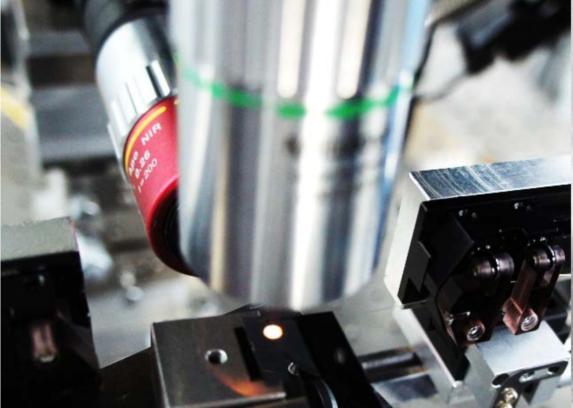
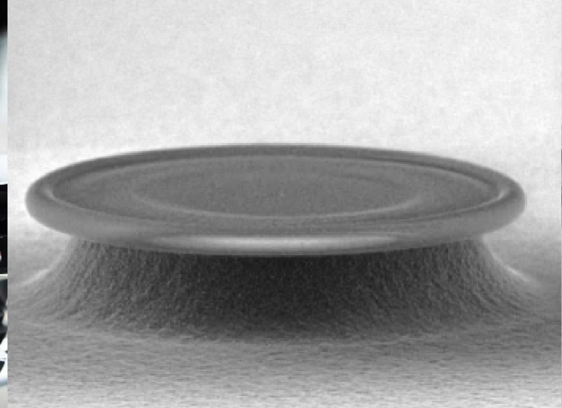
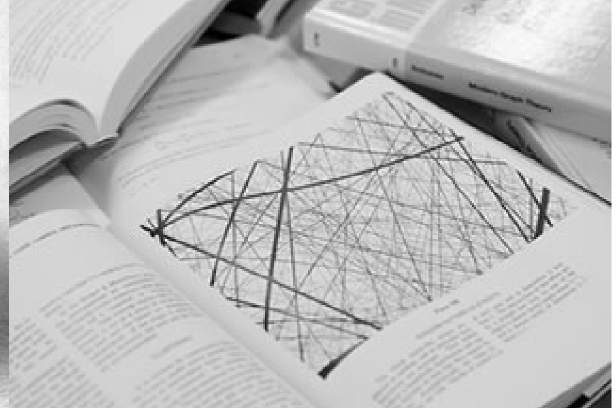
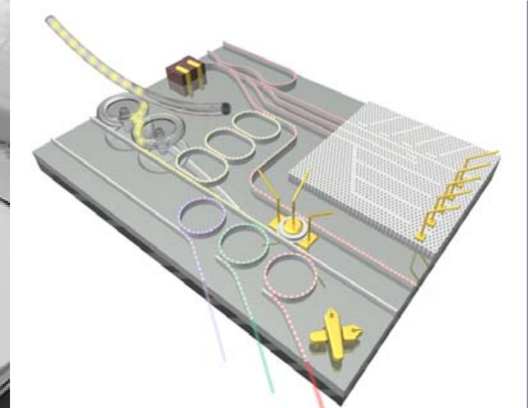





Conference on Lasers and Electro-Optics 2015 (CLEO2015)
[STu1I.4]

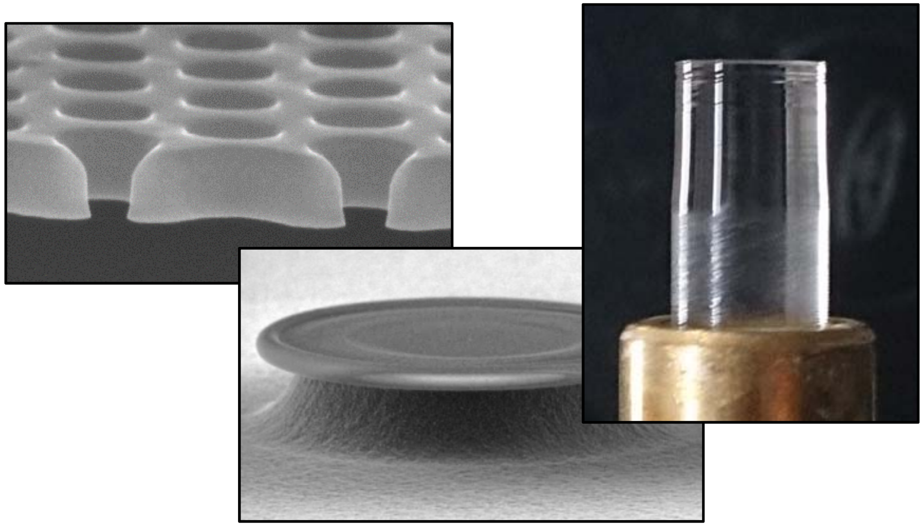
Low-power on-chip all-optical Kerr switch with silica microcavity

Wataru Yoshiki & Takasumi Tanabe

Department of Electronics and Electrical Engineering,
Faculty of Science and Technology,
Keio University, Japan

Microcavity-based all-optical switch

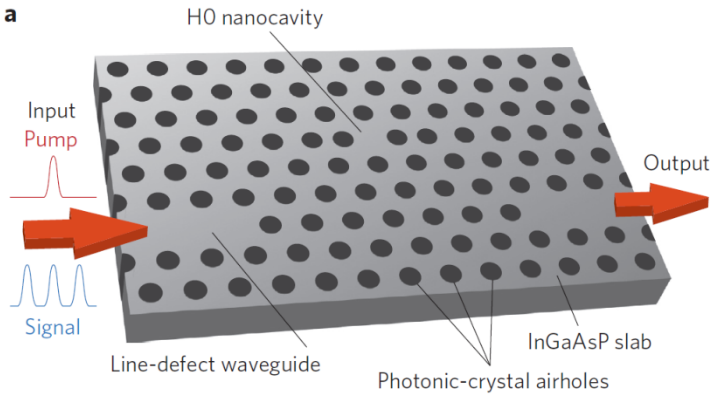
● Optical microcavities



Optical microcavities have
- High Q factor
- Small mode volume

$$P_{\mathrm{switch}} \propto V_{\mathrm{cavity}}/Q^2$$

● All-optical switch based on a PhC nanocavity

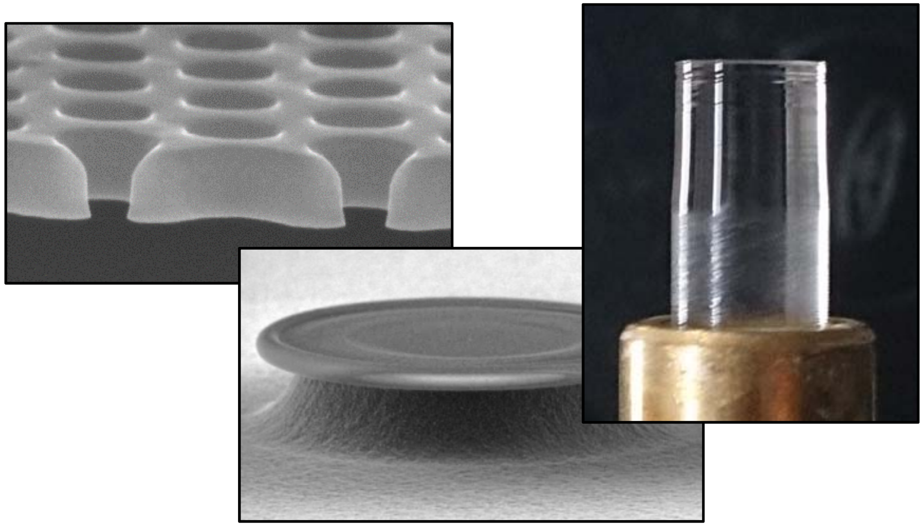


- **Principle**: Refractive index change by carrier
- **Record low energy consumption** (0.42 fJ)
- **Small foot print**(0.025 μm^3)
- **Fast switching** (>20GHz)

K. Nozaki et al., Nat. Photonics 4, 477- (2010)

Microcavity-based all-optical switch

- **Optical microcavities**



Optical microcavities have
- High Q factor
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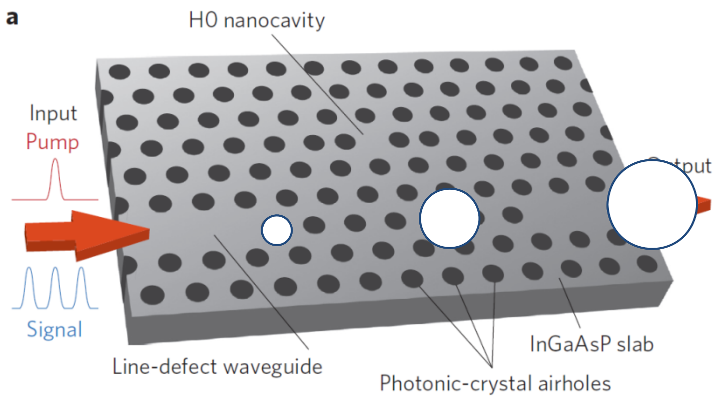
$$P_{\text{switch}} \propto V_{\text{cavity}}/Q^2$$

- **All-optical switch based on a PhC**



K. Nozaki et al., Nat. Photonics 4, 477- (2010)

- **Fast**

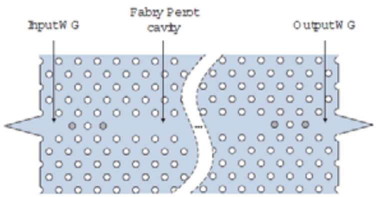
Large insertion loss
- **Free carrier absorption**
- Coupling loss
- Propagation loss

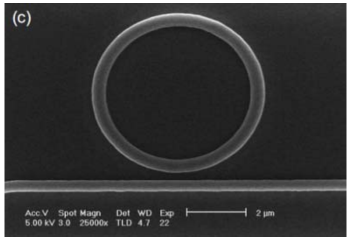
Not suitable for Loss-sensitive application (e.g. quantum optics)

All-optical switch using Kerr effect

Previously reported all-optical Kerr switches

Based on microcavity fabricated on a chip

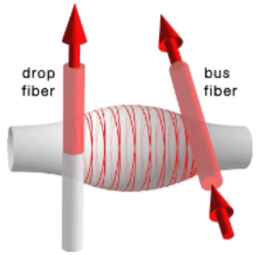


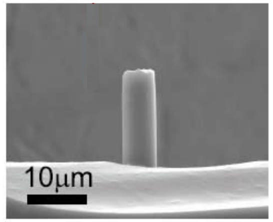


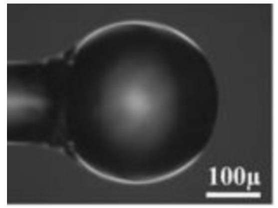
Low-Q (high control power) / Large insertion loss / On-chip

V. Eckhouse et al., Opt. Expres 20, 8524- (2012)
J. Pelc et al., Opt. Express 22, 3797– (2014)

Based on whispering gallery mode (WGM) microcavity







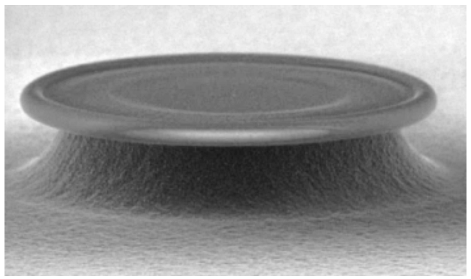
High-Q (Low control power) / Small insertion loss / Bulky

M. Pöllinger & A. Rauschenbeutel, Opt. Express 18, 17764– (2010)
N. Vukovic et al., Sci. Rep. 3, 2885-(2013).
I. Razdolskiy et al., Opt. Express 19, 9523- (2011).

High-*Q*
Low insertion loss

On-chip fabrication

Silica toroid microcavity



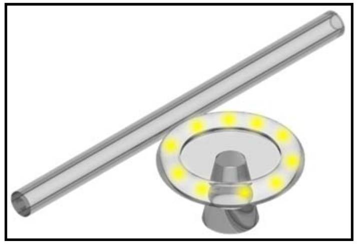
- **Ultra-high Q** ($>10^8$)
- **Small insertion loss**
- **On-chip fabrication**

Objective & Table of contents

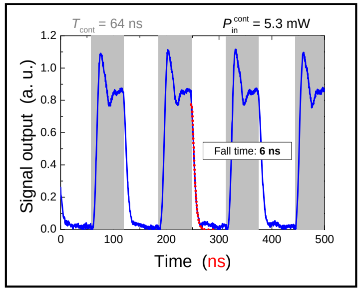
Objective

To achieve all-optical switching using Kerr effect
in a silica toroid microcavity with an ultra-low control power

Table of Contents

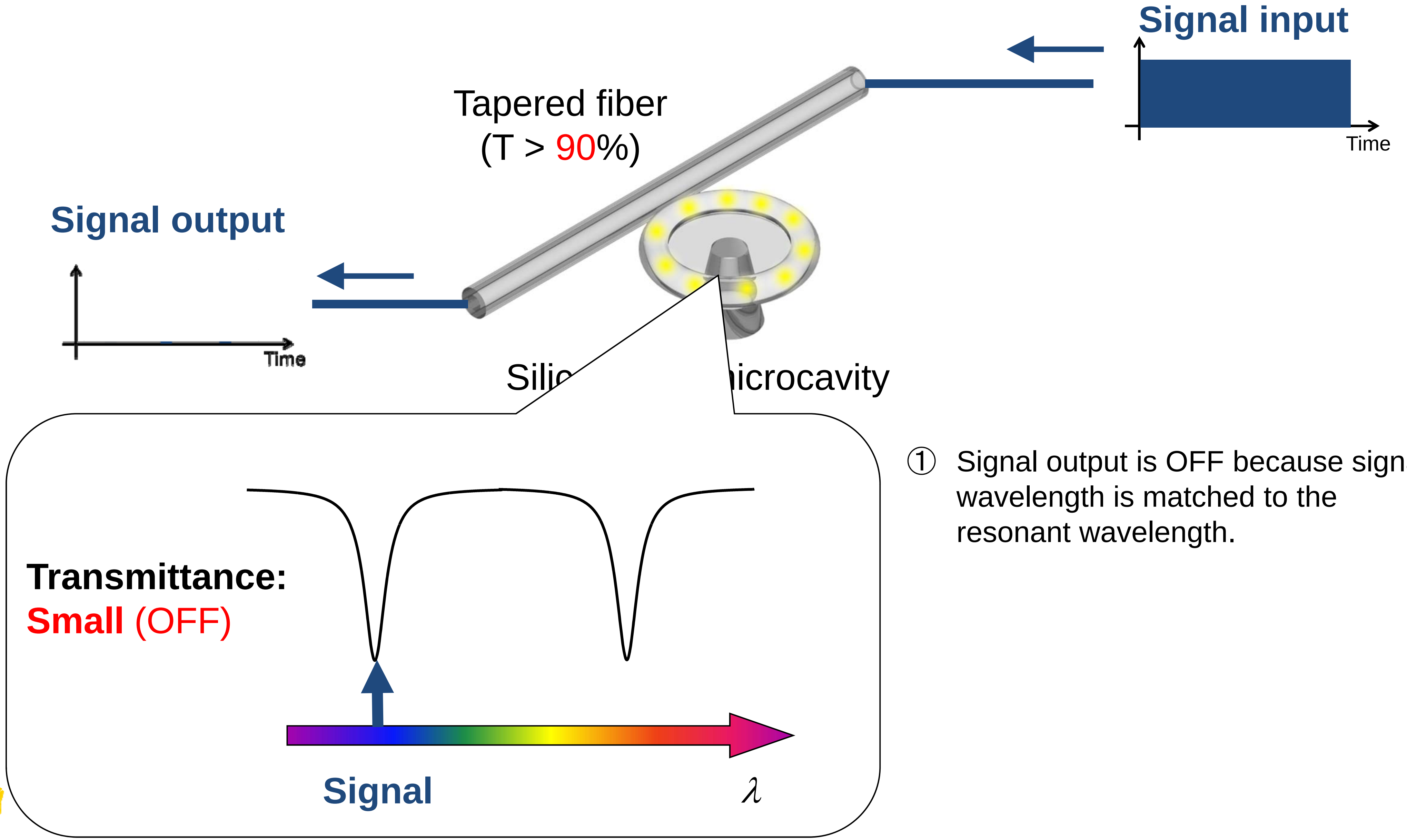


1. **Basics of optical Kerr switch**
   - Principle of switching
   - How to modulate refractive index



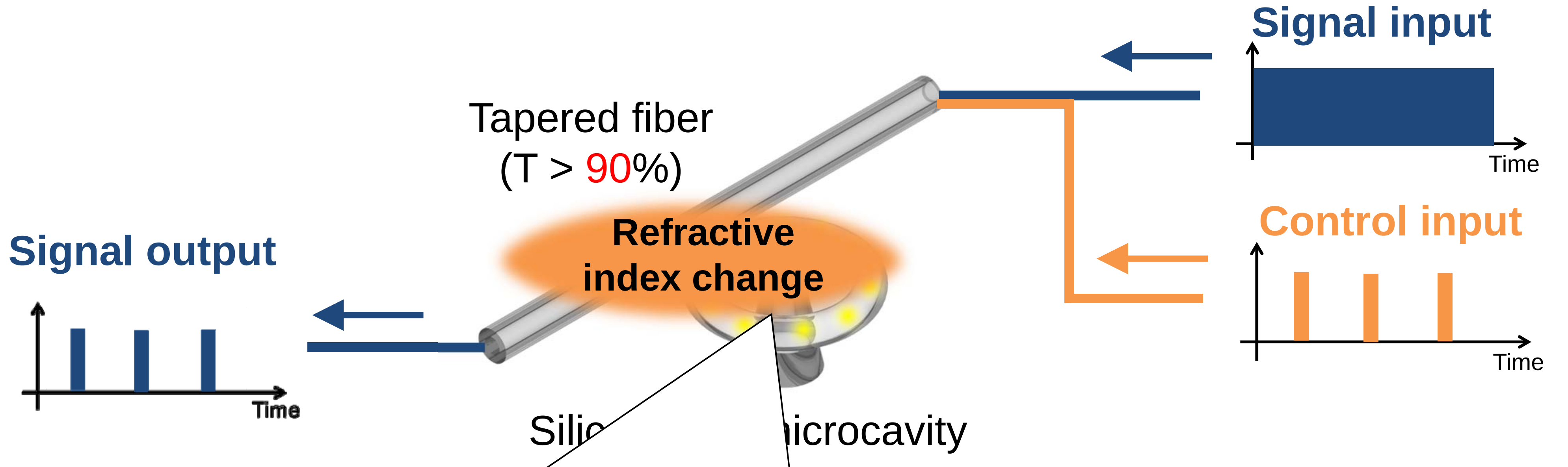
2. **Results**
   - All-optical switching operation
   - Dependence on control pulse width
   - Reduction of required control power
   - Comparison to other optical Kerr switches

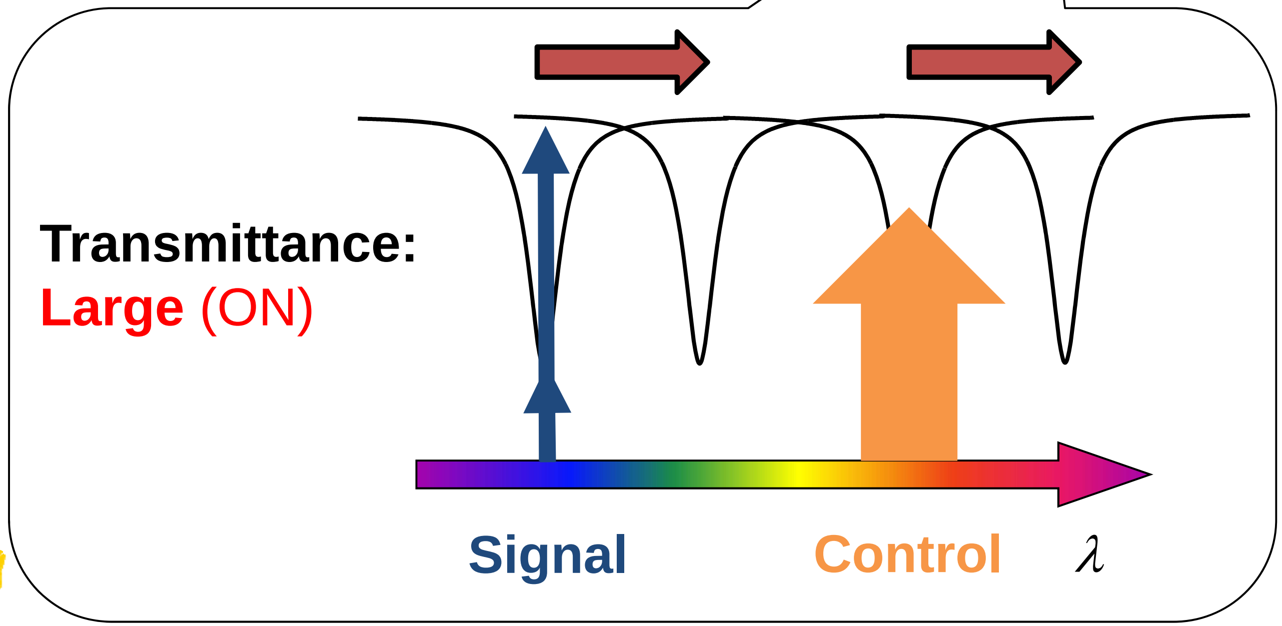
Principle of optical Kerr switch



① Signal output is OFF because signal wavelength is matched to the resonant wavelength.

Principle of optical Kerr switch





① Signal output is OFF because signal wavelength is matched to the resonant wavelength.

② Refractive index change is increased by strong control light.

③ Resonant wavelength shifts due to the refractive index change.

④ Signal output turns ON because signal and resonant wavelength are no longer matched.

How to modulate refractive index

- **Carrier-plasma effect**
  (∝ *Carrier density*)

Negligible in silica.
(Large bandgap for telecommunication band)

- **Thermo-optic (TO) effect**
  (∝ *Temperature*)

- **Optical Kerr effect**
  (∝ *Light intensity*)

1. TO effect is dominant in an equilibrium.

$$\Delta n_{\mathrm{Kerr}} \ll \Delta n_{\mathrm{TO}}$$

2. Kerr effect is much faster than TO effect

$$\tau_{\mathrm{Kerr}}\ (\mathrm{ps}) \ll \tau_{\mathrm{TO}}\ (\mu\mathrm{s\text{-}ms})$$

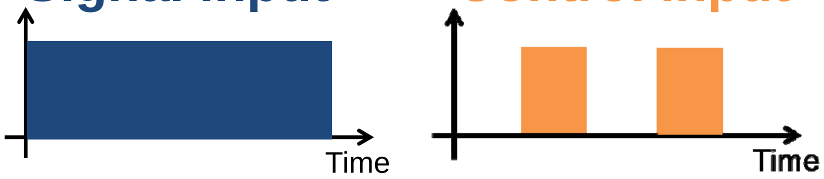
Kerr effect can be induced selectively by inputting short control pulses

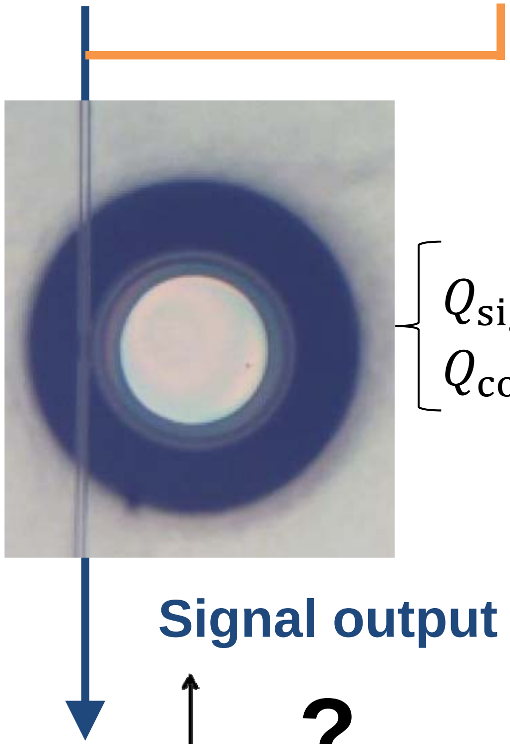
All-optical switching operation using Kerr effect (1)

Method

Pulse width: **1 ms**

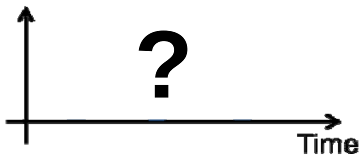
Signal input **Control input**



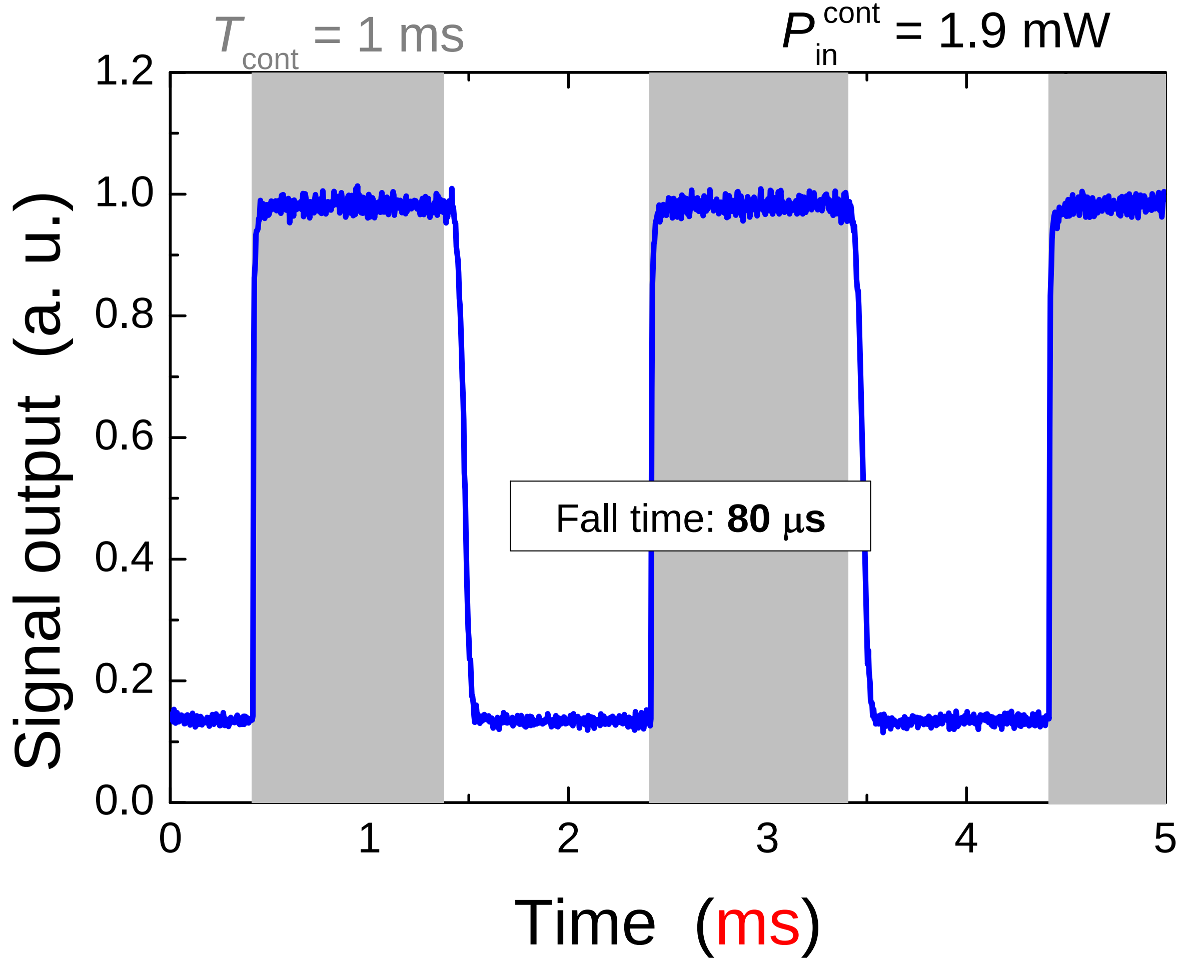


$$\begin{cases} Q_{\text{sig}} = 5.1 \times 10^6 \\ Q_{\text{cont}} = 3.3 \times 10^6 \end{cases}$$

Signal output



Results

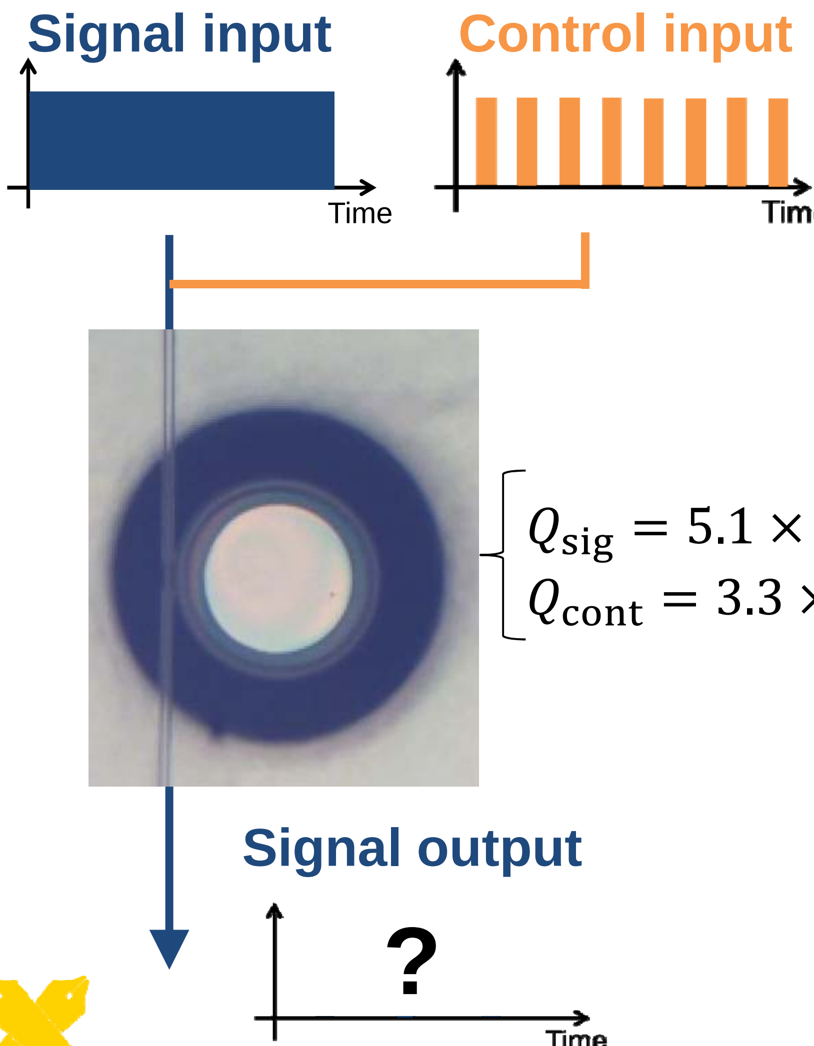


Switching based on TO effect

All-optical switching operation using Kerr effect (2)

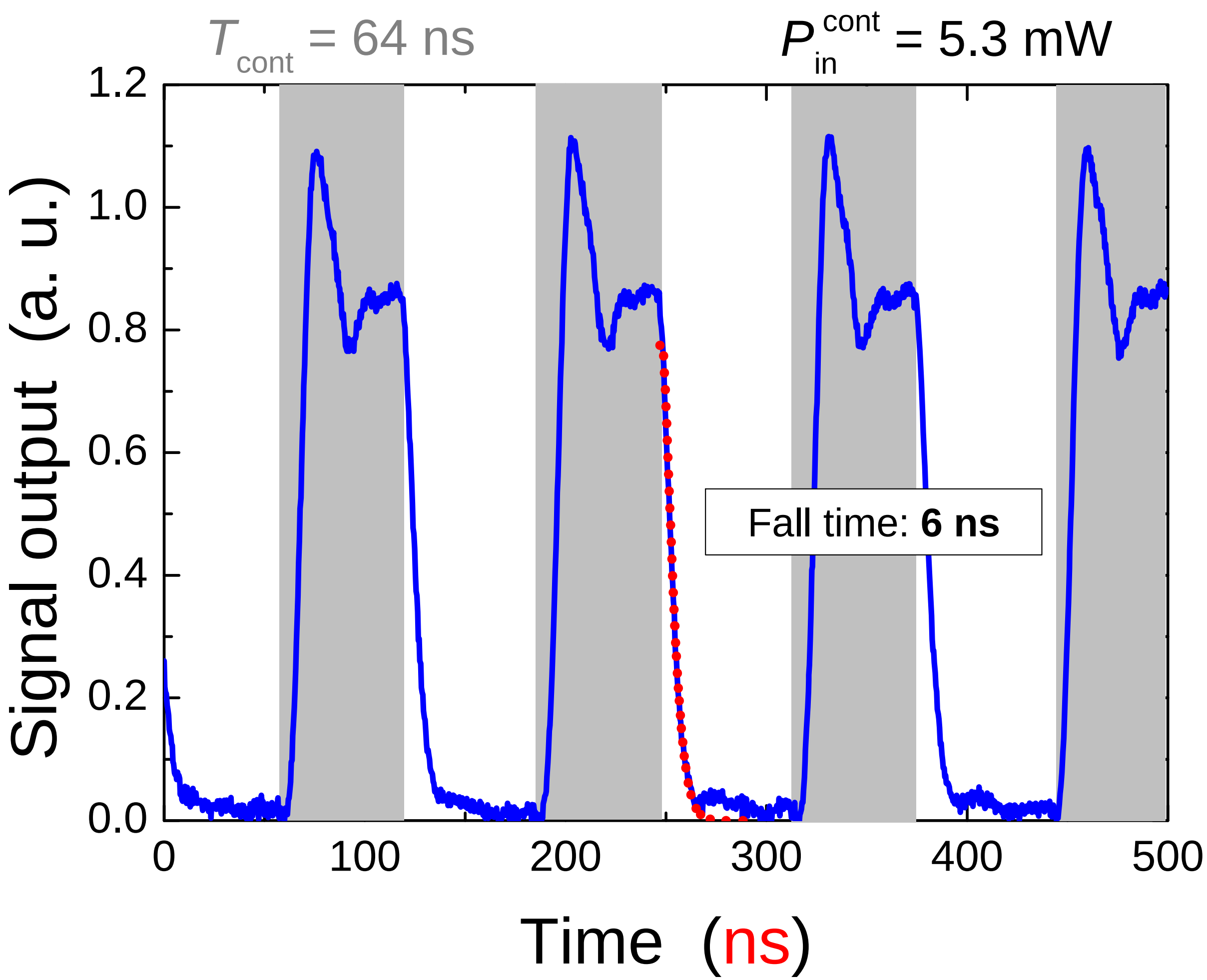
Method

Pulse width: **64 ns**



$$Q_{sig} = 5.1 \times 10^6$$
$$Q_{cont} = 3.3 \times 10^6$$

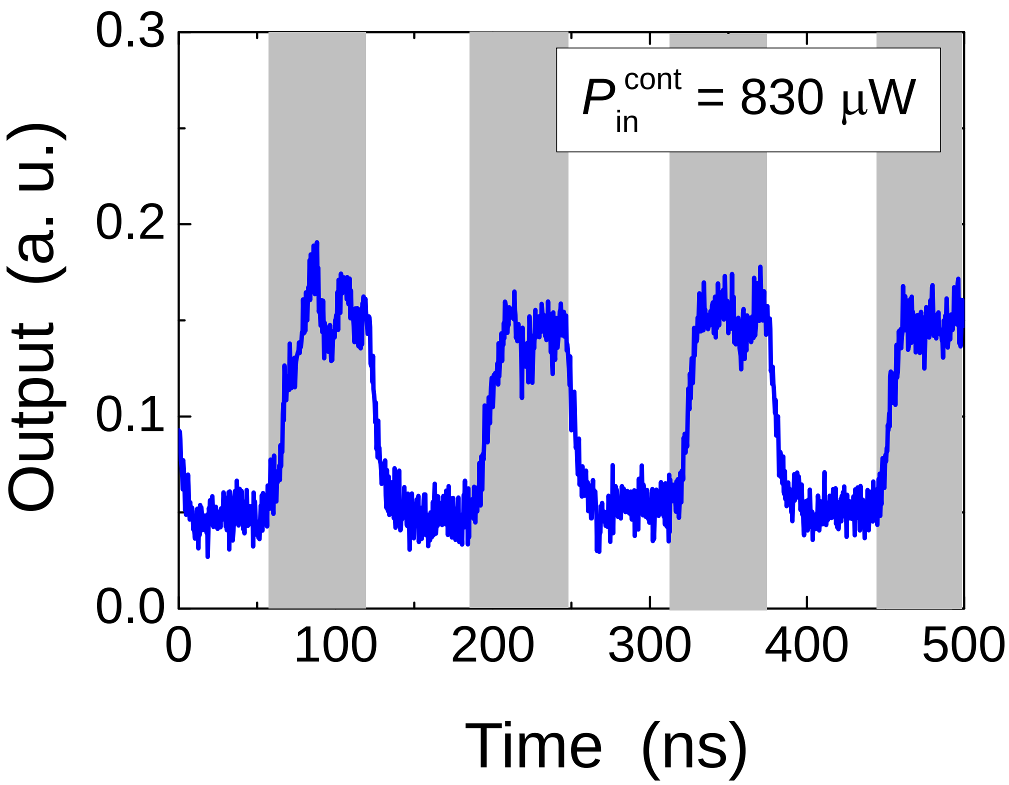
Results



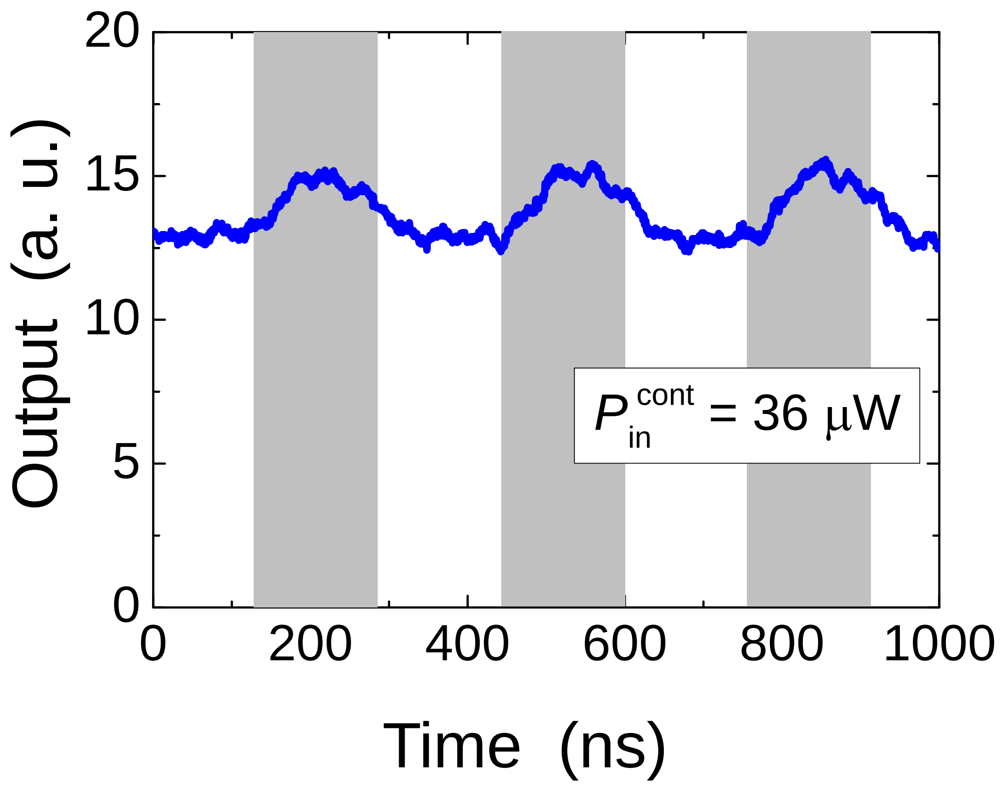
Switching based on Kerr effect

Reduction of required control power

- 830 μW @ Q~5×10^6



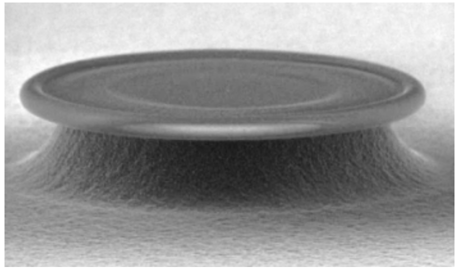
- **36 μW @ Q~4×10^7**



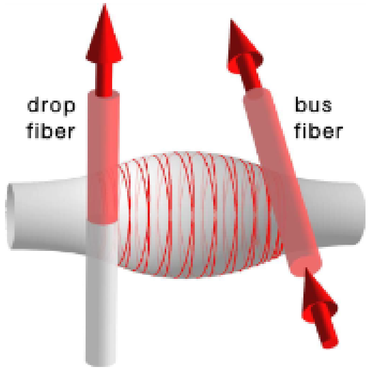
Modulation w/ control power of 36 μW was observed.

Comparison to other optical Kerr switches

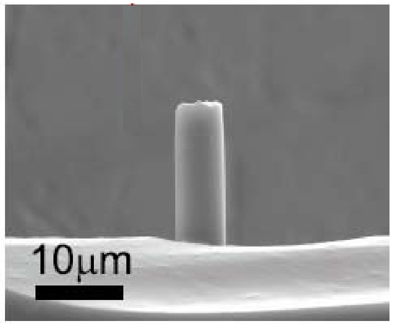
Silica toroid (This work)



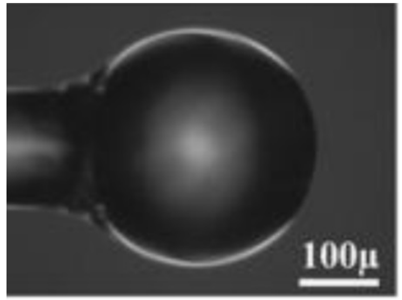
Silica bottle[1)]



a-Si:H cylinder[2)]

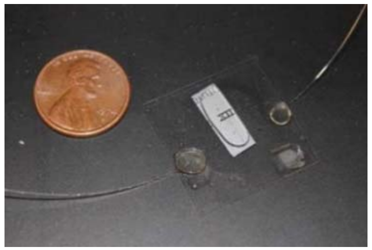


Hybrid silica sphere[3)]

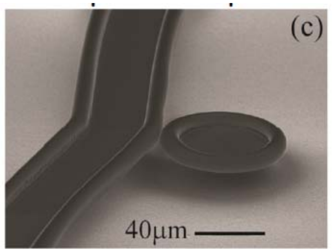


	Silica toroid (This work)	Silica bottle[1)]	a-Si:H cylinder[2)]	Hybrid silica sphere[3)]
Material	**Silica**	**Silica**	a-Si:H	Silica and polymer
Required Power	**36 μW**	50 μW	5 mW	1.5 kW
On-chip fabrication	**Yes**	No	No	No

Packaging in polymer[4)]



Integration w/ wg [5)]

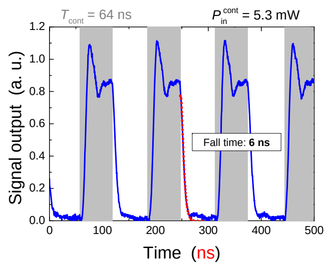


1) M. Pöllinger & A. Rauschenbeutel, Opt. Express 18, 17764– (2010)
2) N. Vukovic et al., Sci. Rep. 3, 2885-(2013).
3) I. Razdolskiy et al., Opt. Express 19, 9523- (2011).
4) X. Zhang & A. Armani, Opt. Express 21, 23592- (2013)
5) F. Monifi et al., IEEE Photon. Technol. Lett. 25, 1458- (2013)

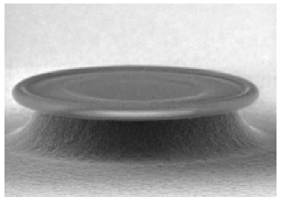
Summary & Conclusion

All-optical Kerr switch driven with control power of 36 μW and fiber transmittance of 90% was achieved experimentally.

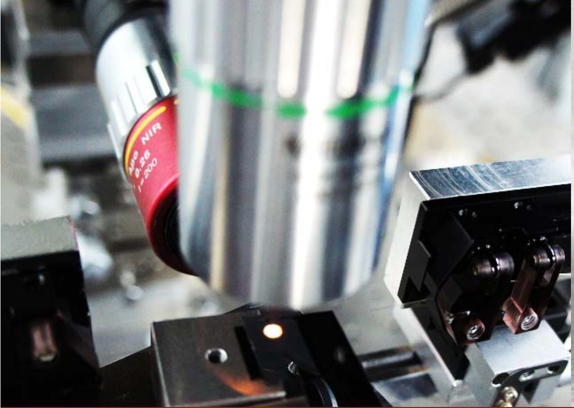
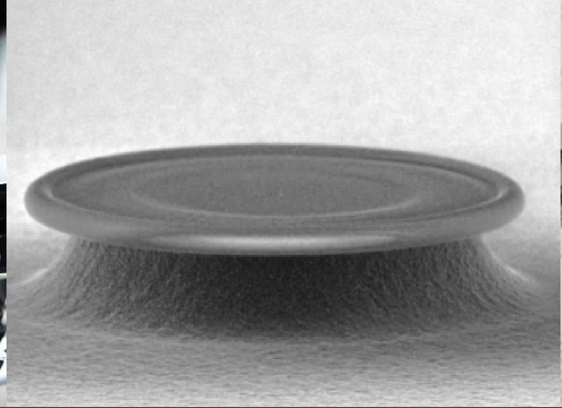
Novelties & superiorities

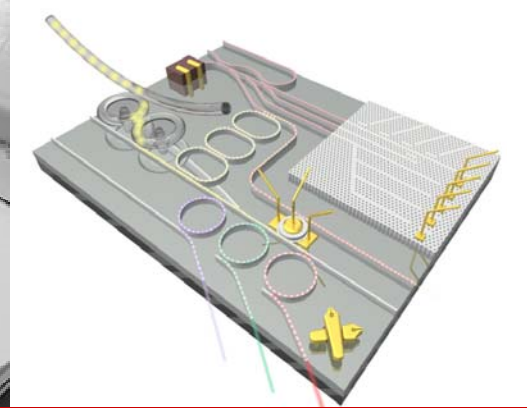


The control power of 36 μW is the lowest among previously reported all-optical Kerr switches.



All-optical Kerr switch which can be fabricated on chip was achieved by taking advantage of a silica toroid microcavity.



Thank you for your attention!

Acknowledgement

Keio Program for Leading Graduate School
“*Science for Development of Super Mature Society*”

For more information

W. Yoshiki and T. Tanabe, “All-optical switching using Kerr effect in a silica toroid microcavity,” Opt. Express **22**, 24332-24341 (2014).