# Proposal of Optical Thresholder Consisting of Two MZIs with Nonlinear Micro-Ring Resonator

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We propose a novel optical thresholder having a flat power transfer function both in low-level and high-level output. Fig. 1 shows a configuration of the optical thresholder consisting of a single MZI with a ring resonator in the upper arm and a phase shifter in the lower arm. The bar path coupling coefficient of optical electric fields between the straight waveguide and the ring waveguide is denoted by $\gamma_R$. The phase shifter is used to adjust the thresholding characteristics. A similar structure but without the phase shifter in the lower arm was reported by Heebner and Boyd [1]. A fraction of the field through the upper arm is coupled to the ring waveguide and circularly propagates along the ring. The transfer function of optical electric fields through the ring resonator is derived as

$$t(\phi) = e^{j(\pi+\phi)} \frac{a-\gamma_R e^{-j\phi}}{1-a\gamma_R e^{j\phi}} \tag{1}$$

where $\phi$ and $a$ are the round trip phase shift and the round trip loss in the nonlinear ring resonator, respectively. The round trip phase shift $\phi$ depends on the optical power in the upper arm [2]. The input and output relation in the optical electric fields is given by

$$E_{\mathrm{out2}} = -j\gamma\sqrt{1-\gamma^2}\left(t + e^{j\phi_s}\right)E_{in1} \tag{2}$$

$$t = t\left(\phi(\gamma^2 P_{\mathrm{in1}})\right). \tag{3}$$

Fig. 2 shows the power transfer function $|E_{\mathrm{out2}}/E_{\mathrm{in1}}|^2$ as a function of the incident power $P_{\mathrm{in1}}$ with the phase $\phi_S$ as a parameter. Thresholding behavior is observed. We assume silicon as the optical waveguides and set the parameters as follows: the round trip loss $a = 0.9991$, radius of the ring resonator $R = 5$ µm, $\gamma = \sqrt{0.5}$, $\gamma_R = 0.986$, optical wavelength $\lambda = 1548.46$ nm, second order nonlinear refractive inde $n_2 = 7.5 \times 10^{-18}$ m$^2$/W, and effective waveguide cross section $A_{eff} = 1.2 \times 10^{-14}$m$^2$. The blue curves represent the bistable regions. It is also found that the low-level and high-level outputs cannot be simultaneously flat over input power.

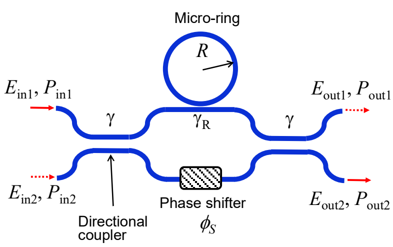


**Fig. 20. An optical thresholder with a MZI.**

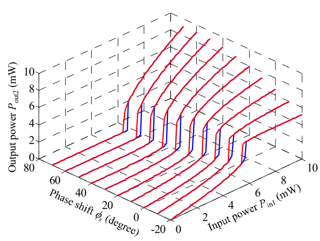


**Fig. 2. Power transfer characteristics.**

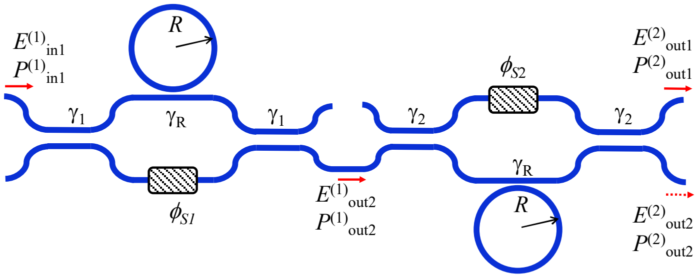


**Fig. 3. An improved thresholder consisting of cascaded two MZIs with ring resonators.**

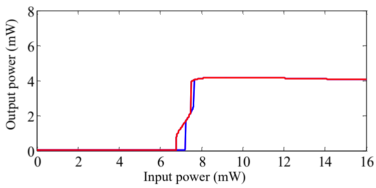


**Fig. 4. The power transfer function**

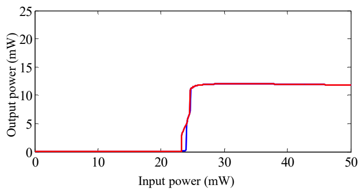


**Fig. 5. The power transfer function for improved response speed**

We propose an improved thresholder consisting of two cascaded MZI with a nonlinear ring resonator in each MZI as shown in Fig. 3. The flat low-level output region is realized by the 1st-stage MZI with a large phase shift, whereas the flat high-level output region is realized by the 2nd-stage MZI with a smaller phase shift. The input and output relation in the optical electric fields can be given by

$$E_{\text{out1}}^{(2)} = -j\gamma_1\gamma_2\sqrt{1-\gamma_1^2}\sqrt{1-\gamma_2^2}\left(t_1 + e^{j\phi_{s1}}\right)\left(t_2 + e^{j\phi_{s2}}\right)E_{\text{in1}}, \quad (4)$$

$$t_1 = t\left(\phi\left(\gamma_1^2 P_{\text{in1}}^{(1)}\right)\right), \qquad t_2 = t\left(\phi\left(\gamma_1^2(1-\gamma_1^2)\left|t_1 + e^{j\phi_{s1}}\right|^2 \gamma_2^2 P_{\text{in1}}^{(1)}\right)\right). \quad (5)$$

Fig. 4 shows the power transfer function of the cascaded two-stage MZI thresholder, where$\lambda = 1548.46$ nm, $\gamma_R = 0.986$, $R = 5$ μm, $\phi_{s1} = 70^\circ$, $\phi_{s2} = -20^\circ$, $\gamma_1 = \sqrt{0.4}$, and $\gamma_2 = \sqrt{0.6}$. It is found that the power transfer in low-level and high-level is flat.

The response speed of the thresholder consisting of ring resonators is mainly restricted by the transient response of the ring resonator. The maximum response frequency $f_{max}$can be roughly evaluated by [1], [3]. The response frequency $f_{max}$ for the device parameters of Fig. 4 is 13.0 GHz. The response speed can be adjusted by device parameters such as coupling ratio and ring radius. An example of the power transfer function achieving response frequency $f_{max}$= 40.5 GHz is shown in Fig. 5. The parameters are $R = 2$ μm, $\phi_{s1} = 70^\circ$, $\phi_{s2} = -20^\circ$, $\gamma_1 = \sqrt{0.4}$, $\gamma_2 = \sqrt{0.7}$ $\gamma_R = 0.982$ .

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References

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