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2017

Li, Z. Y., Huang, J. G., Yang, Z. C., Hao, Y. L., Jin, Y. F., Wu, J. H., Chen, T. N. & Liu, A. Q. (2017). A reconfigurable coupled optical resonators in photonic circuits for photon shutting. 2017 19th International Conference on Solid-State Sensors, Actuators and Microsystems (TRANSDUCERS), 619-621. https://dx.doi.org/10.1109/TRANSDUCERS.2017.7994125

https://hdl.handle.net/10356/151467

https://doi.org/10.1109/TRANSDUCERS.2017.7994125

# A RECONFIGURABLE COUPLED OPTICAL RESONATORS IN PHOTONIC CIRCUITS FOR PHOTON SHUTTING

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## ABSTRACT

We demonstrate a novel way to control the coupling rate in coupled ring resonators by controlling the relative position of the nanowires between the two cavities to modulate the resonance frequencies, compared to state of the art where the coupling rate between different photonic cavities is extremely low due to less spatial overlapping of the optical modes of both cavities. A new system is presented and experimental results show that by tuning the coupling rate, the coupled ring resonators can be stimulated at the same time due to the same resonance frequency. This study will open new ways to manipulate coupled photonic cavities in the silicon photonic circuits and will benefit the development of the coupled optical cavities to achieve advanced functions.

## KEYWORDS
Ring Resonator, Coupling Rate, Nanowires

## INTRODUCTION

With high quality factor and small volume, photonic cavities are important components in integrated optical systems as registers or buffers to trap and store photons for processing both in classical and quantum information [1-4].

In order to achieve advanced functions of the optical cavity, it's desired to couple different optical cavities to perform complex functions. For examples, by coupling two distant optical cavities, the photon can be exchanged between each other, which is a requirement for the optical networks.

Traditional coupled photonic cavities are evanescently coupled and the coupling rate is determined by the spatial overlap of the optical modes of both cavities [5]. A key obstacle to further development of this platform is the ability to control the coupling rate between different photonic cavities so that photons can be exchanged between them to achieve signal processing and computational operation [6]. This is especially important for manipulating two distant cavities, where the coupling rate is extremely low due to less spatial overlapping [7-8].

In this paper, we demonstrate the photon shuttling between two coupled optical cavities controlled by the electrostatic force. It is achieved that the resonance frequencies of the two cavities are modulated by the nanowire and the coupling rate is determined by the relative position of the nanowires. In this structures, the photon coupling is well controlled and open a new door for the manipulations of two coupled optical cavities in the silicon photonic circuits.

## DESIGN OF THE SYSTEMS

Figure 1 shows the schematic of the coupled silicon ring resonators system. New system consists of two straight waveguides as control waveguide, two coupled ring resonators and two nanowires. The principle is as follows. The input light is pumped into the control waveguide and then couples into the cavity 1. In the absence of the silicon nanowires, due to the difference in the resonance frequency from fabrication process between the two cavities and small spatial evanescent wave overlapping, the photon in the cavity 1 can't couple into the cavity 2.

On the other hand, with the silicon nanowires and by controlling the position of the nanowires between the cavities using the electrostatic force, the resonance frequency of the two cavities can be tuned to the same for the varied displacement between photonic cavities. Then the photon in cavity 1 can be transferred from cavity 1 to cavity 2 due to a large coupling rate.

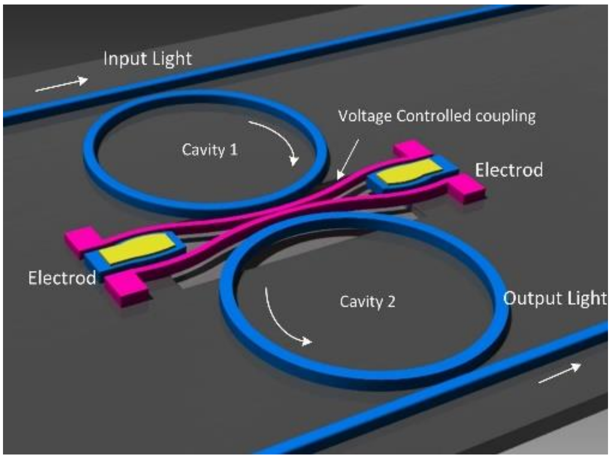


*Figure 1: Schematic illustration of proposed coupled ring resonator with coupling coefficient tuned by the electrostatic force.*

## FABRICATION PROCESSES

The scanning electron microscope (SEM) graphs of the coupled ring resonators system is shown in Figure 2. The ring resonator is fabricated with the standard CMOS compatible nano photonic process on silicon-on-insulator (SOI) wafer with structure layer thickness of 220nm [9-10].

The waveguides and ring resonators are first transferred from the mask and then patterned by deep UV lithography, etched by plasma dry etching. The total structure is deposited by a layer of $SiO_2$ cladding (2μm thick), which is deposited using plasma enhanced chemical vapor deposition (PECVD). In the release process, a 50-nm amorphous silicon layer is used as the hard mask to protect the structures not to be released.

Then the buried-oxide layer is removed using HF-vapor with precise time control. A pair of grating coupler is used to couple light into and out of device The two ring resonators both have a radius of 20μm and the coupling gap between the ring resonator and the nanowire is 200nm. The distance between the two nanowires is 200nm. The cross section of the nanowire is 200nm in width and 220nm in height. The air gap between the nanowire and the electrode is 400nm.

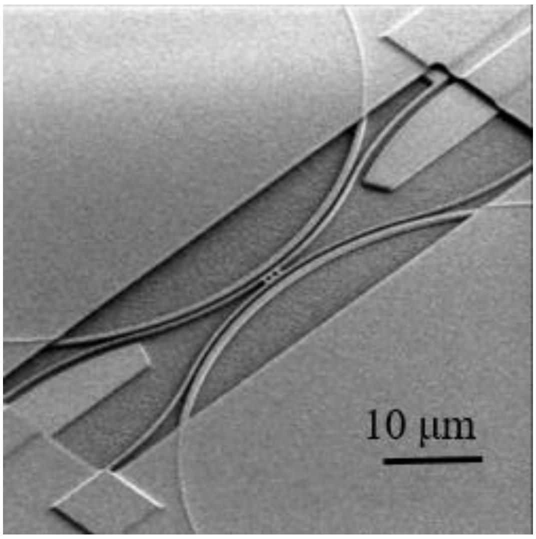


*Figure 2: SEM image of fabricated coupled ring resonator.*

## EXPERIMENTAL RESULTS

Figure 3 shows the transmission spectrum of the two ring resonators with difference in resonance frequency Δw. The ring resonator has an optical quality factor of 30K.

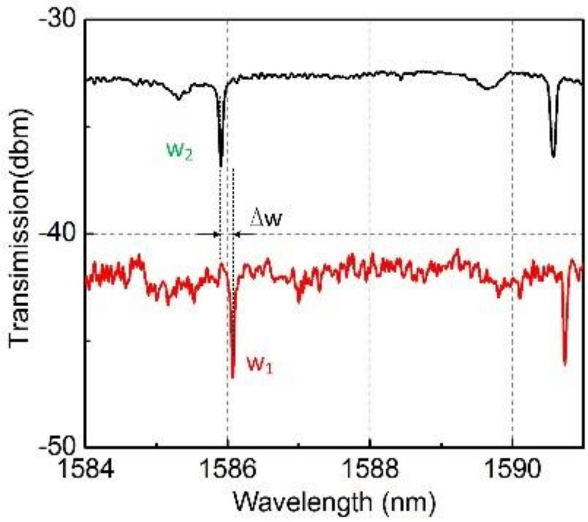


*Figure 3: The transmission spectrum of the two ring resonators with difference in resonance frequency.*

It can be seen that the frequency is different due to the fabrication deviation. The two coupled ring resonators can be understood as two coupled mechanical oscillators as shown in Figure 4(a). When the resonance frequency is different, it's hard to stimulate the two oscillators at the same time. By tuning the coupling rate, the two oscillators can be stimulated at the same time due to the same resonance frequency.

The principle is further explained in the frequency diagram as shown in Figure 4(b). The shuttling between the cavities is forbidden when the frequency is different. Increasing the pumping amplitude, the two frequencies are same at the certain region of the frequency diagram. The photon shuttling is open at this region and the photon in cavity 1 is transferred to cavity 2.

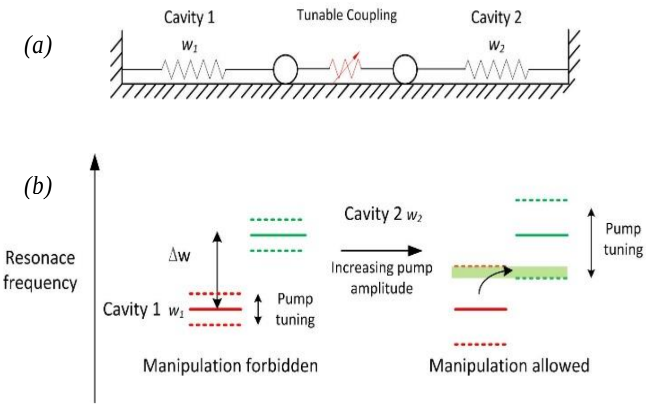


*Figure 4: (a) Schematic of the coupled photonic cavity, which is analog to coupled mechanical resonators with coupling tunable. (b) Schematic of the manipulation in frequency diagram.*

Figure 5 shows the simulation result of the resonance frequency of the two ring resonators as a function of the nanowire displacement. It can be seen that the two cavities have the same frequencies when the displacement is about 4 nm.

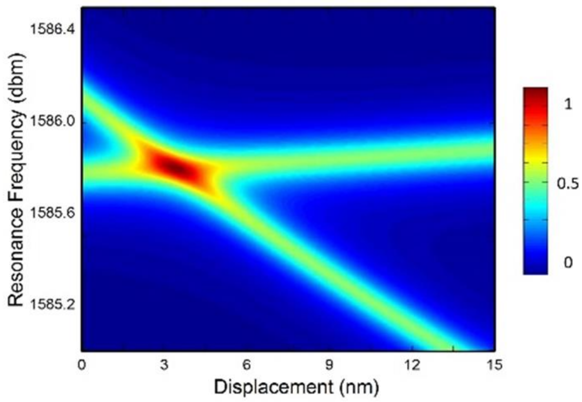


*Figure 5: The resonance frequency of the two ring resonators as a function of the nanowire displacement.*

The experiment is first verified by pumping a CW light into the cavity 1 and detect at the output of cavity 2 as shown in Figure 6 with the critical matching occurring at the 1585.9nm. A single light of 1585.9nm is pumped into the cavity 1 and detect at the output of the cavity 2 as shown in Figure 7.

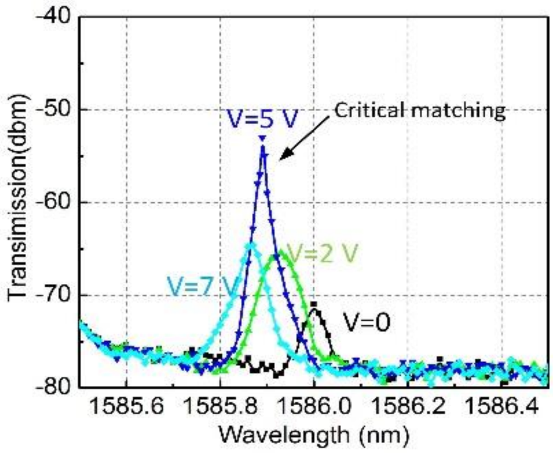


*Figure 6: Experiment result of the energy in cavity 2 by pumping CW light into cavity 1 with voltage control. The critical coupling is achieved when the voltage is 5V.*

It can be seen from Figure 6, the critical coupling is obtained when the voltage is 5V. This is because the optical coupling is the maximum is due to displacement of the nanowire is changed.

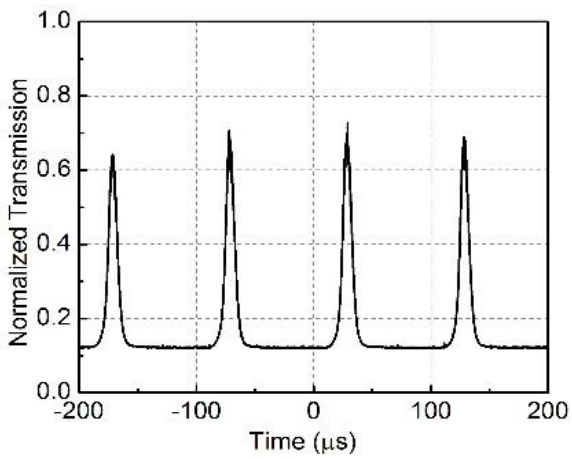


*Figure 7: The time domain traces of the energy in cavity 2 by pumping 1585.9 nm light into cavity 1 with beam oscillation.*

## CONCLUSIONS

In conclusion, we demonstrate a novel way to design a new system to achieve good coupling between two ring resonators even the resonant frequencies are not the same from fabrication process. The principle is to use silicon nanowires between the ring resonators to tune their resonant frequency. This study will open new ways to manipulate coupled photonic cavities in quantum information or other field.

## ACKNOWLEDGEMENTS

This work was supported by Singapore National Research Foundation under the Incentive for Research & Innovation Scheme (Grant No. 1102-IRIS-05-01) administered by PUB, and under the Competitive Research Program (Award No. NRF-CRP13-2014-01 and Project No. NRF2014NRF-CRP001-002), and Singapore Ministry of Education (Grant No. RG89/13).

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