[FTu3A.5] Revealing conditions required for achieving Kerr bistable memory based on whispering gallery mode cavity

Wataru Yoshiki & **Takasumi Tanabe***

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

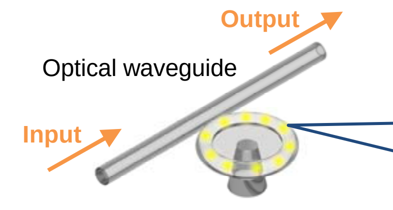
*takasumi@elec.keio.ac.jp

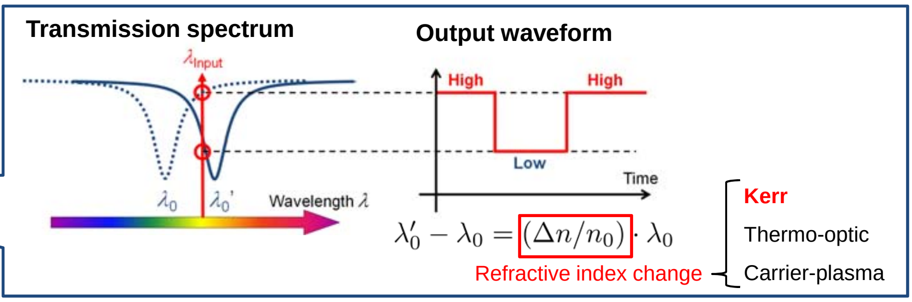
Abstract

We numerically studied conditions required for achieving a memory operation based on Kerr bistability in the presence of the thermo-optic effect by assuming a silicon nitride microring cavity and a silica toroid microcavity. We revealed the effect of the absorption on the performance to Kerr bistable memory and show the trade-off between switching speed and required power.

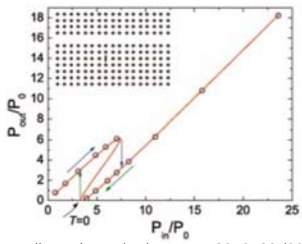
Background: *Kerr bistability in a microcavity*

Optical bistability in a microcavity





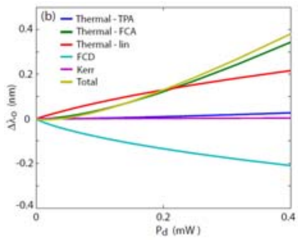
Kerr bistable memory



M. Fatih *et al.*, Appl. Phys. Lett. **83**, 2739 (2003).

Kerr bistable memory in an ideal material

Refractive index change in a Si



P. Barclay, *et al.*, Opt. Express **13**, 801- (2005).

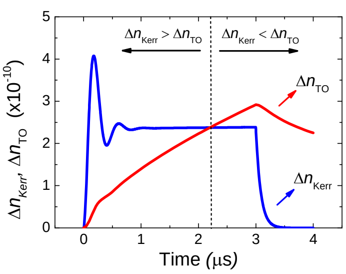
Kerr can be easily overwhelmed by other effects

Objective

- Study the required detuning & coupling between the cavity and the waveguide to achieve Kerr bistable memory in the presence of TO effect.
- Demonstrate the trade-offs between switching speed and required power.

Strategy

Kerr effect vs TO effect

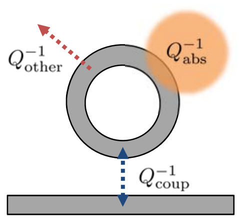


Fast switching speed (i.e. low-Q_{load}) is necessary for avoiding influence from TO effect.

$$\text{Speed} \propto Q_{\text{load}}^{-1}$$

W. Yoshiki and T. Tanabe, J. Opt. Soc. Amer. B **29**, 3335-3343 (2012).

Quality factor



Loaded quality factor

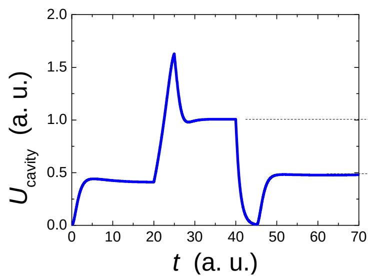
$$Q_{\text{load}} = \omega_0 \tau_{\text{load}}$$
$$= \omega_0 (\tau_{\text{abs}}^{-1} + \tau_{\text{other}}^{-1} + \tau_{\text{coup}}^{-1})^{-1}$$

τ_{abs}^{-1} : Absorption loss (material)

τ_{other}^{-1} : Other intrinsic loss (structure)

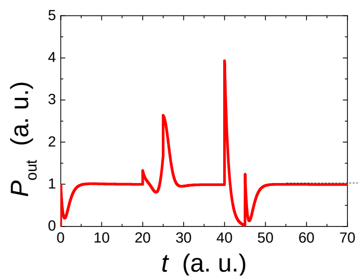
τ_{coup}^{-1} : Leakage to waveguide (**position of waveguide**)

An example of Kerr memory operation



- The light energy in a cavity U_{cavity}

Bistability

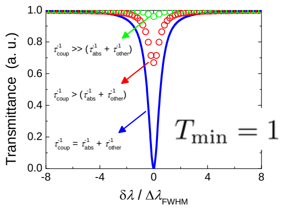


- The output power P_{out}

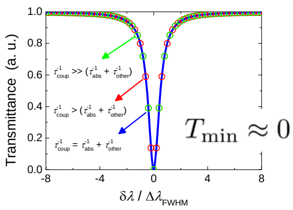
No bistability

Transmittance

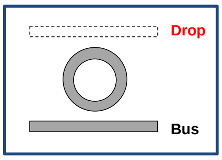
$\tau_{coup}^{-1} \gg \tau_{abs}^{-1} + \tau_{other}^{-1}$



$\tau_{coup}^{-1} = \tau_{abs}^{-1} + \tau_{other}^{-1}$

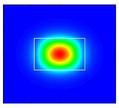


- τ_{abs}^{-1} → **Inducing additional heat**
- τ_{other}^{-1}
  - τ_{scat}^{-1} → : Scattering loss
  - τ_{drop}^{-1} → : **Leakage to drop waveguide**



Calculation model

Platforms

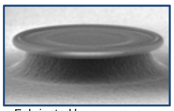
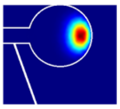
J. Levy et al., Nat. Photonics 4, 37- (2010)

Si_3N_4 ring

Bandgap :250 nm

Q_{abs} : 5.3x10[6]

A. Gondarenko *et al.*, Opt. Express **17**, 11366- (2009)

Fabricated by our group

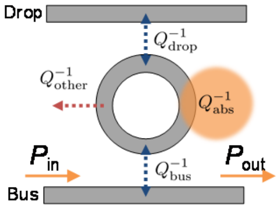
Silica toroid

Bandgap :140 nm

Q_{abs} : 2x10[11] ($Q_{water} \cong 10^8$)

H. Rokhsari *et al.*, Appl. Phys. Lett. **85**, 3029- (2004)
A. Savchenkov et al., Phys. Rev. A **70**, 051804 (2004)

Coupled mode theory (CMT)



- Cavity mode: $\frac{da}{dt} = \left(j\omega_0' - \frac{1}{2\tau_{load}}\right)a + \sqrt{\frac{1}{\tau_{bus}}}\exp(j\theta)s_{in}$
- Input mode: $s_{out} = s_{in} - \sqrt{\frac{1}{\tau_{bus}}}\exp(-j\theta)a$
- Resonant frequency: $\omega_0' = \frac{n_0}{n_0 + \Delta n_{Kerr} + \Delta n_{TO}}\omega_0$
- Refractive index change: $\Delta n_{Kerr} = \frac{n_2 c}{n_0 V}U_{cavity}$
  $\Delta n_{TO} = n_0 \xi T$

W. Yoshiki and T. Tanabe, J. Opt. Soc. Amer. B **29**, 3335-3343 (2012).

Required condition

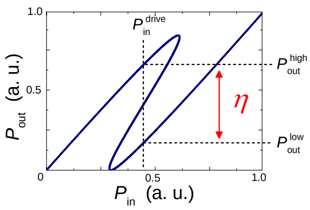
$\eta = (P_{out}^{high} - P_{out}^{low})/P_{out}^{high} \gg 0$

: Contrast at output.

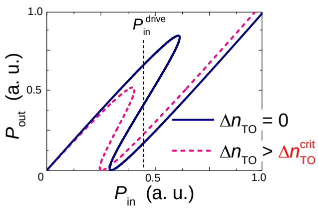
$\sigma = \Delta n_{TO}^{end}/\Delta n_{TO}^{crit} < 1$

: Induced heat during memory operation

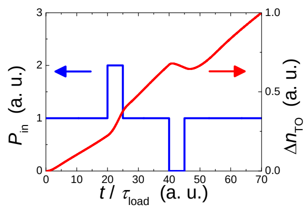
η : contrast between P_{out}^{high} and P_{out}^{low}



Δn_{TO}^{crit} : critical Δn_{TO}



Δn_{TO}^{end} : Δn_{TO} at the end of memory operation

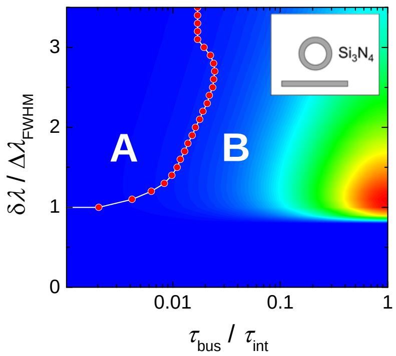


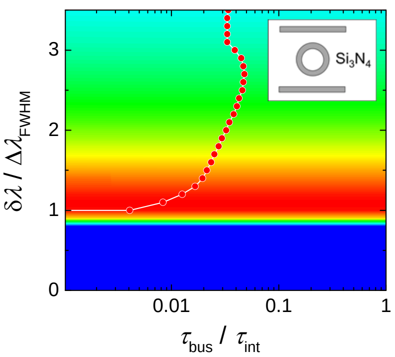
Results

Required value of τ_{bus} and detuning $\delta\lambda$

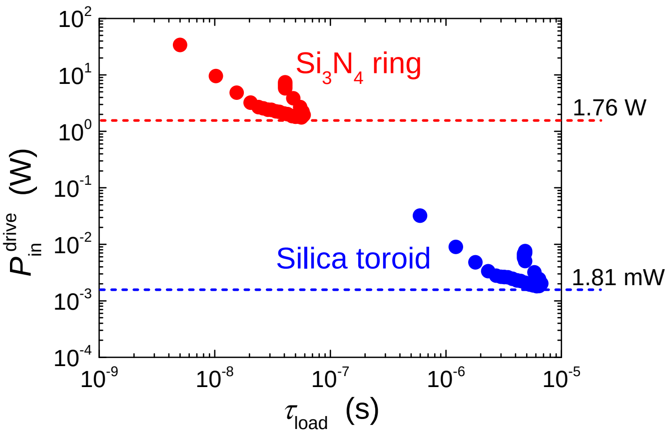
0 — 1 η: Output contrast obtained by static analysis

A: Usable area ($\sigma < 1$)
B: Unusable area ($\sigma > 1$)
} Obtained by transient analysis





Trade-off between τ_{load} and P_{drive}



- Trade-off between τ_{load} and P_{drive}
- P_{drive} cannot be reduced when Q_{abs} is large.

Conclusion

We revealed τ_{bus} and $\delta\lambda$ values required for achieving a Kerr bistable memory in the presence of TO effect. In addition, we demonstrated impact of Q_{abs} on required power and switching speed.

Acknowledgement:

総務省 MIC Ministry of Internal Affairs and Communications

Strategic Information and Communications R&D Promotion Programme (SCOPE), from the Ministry of Internal Affairs and Communications of Japan

The Leading Graduate School program for "Science for Development of Super Mature Society" from the Ministry of Education, Culture, Sports, Science and Technology of Japan