

Light propagation in periodic waveguide-resonator structure – Theory and applications

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Abstract - We present a systematic study of the optical properties of waveguide-microresonator structures. Using numerical simulations, we show that an asymmetrically apodized Kerr nonlinear microresonator structure with 5 microresonators can be used as an all-optical diode.

In this paper we study Kerr nonlinear effects in the class of structure depicted in Figure 1a, which consists of two channel waveguides coupled periodically to circular microresonators. Light traveling in the forward (backward) direction in the lower channel can couple to light traveling in the backward (forward) direction in the upper channel. In general this coupling is quite small, but its effect can be enhanced by two different mechanisms: by exciting a resonance of the microresonators; or by a Bragg mechanism associated with the periodicity of the resonators. The contributions of the two mechanisms can be seen in the (linear) dispersion relation of the structure shown in Figure 1b. The Bragg gap is direct (both band edges are at the same wave number), and has a high curvature, and hence high GVD, at the band edges. The resonator gap is indirect, and has a very low curvature and GVD at the band edges.

The resonator gap is particularly advantageous for short SCISSOR structures. It has been numerically demonstrated that gap soliton switching should be readily achieved at low input intensities

($\sim 20\text{MW}/\text{cm}^2$) in a Kerr nonlinear microresonator structure that contains as few as five unit cells ($\sim 80\mu\text{m}$ long) [1]. Moreover, it has been observed that switching characteristics are markedly improved by apodization – varying the degree of coupling between the resonator and waveguide for each resonator. Heuristically speaking, this apodization is effective because it allows light to ‘ease into’ the structure by first encountering the less reflective resonators before encountering the more reflective resonators. Building on this observation we note that a Kerr nonlinear SCISSOR structure can be used as an all-optical diode (structure that transmits light in forward direction only) by apodizing only one side of the structure (Figure 2). Light incident from the left should be able to ‘ease into’ the structure, and hence will have a lower switching threshold than light incident from the right. To confirm the diode operation of our structure we use numerical simulations based on a hybrid

technique where light at the coupling points is described by a unimodular coupling matrix [2], and light away from the coupling points is described by a simple propagation equation [1] which includes the effects of Kerr nonlinearity, linear loss, two-photon absorption and three-photon absorption.

We simulate pulse propagation using input pulses whose full width, at half maximum intensity is 100ps, with a carrier frequency that lies in the (linear) stop band of the diode structure. In Figure 3 we plot the transmission versus the peak input intensity for left-incident (square) and right-incident (triangle) light. Both curves display nonlinear switching, but for the intensity range $50\text{--}70\text{MW}/\text{cm}^2$ the structure exhibits diode operation, because left-incident light is significantly transmitted, while right-incident light is almost fully reflected. Although our device is only 80mm long, the delay between the input and the transmitted pulse is about 70ps so that the group delay experienced by the transmitted light is about 100 times larger than in a straight waveguide of the same length. This enhanced group delay, and the consequent enhancement of the effect of the Kerr nonlinearity, is primarily responsible for the low operating intensity for our device.



Figure 2 Schematic of apodized microresonator structure.

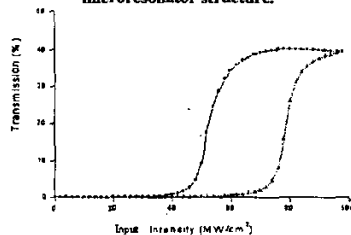


Figure 3 Nonlinear switching curve for microresonator diode.

References

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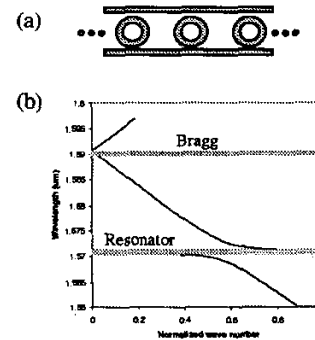


Figure 1(a) Schematic of microresonator structure.
Figure 1(b) Dispersion relation of the structure in (a)