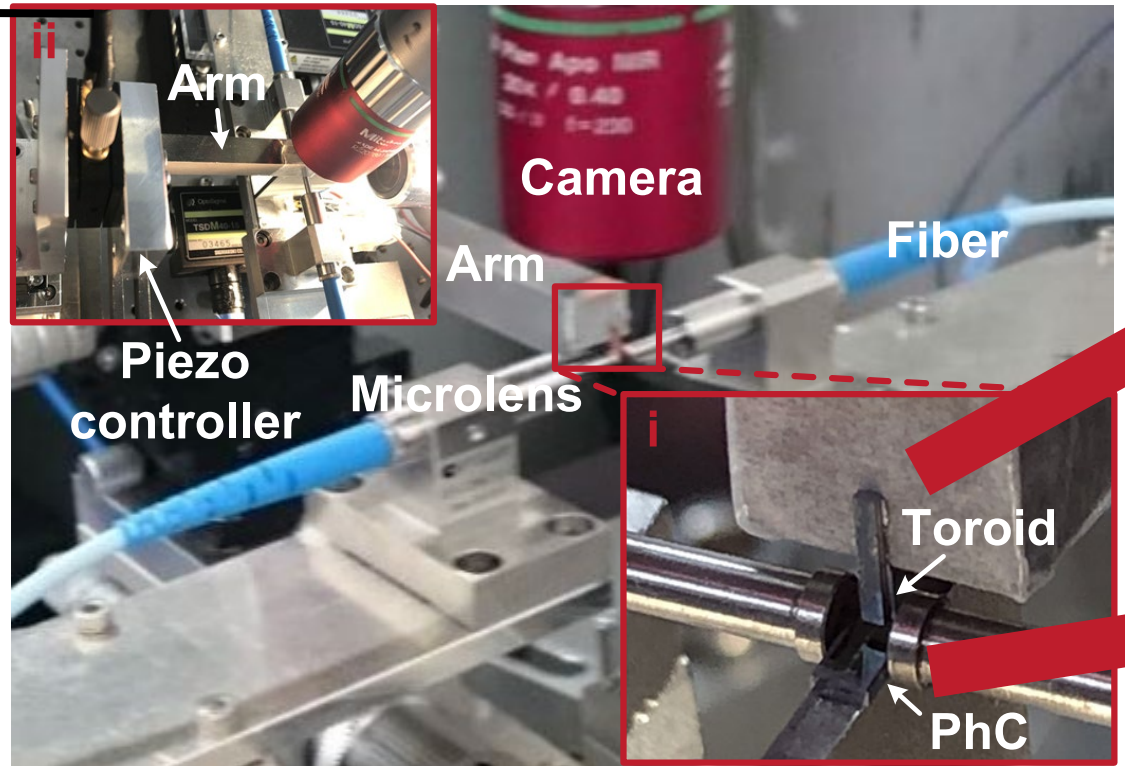



TLS: Tunable laser source
ML: Microlens
OM: Opitcal microresonator
PWM: Powermeter
DAQ: Data acquation

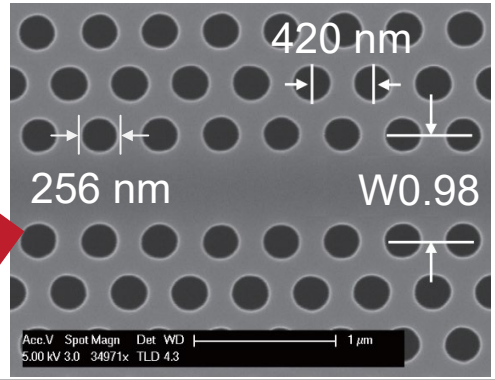
## Schematic illustration




333 nm/V

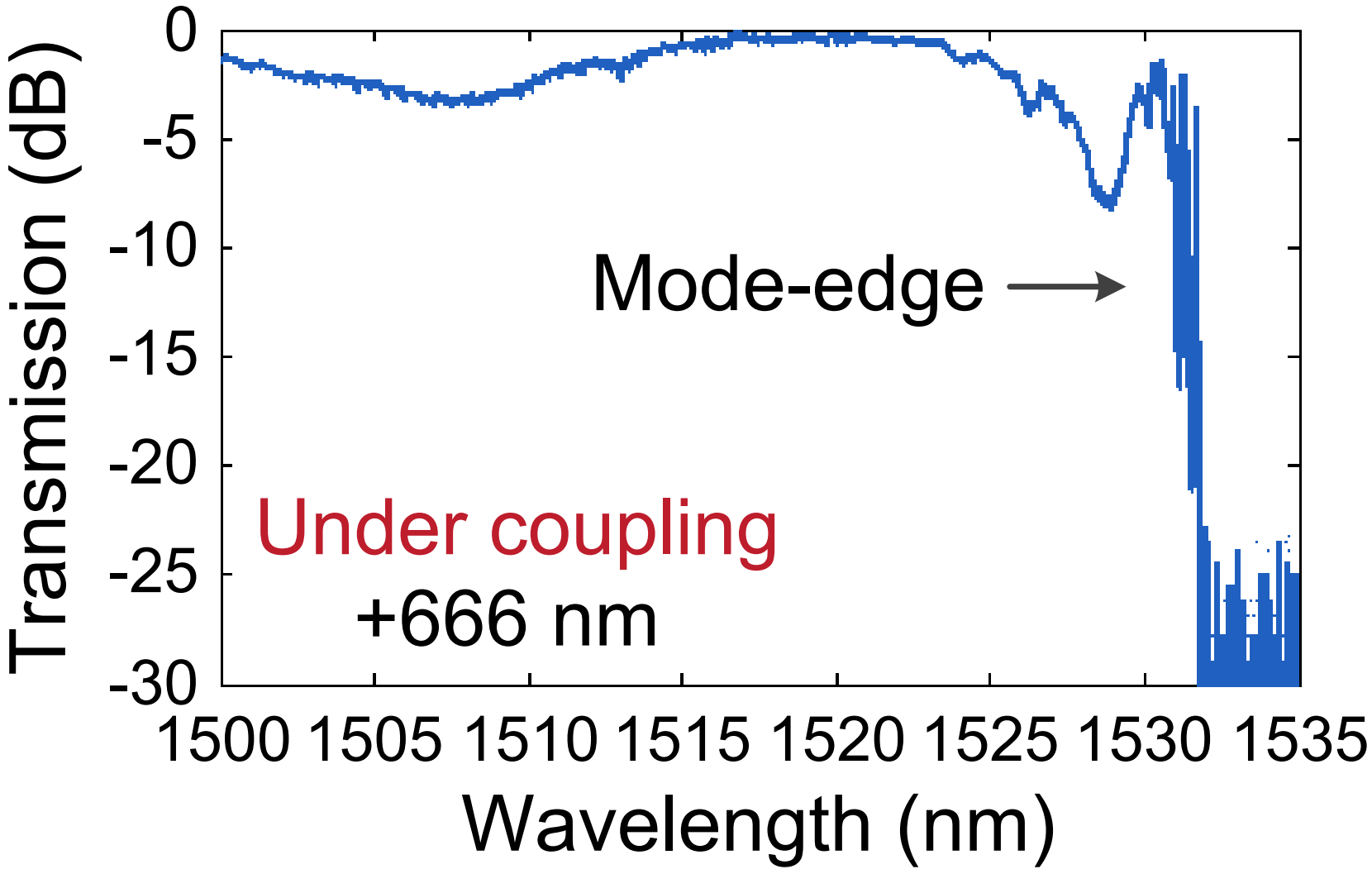






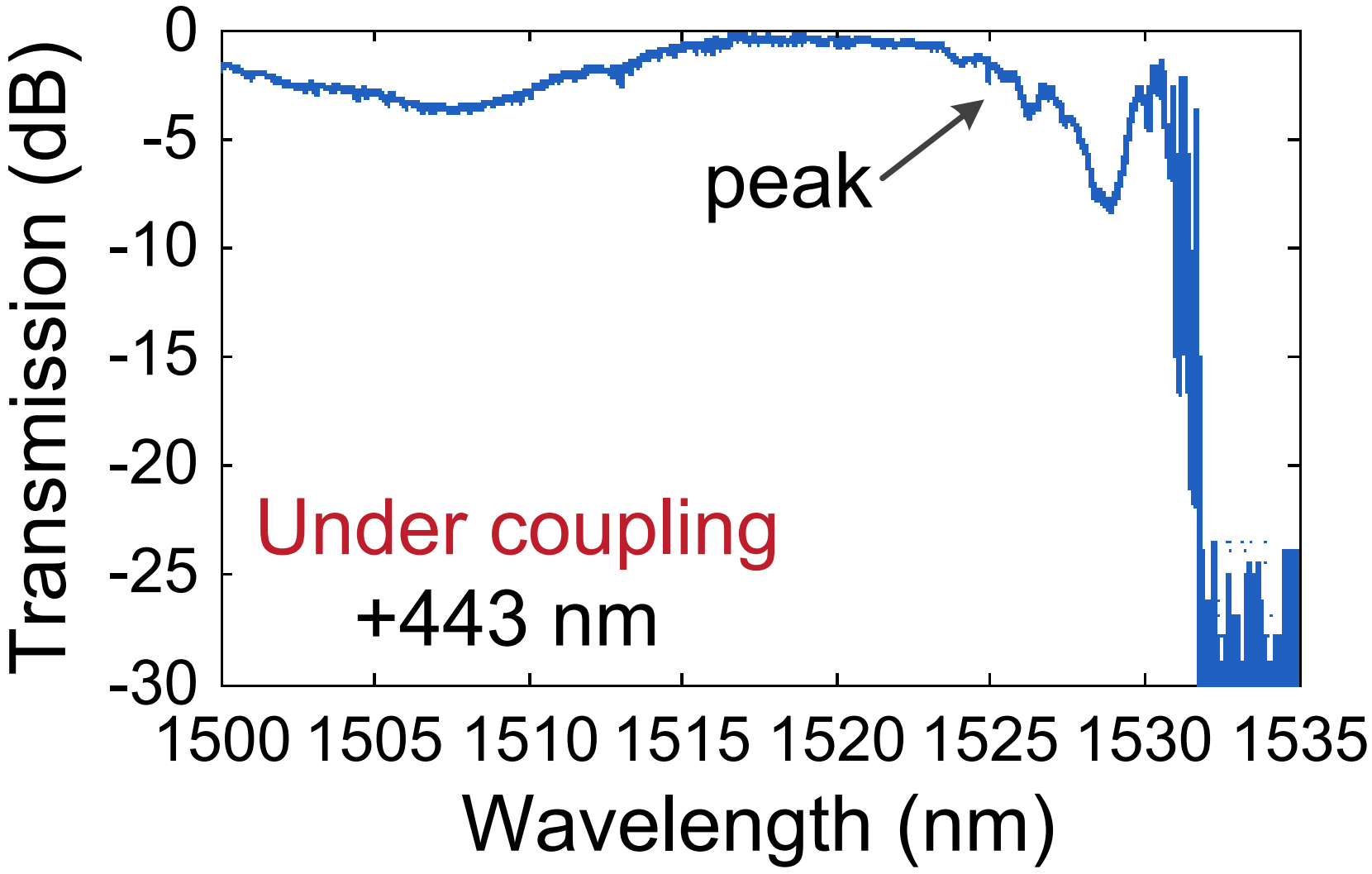
# Results

- Transmission spectrum



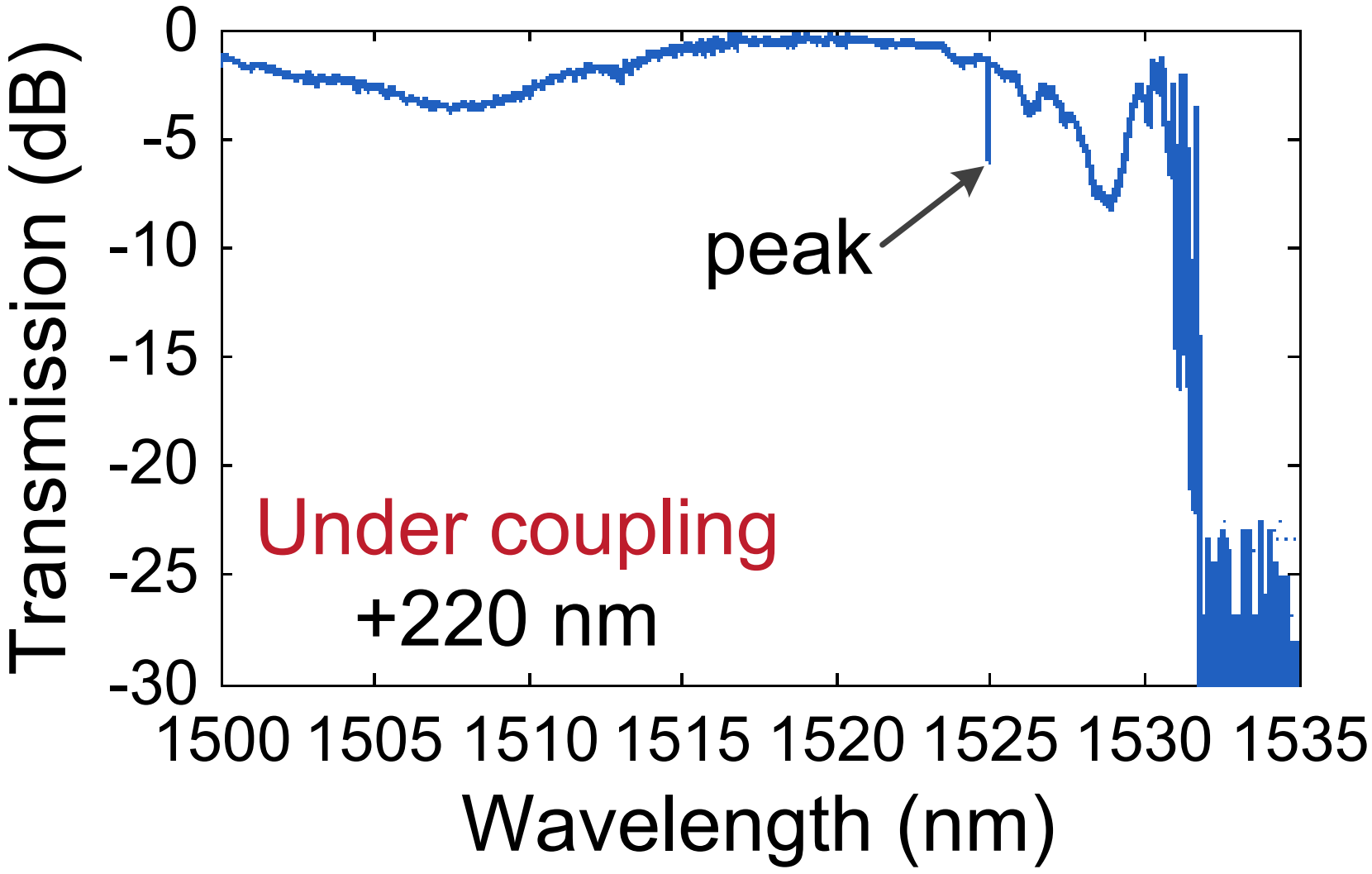
# Results

- Transmission spectrum



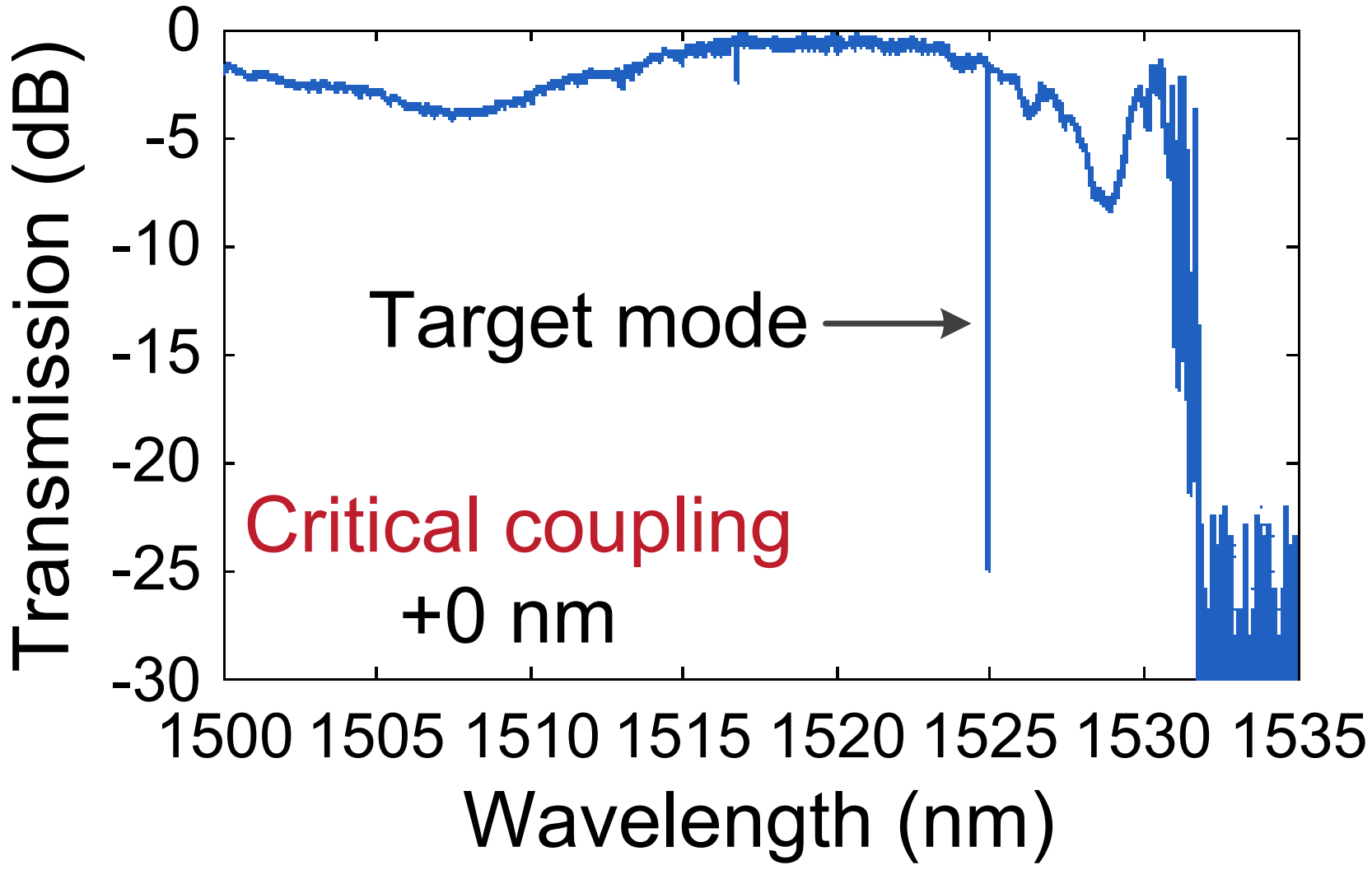
# Results

- Transmission spectrum



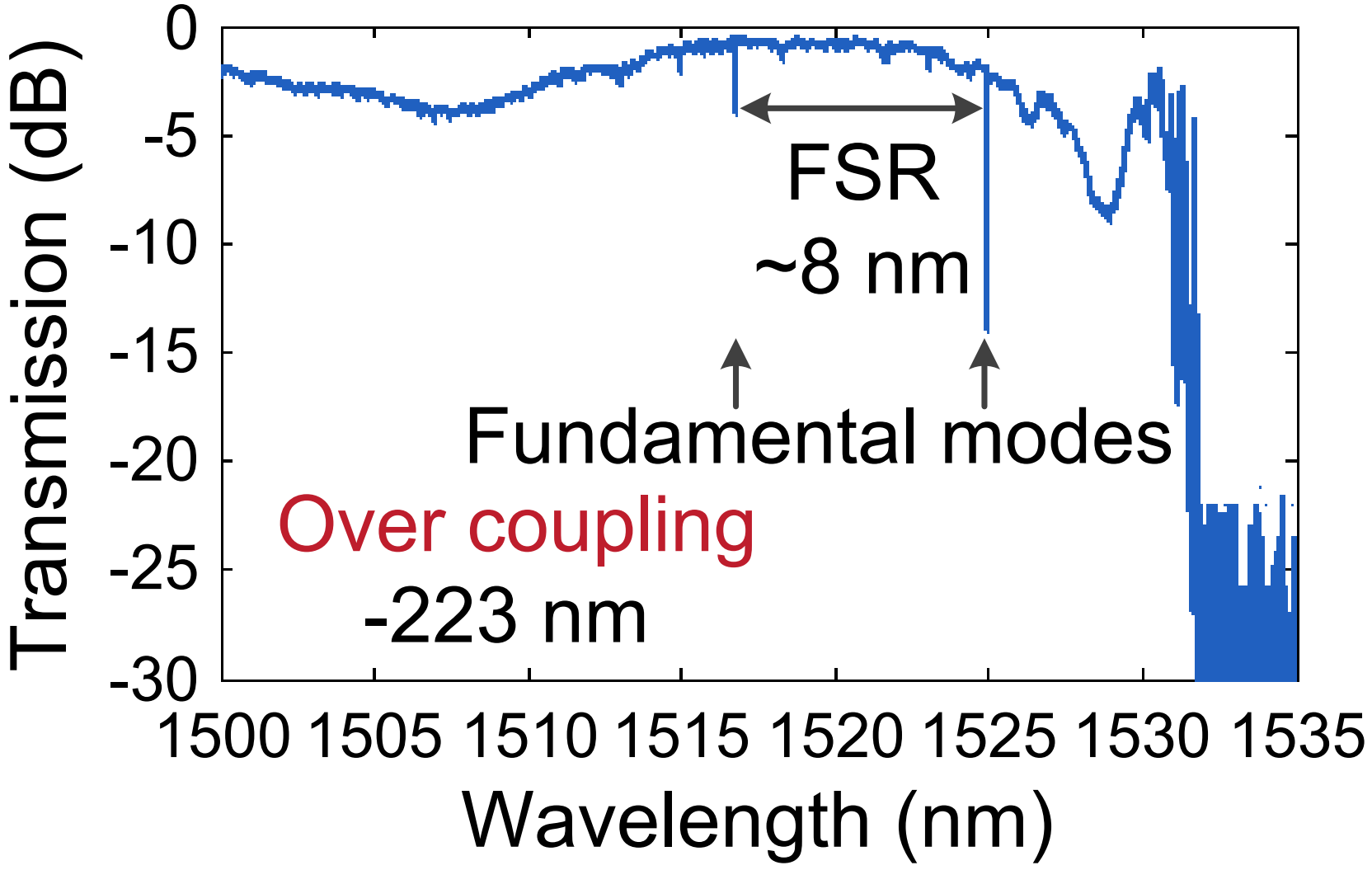
# Results

## Transmission spectrum



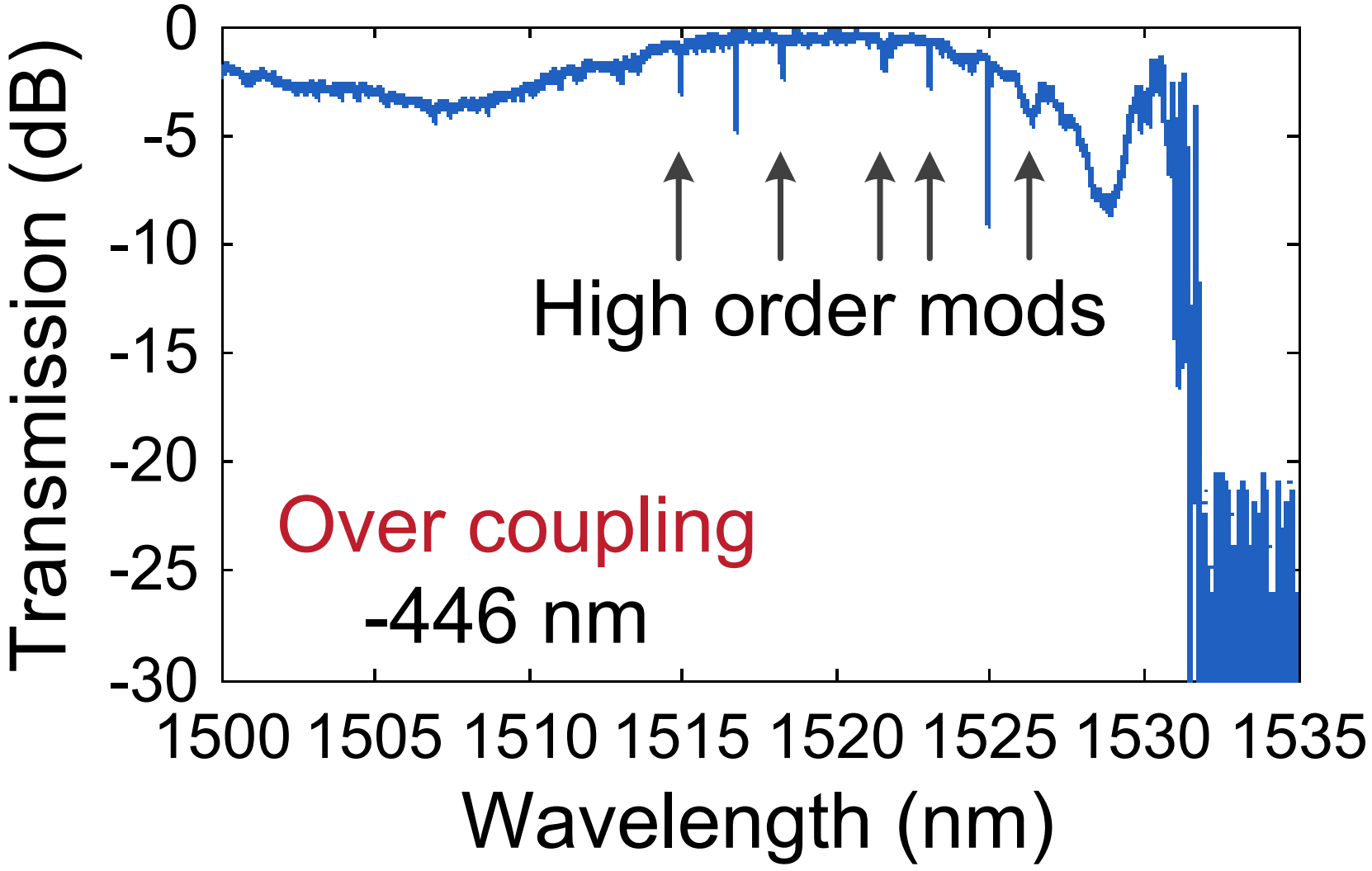
# Results

## Transmission spectrum



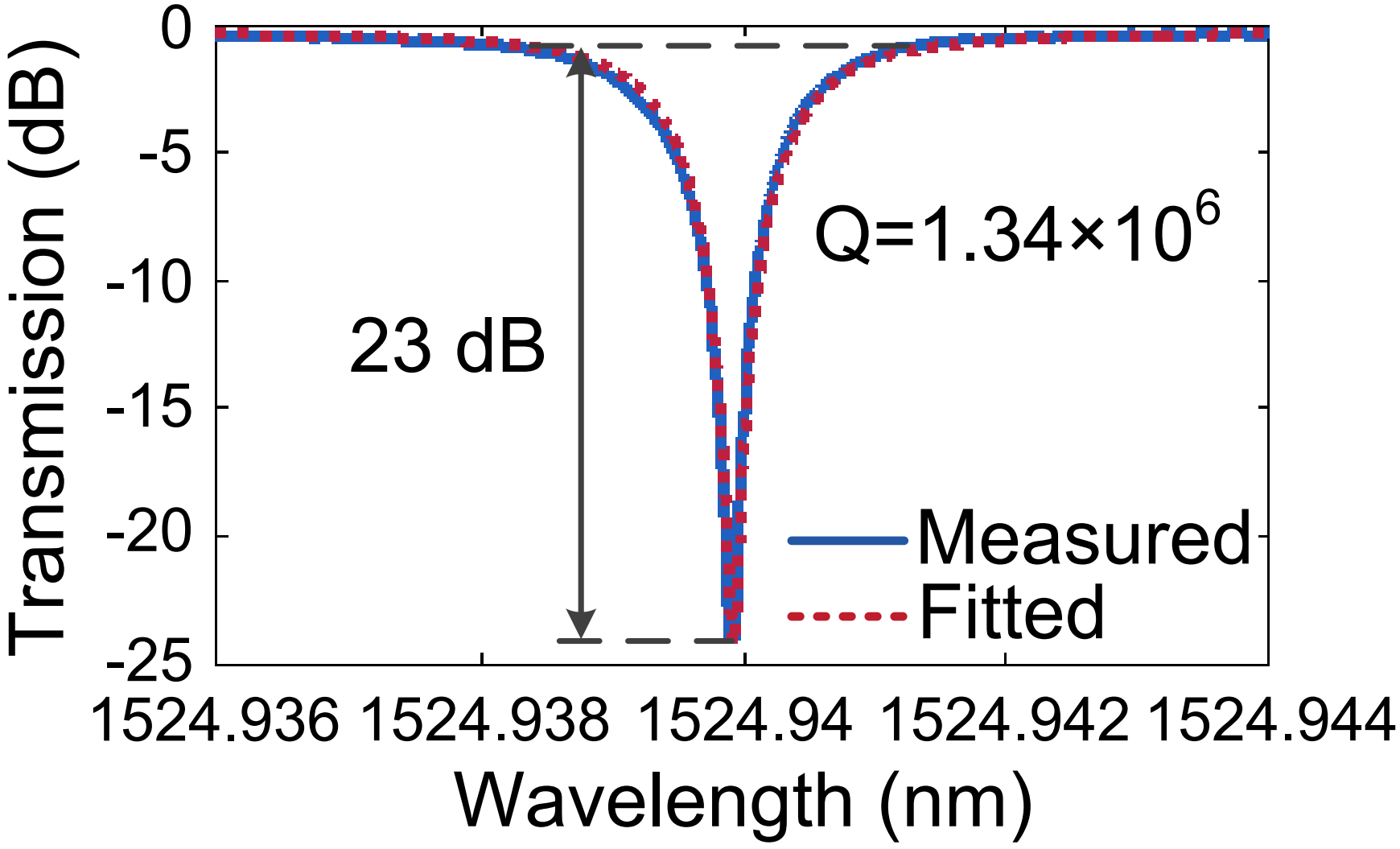
# Results

## Transmission spectrum



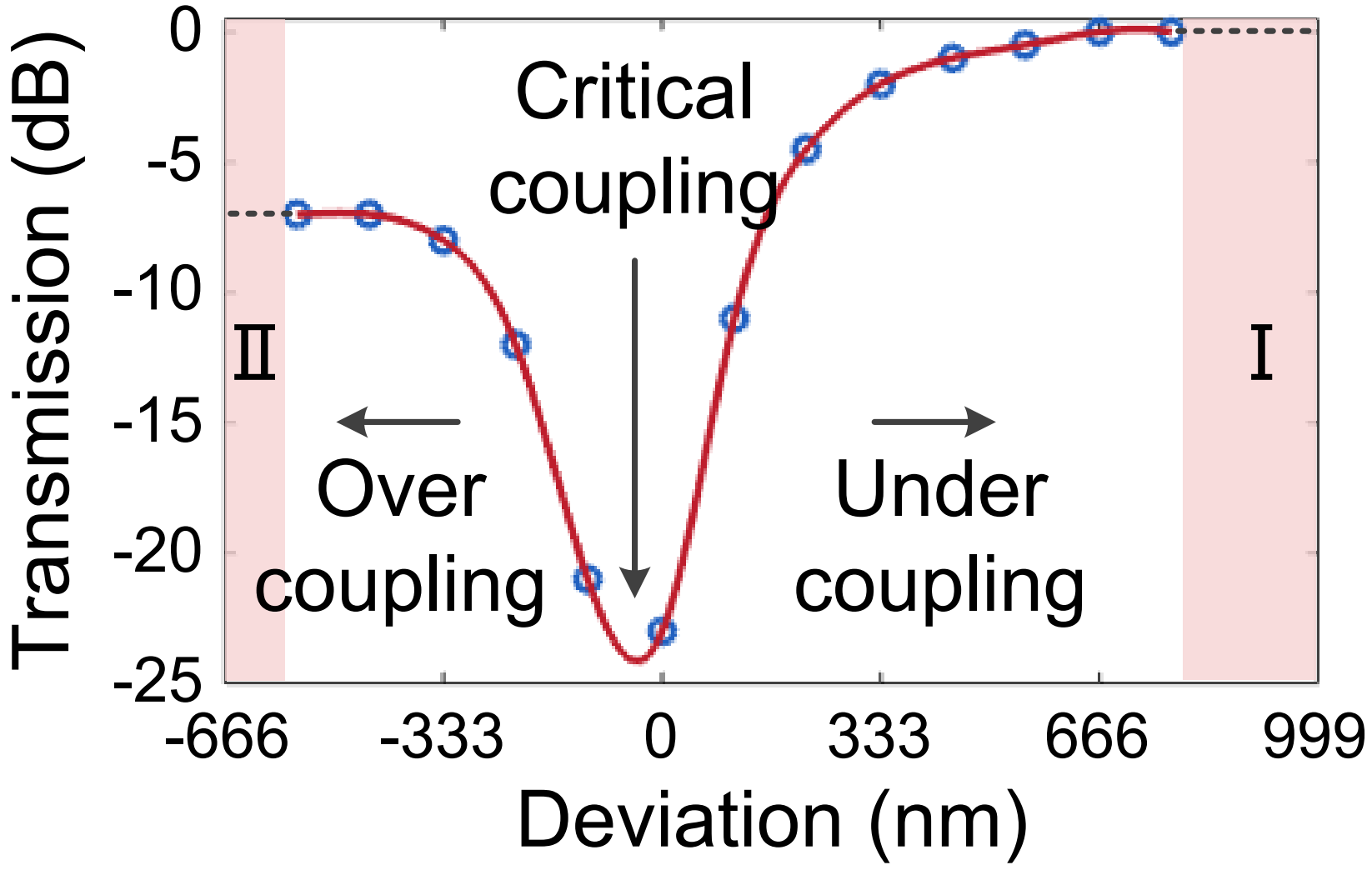
# Results

- Transmission spectrum at critical coupling



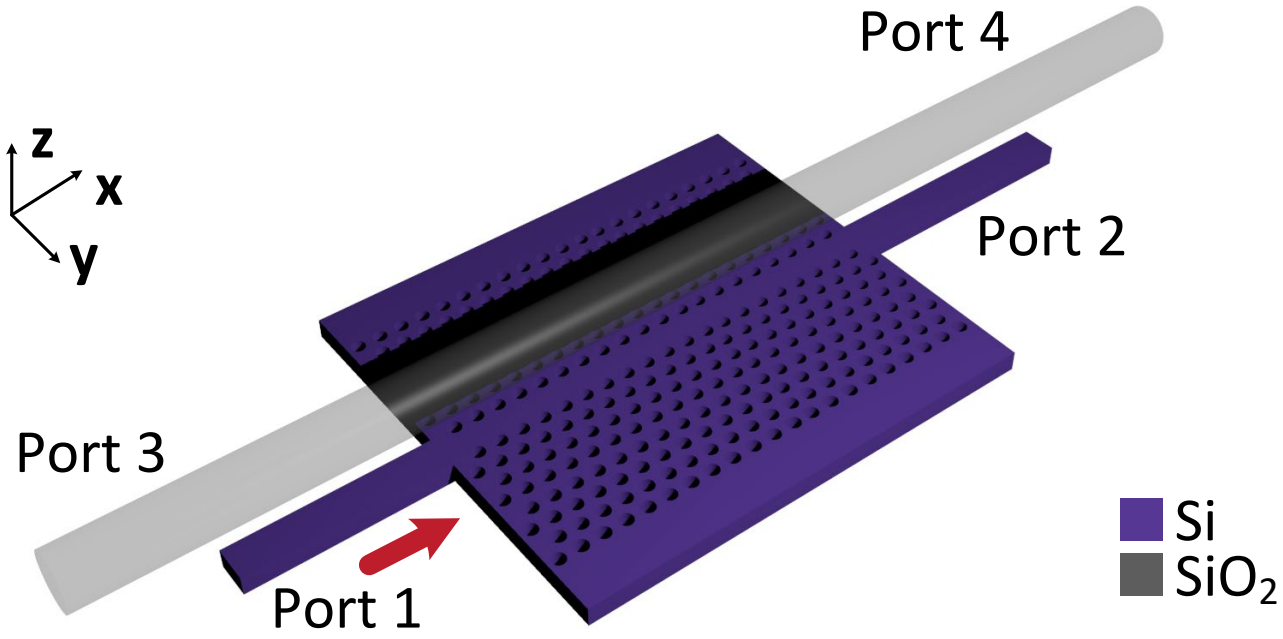
# Results

- Relationship of efficiency and deviation

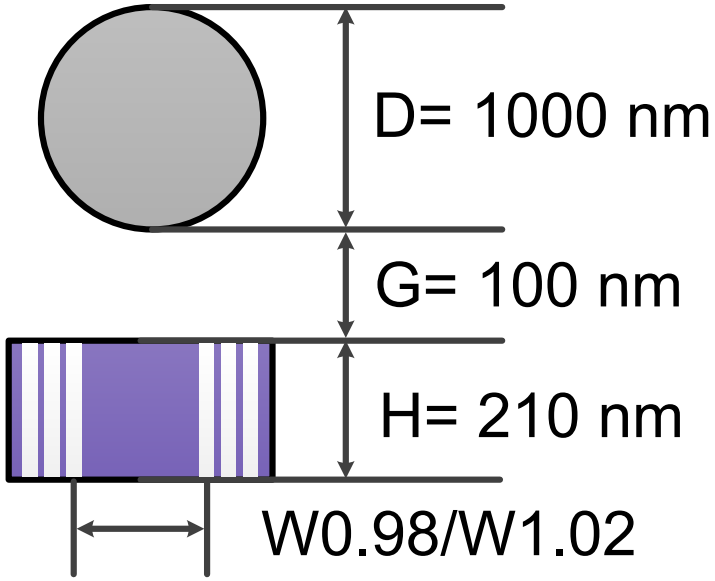


# n_eff & n_g discussion

## Fiber w/ Si-PhC coupling



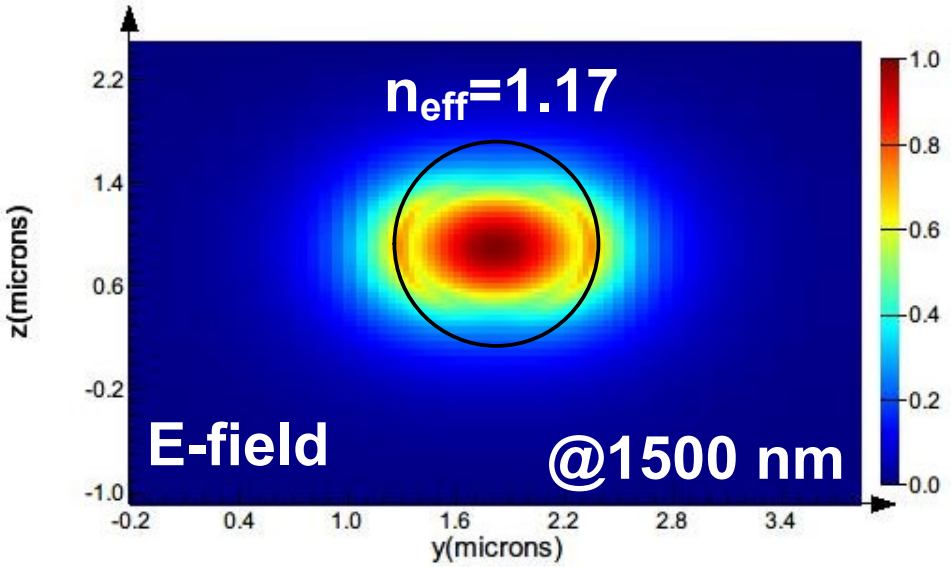

3-D view



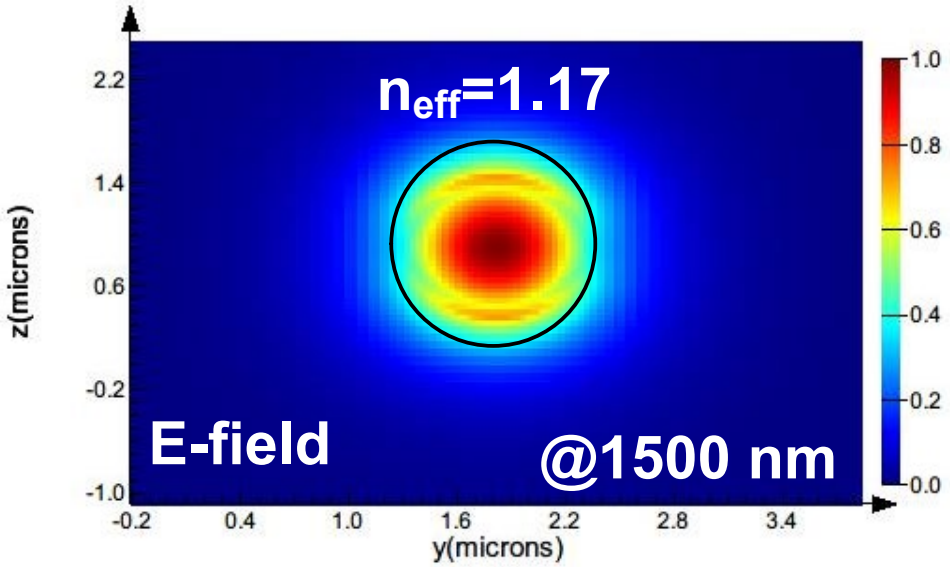

Side view

# n_eff & n_g discussion

- Fundamental mode of fiber



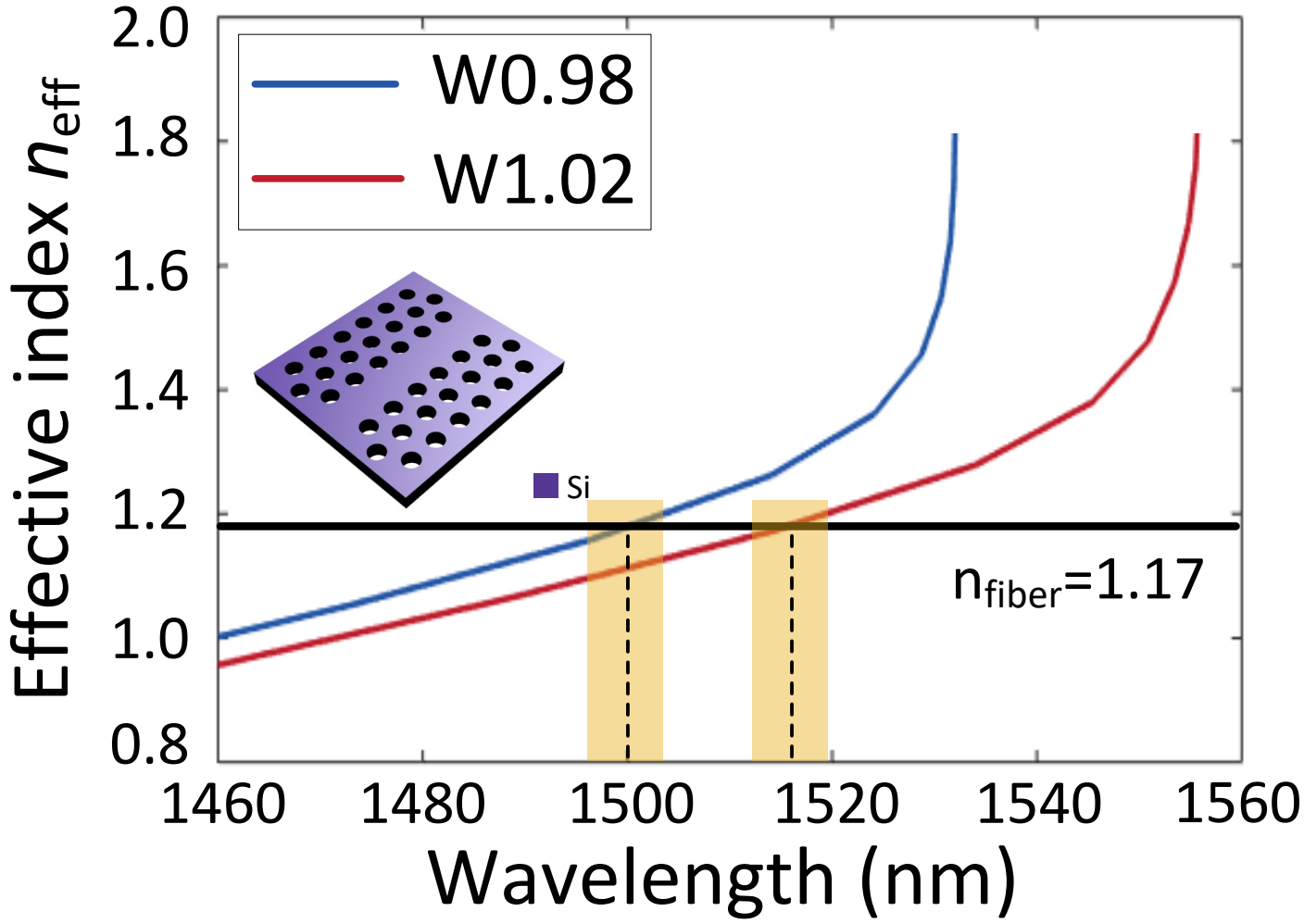

TE mode




TM mode

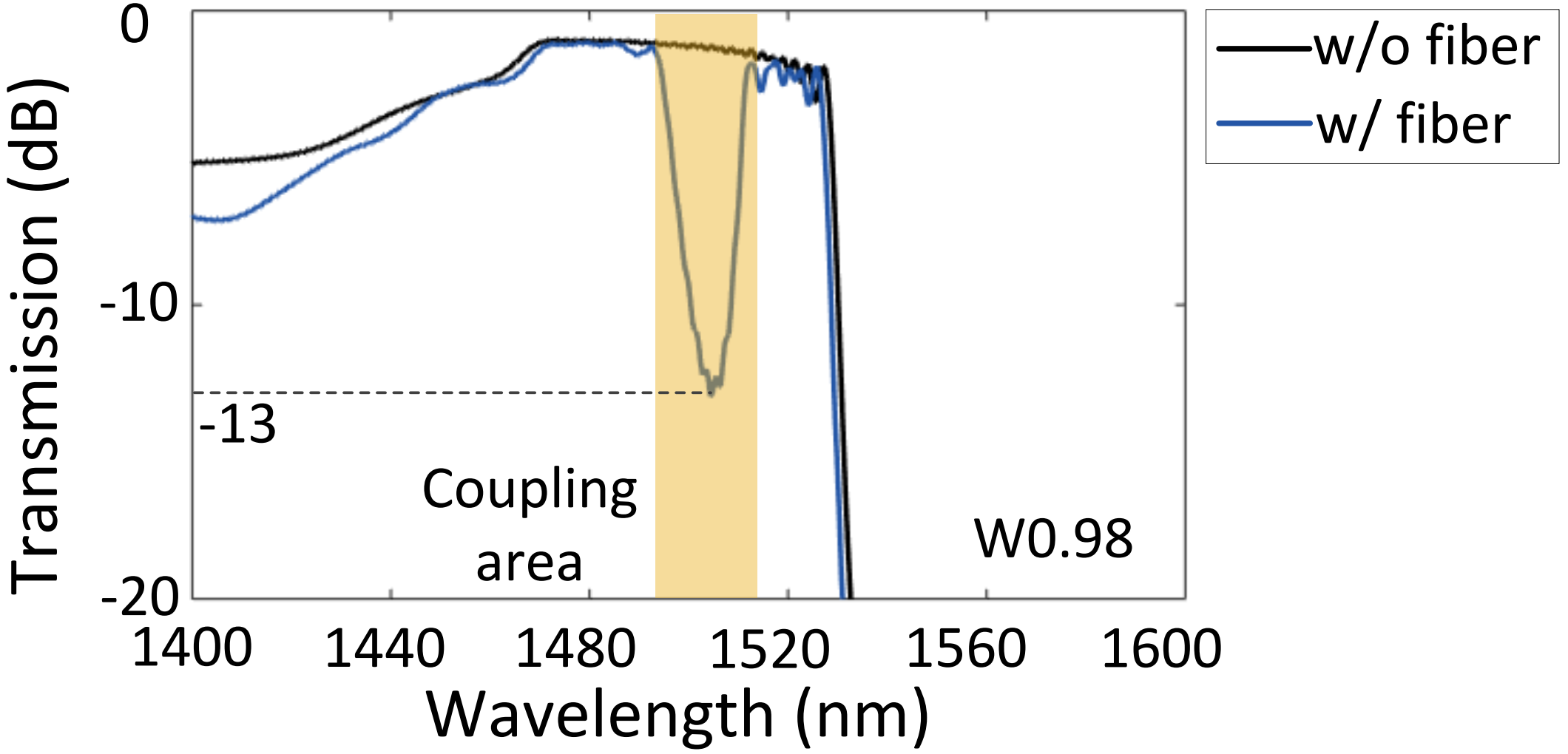
# n_eff & n_g discussion

- Effctive index map (W0.98 & W1.02)



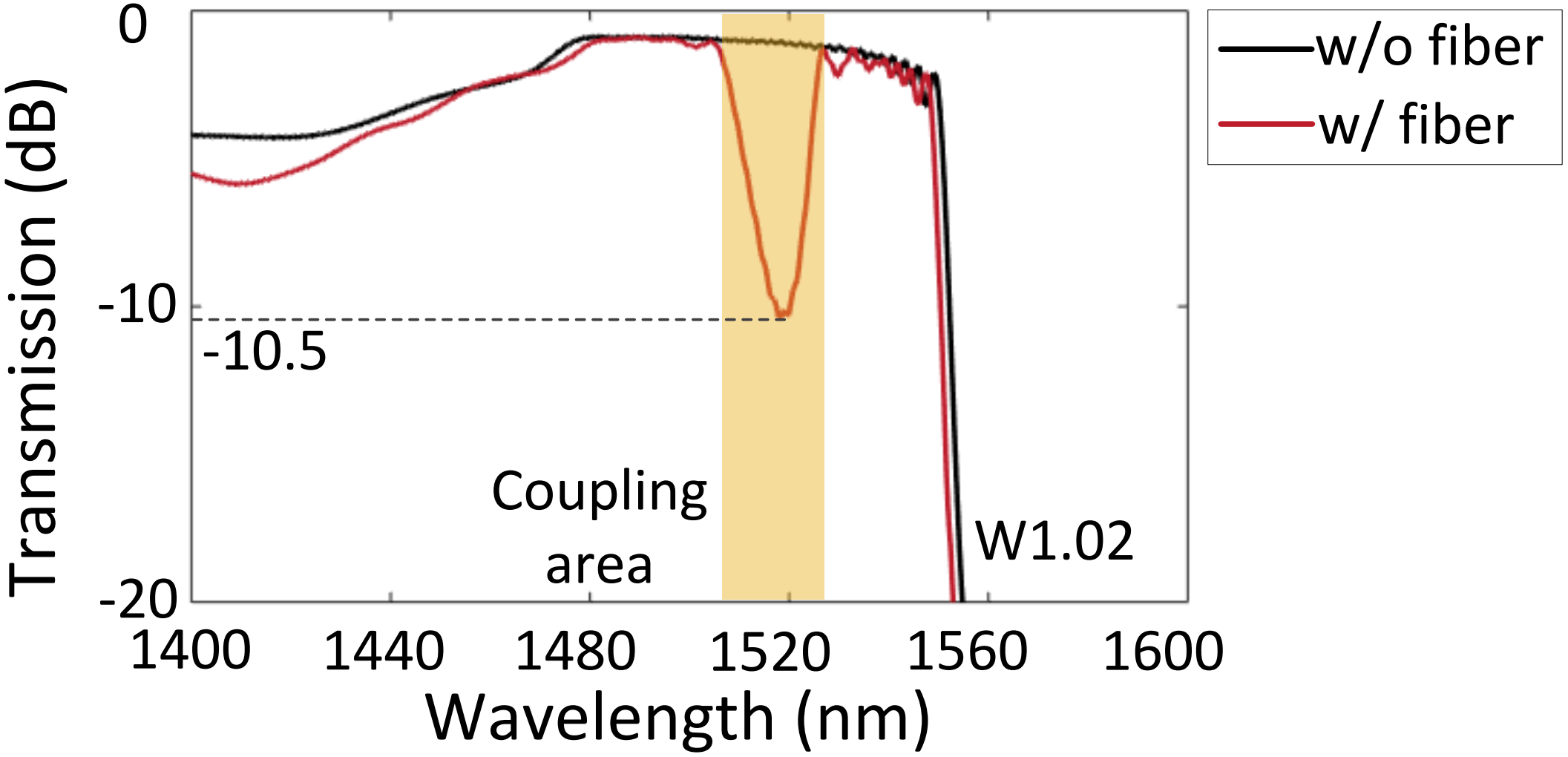
# n_eff & n_g discussion

## Transmission spectrum (W0.98)



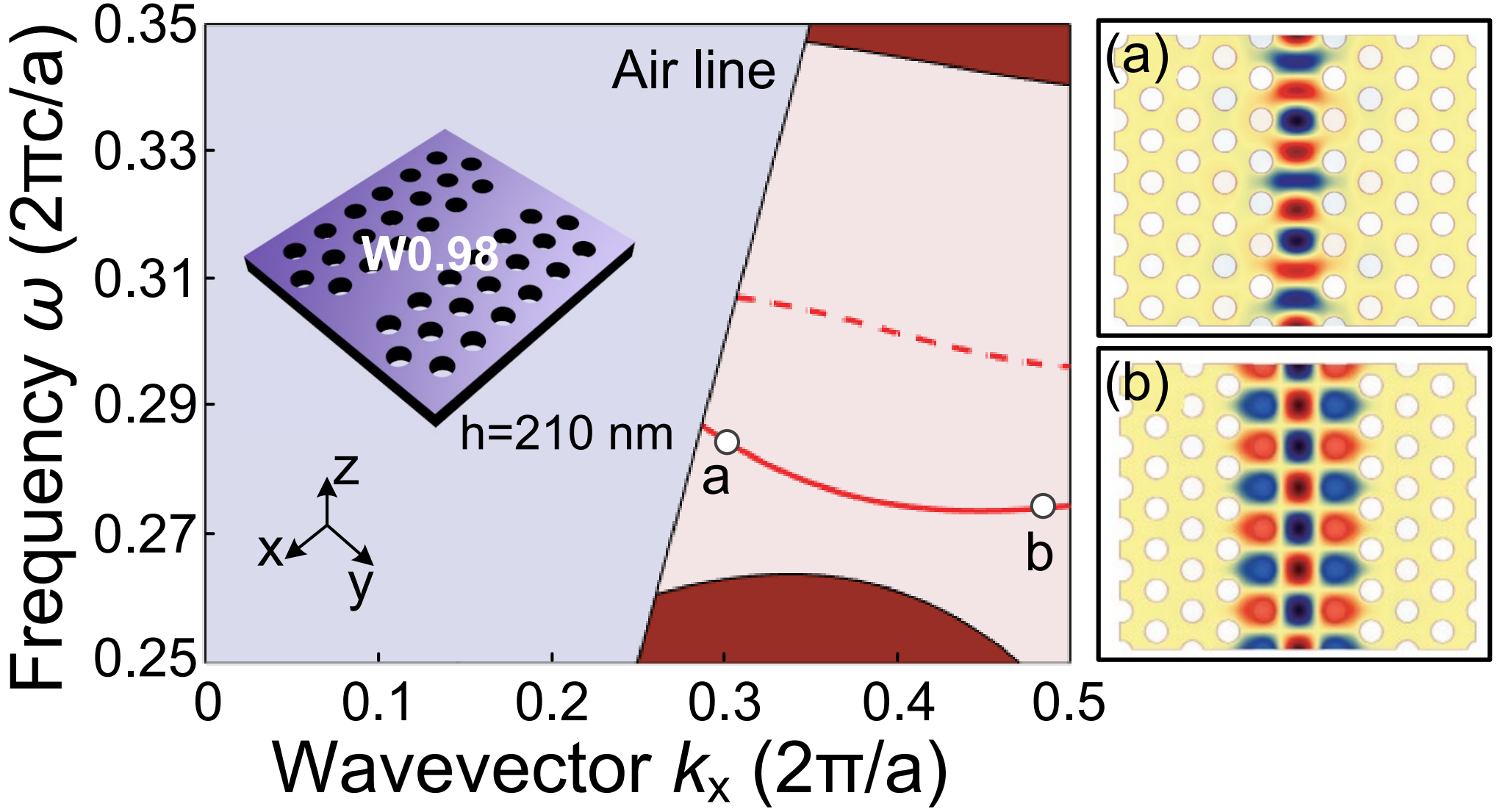
# n_eff & n_g discussion

## Transmission spectrum (W1.02)

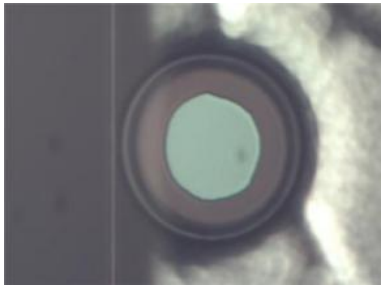


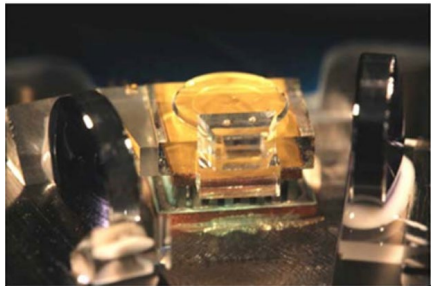
# n_eff & n_g discussion

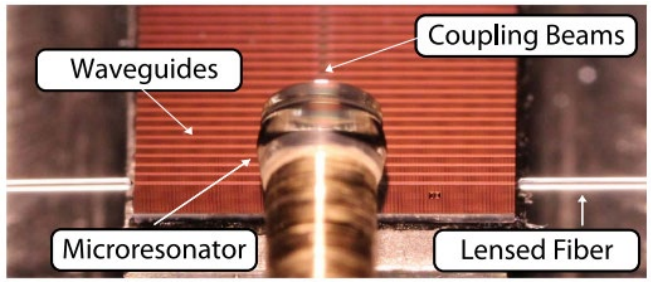
## Dispersion line map



# Comparing with other structures








| | Our work | A. A. Savchenkov, Opt. Lett. (2015) | M. Anderson, Opt. Lett. (2018) | |
|---|---|---|---|---|
| Cavity material | $SiO_2$ | $SiO_2$ | $SiO_2$ | $BaF_2$, $CaF_2$ |
| Waveguide material | Si | $SiO_2$ | $SiO_2$ | $SiO_2$ |
| Large index difference | √ | × | × | × |
| Robust | √ | × | × | √ |
| Efficiency | 99.5% | 62.9% | ~50% | 98.1% |
| Polarization | TE | TE/TM | TE/TM | TE/TM |

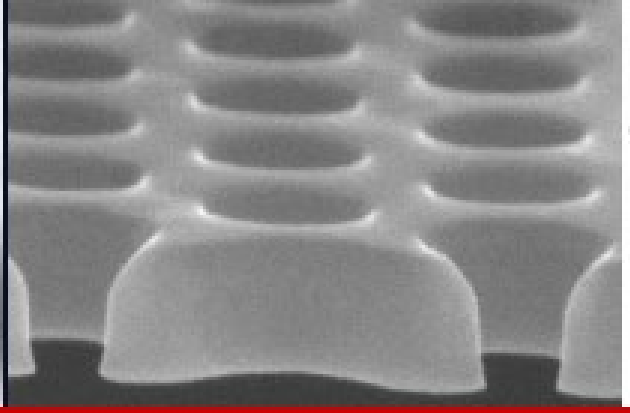
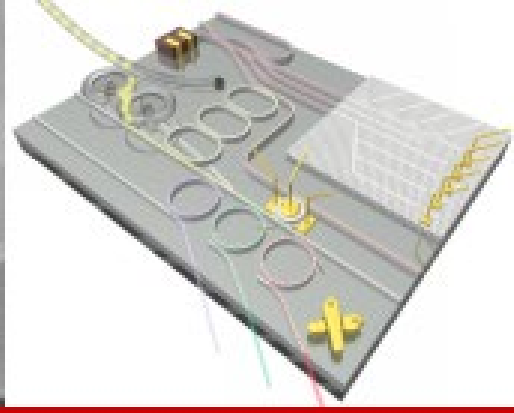
# Conclusion

- Merits of the proposed coupling structure
  - High coupling efficiency: 99.5% (~23 dB)
  - Robust and compact (10 μm × 110 μm).
  - CMOS compatible: easy to fabricate.
  - Can filter high order modes.
  - Polarization depended.

We demonstrated efficient coupling a low-index material microcavity to a high-index material waveguide.

Acknowledgement: This work was supported by JSPS KAKENHI Grant Number JP18K19036



**Thank you for your attention!**