Experimental Observations of Optical Bistability in Semiconductor Microring Resonators

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Abstract: We present measurements of optical bistability in GaAs/AlGaAs optical microring resonators at 1.55μm wavelength.

1. Introduction:

Microring resonators have been shown to be versatile elements for passive filter synthesis [1]. Recently the use of semiconductor microrings to enhance nonlinear optical effects was proposed and investigated [2,3]. In [2] analysis of optical switching in a Mach-Zehnder interferometer loaded with a nonlinear fiber ring resonator shows that the speed of such a device would be limited by the propagation time through the fiber ring. Microring resonators should show similar effects if the ring material has sufficient $\chi^{(3)}$ optical nonlinearity. In addition the charging time in microrings is in the range of a few picoseconds, allowing switching speed in the 100-GHz regime if the response time of the nonlinear effect is much faster than the cavity lifetime.

In this paper we report experimental observations of switching phenomena in semiconductor microring resonators. The devices used in this study, which are described in detail elsewhere [4], are add/drop filters and ring-loaded Mach-Zehnder interferometers comprising of a single 10μm-radius GaAs/AlGaAs ring vertically coupled to straight waveguide tracks. These microrings have quality factors ranging from 6000 to 10,000 and a free spectral range of 11nm.

2. Experiment:

The experiment consisted of two parts. In the first part, slow (1ms) switching due to thermal effects was observed. The experimental setup is shown in Fig. 1. The current of a tunable external-cavity laser diode was modulated at a low frequency (10Hz). The wavelength of the propagating beam was tuned to one of the microring's TM modes. The polarization of the input beam was controlled using a fiber polarization controller (FPC). The amplified beam was then split into a reference beam and a probe beam. The reference beam was attenuated and monitored by detector D1. The probe beam was coupled into the input waveguide using a conically-tipped fiber, and the output was measured at the drop-port of the device (Fig. 2a) using a second conical-tipped fiber and detector D2.

In the add/drop configuration used here, when the source is tuned to one of the microring resonances, the field circulating in the ring builds up to a much higher value than the input field, thus effectively lowering the switching threshold. In the switching measurement the source wavelength was tuned to 1561.3nm, which is 0.3nm red-detuned from the microring resonance wavelength of 1561nm. The laser power was modulated at a 10Hz rate to give a 0 to 50mW power variation at the input of the device. The time traces for the input and output signals are shown in Fig.3a. The switching time is in the microseconds range, indicating that switching was due mainly to thermal effects. In Fig. 3b, the output intensity is plotted versus the input intensity.

Switching thresholds and hysteresis are clearly observed. This bistable behavior of the microring can be explained by a thermal increase in the effective ring index with increasing intensity.

When a microring is coupled to one arm of a Mach-Zehnder interferometer (Fig. 2b), the switching threshold of the device is lowered by the square of the ring finesse [2]. To avoid thermal switching the following setup was used. An external modulator was used to chop a CW beam to obtain a 300ps pulse train at a 250MHz repetition rate. The fast pulsed input signal reduces heating of the ring and increases the instantaneous peak power of the pulses. The polarization of the input beam was set to TM using a fiber polarization controller. An EDFA amplifier was used to amplify the pulses and deliver an average power of 25mW to the input waveguide. Resonance caused the power circulating in the ring to be quadratically enhanced. Using an estimated field enhancement factor of 3 in our device, we calculated a peak intensity of 10^9W/cm^2 circulating in the ring. Fig. 4 shows time traces of the input and output pulses. Fast nonlinear switching is observed with a rise time of 18ps, which is comparable to the charging time of the microring. We note that in our device the switching speed is limited mainly by the microring cavity lifetime, which can be reduced by decreasing the ring radius.

3. Conclusion:

In conclusion, we report observations of both thermal and fast nonlinear switching in microring resonators. Experimental results showed that the ring could be used as an optical switch in the 100GHz regime.

References:

[1] B. E. Little, S. T. Chu, H. A. Haus, J. Foresi and J.-P. Laine, “Microring resonator channel dropping filters”, *J. Lightwave Technol.*, vol. 15, pp. 998-1005, June 1997.

[2] J. E. Heebner and R. W. Boyd, “Enhanced all-optical switching by use of a non-linear fiber ring resonator”, *Opt.Lett.*, vol. 24, pp. 847-849, June 1999.

[3] P. P. Absil, J. V. Hryniewicz, B. E. Little, P. S. Cho, R. A. Wilson, L. G. Joneckis and P.-T. Ho, “Wavelength conversion in GaAs micro-ring resonators”, *Opt. Lett.*, vol. 25, pp. 554-556, Apr. 2000.

[4] P. P. Absil, J.V. Hryniewicz, B.E. Little, F.G. Johnson, K.J. Ritter and P.-T. Ho, “Vertically coupled microring resonators using polymer wafer bonding,” *IEEE Photon. Technol. Lett.*, vol 13, pp. 49-51, Jan.2001.

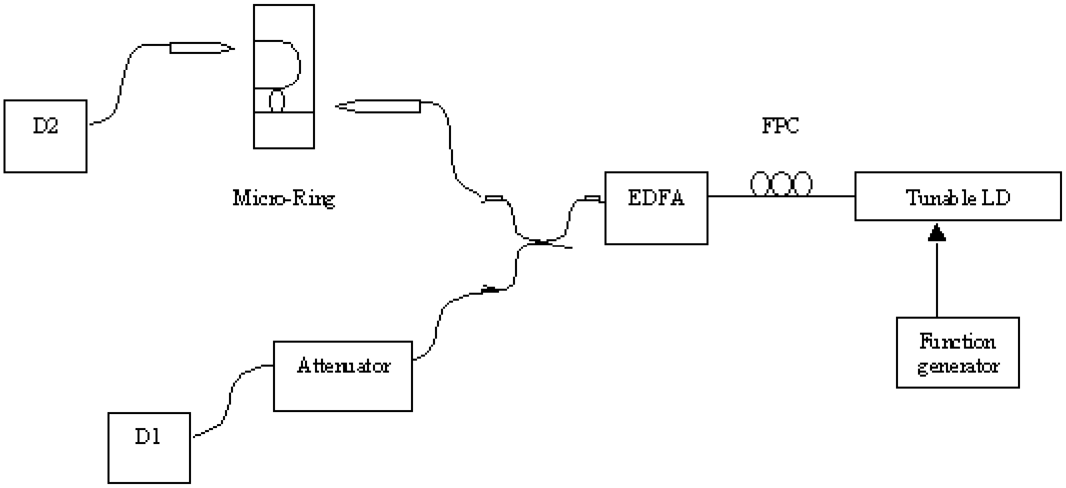
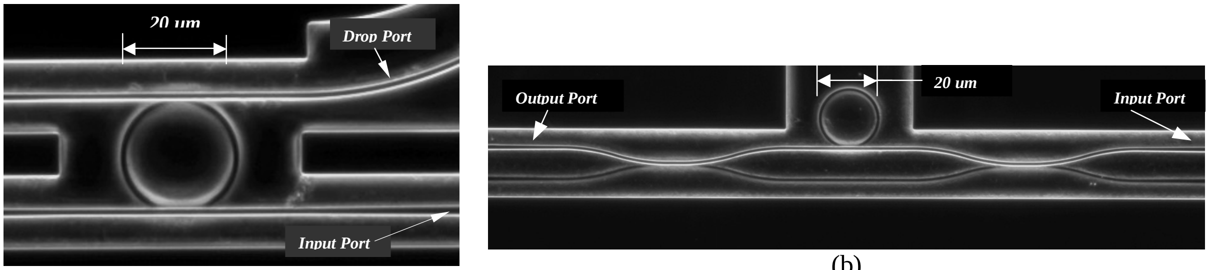


Figure 1: Experimental setup for slow switching in microrings.



(a) (b)

Figure 2. Optical micrographs of (a) an Add/Drop GaAs/AlGaAs micro-resonator and (b) a microring-loaded Mach-Zehnder GaAs/AlGaAs interferometer.

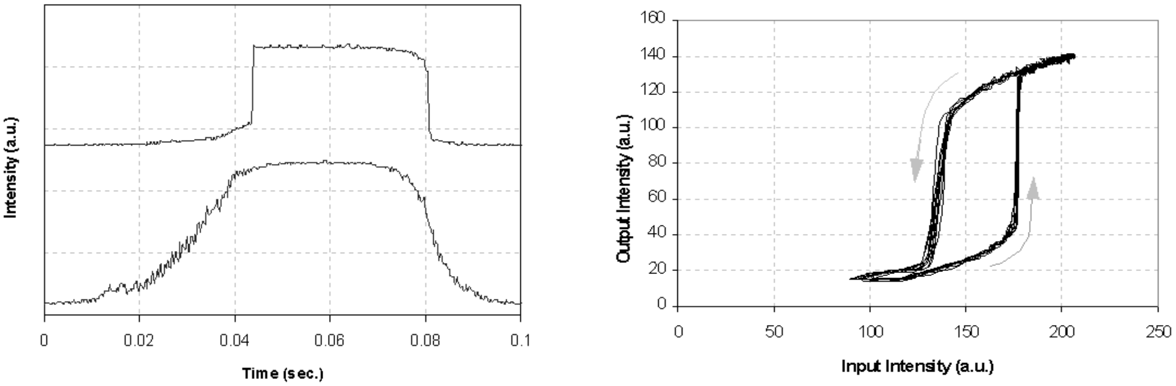


Figure 3. (a) Input (lower trace) and output (upper trace) time traces in slow thermal switching experiment; (b) intensity bistability curve.

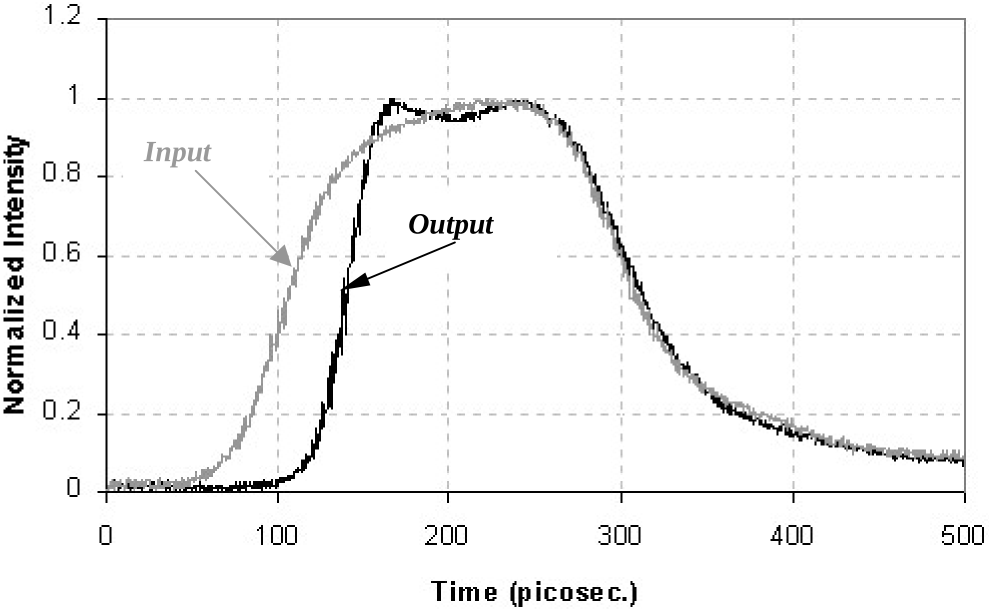


Figure 4. Time traces of input and output pulses in fast nonlinear switching experiment.