Nonlinear Magnetic Scattering from Polymer Micro-ring Resonators

A. Chakrabarty[1], C. Zhang[1], A. A. Fisher[2], E. F. C. Dreyer[1], Qiaochu Li[1], L. Jay Guo[1] and S. C. Rand[1,2]
[1]Optics & Photonics Laboratory, EECS Dept., University of Michigan, Ann Arbor, MI 48109-2099
[2] Division of Applied Physics, University of Michigan, Ann Arbor, MI 48109-1022
E-mail: achakra@umich.edu

Abstract: Optical scattering from a high-Q polymer micro-ring resonator shows evidence of intense magnetic interactions due to a second order magneto-electric nonlinearity.

OCIS Codes: (070.5753) Resonators; (190.0190) Nonlinear optics; (190.4975) Parametric processes

1. Introduction

High-frequency magnetism has received considerable attention over the past several years with the emergence of structurally-engineered media which exhibit large magnetic response at optical frequencies. In contrast to such experiments, recent results in unstructured, homogeneous media have shown that scattering from induced (nonlinear) magnetic dipoles (MD) can be as intense as linear Rayleigh scattering from induced electric dipoles (ED) at intensities of the order 10^8 W/cm^2 [1,2]. These unexpected results point to the importance of magneto-electric interactions involving the optical magnetic field [3], but their study to date has been limited to high-peak power laser systems.

The use of micro- resonators has become widespread in the study of nonlinear phenomena such as high-harmonic generation and parametric oscillation, as well as in applications such as laser cooling with very low input optical power. Micro-resonators confine optical energy in ultra-small mode volumes and attain high intensities through resonant recirculation of light. Here we show for the first time that scattering from magnetic (TE) modes of a high-Q polymer micro-ring resonator injected with only a few mWs of input power is as intense as electric (TM) mode scattering, consistent with predictions for a new nonlinearity driven jointly by the electric and magnetic fields of light.

2. Light Scattering Experiments from Micro-ring Resonator

A high Q polymer micro-ring, together with a straight coupling waveguide, were fabricated from polystyrene by nanoimprinting [4] using a silicon mold fabricated with electron beam lithography (Fig. 1(a)).

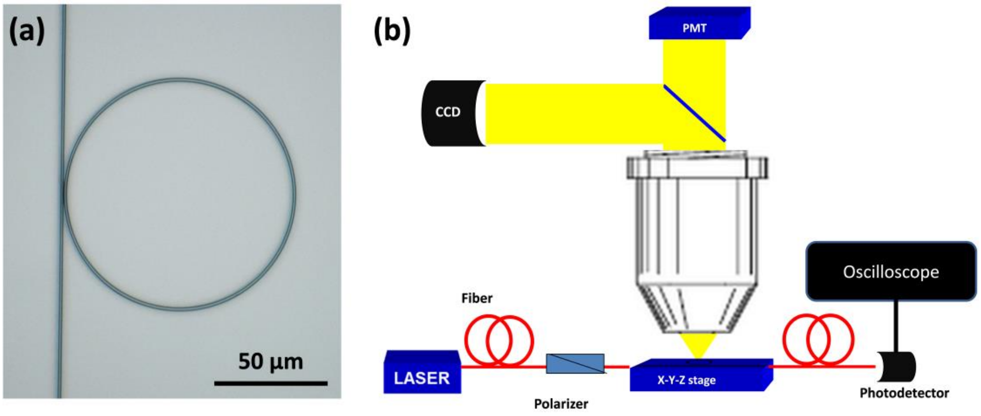

Fig. 1. (a) Optical image of fabricated polymer micro-ring with a coupling waveguide. The diameter of the ring is 100 µm and cross-section of 1 µm×1 µm. (b) Set-up for measurement of the optical scattering. The sample is placed on a x-y-z stage and the scattered light is collected in the orthogonal direction with an objective and measured with PMT. A single mode fiber with a polarizer couples the laser light to the input of the waveguide and a multi-mode fiber collects the output transmitted light. The photodetector and the oscilloscope are used to monitor the resonances of the ring from the transmitted light.

The set-up for measuring the electric and magnetic dipole scattering from the ring is shown in Fig. 1(b). To distinguish between electric and magnetic scattering, light from the sample was collected orthogonal to both the direction of propagation of light inside the resonator and the plane of the resonator itself. An objective lens was used both for imaging the micro-ring on the CCD and for collecting the scattered light which was detected through a 10nm band-pass filter with photon-counting electronics. The long working distance and small NA=0.28 of the objective limited the collection solid angle to $\sim 10^{-4}$.

A single mode fiber was used to couple laser light into the micro-ring. The transmitted light was collected with a multimode fiber and measured with a photo detector connected to an oscilloscope (Fig. 1(b)). The pump laser was tuned over the range 765nm- 781nm to scan through the resonant TE and TM modes of the ring resonator. Fig. 2(a) shows an example of a resonance with a measured Q factor of $\sim 1.3\times 10^5$ at a resonant wavelength of 778.18 nm.

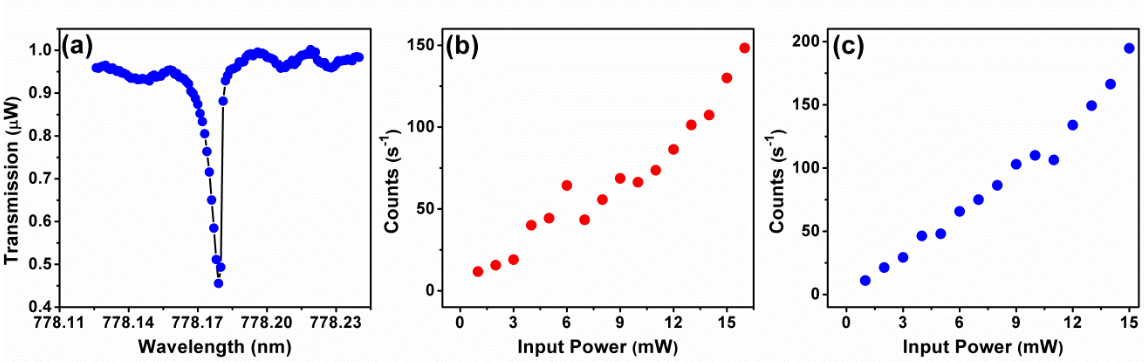

Fig. 2. (a) Normalized transmission spectrum of polymer microring resonator. (b) Scattered intensity of the magnetic (TE) mode resonance at 778.18nm. (c) Scattered intensity of the electric (TM) mode resonance at 778.34nm.

To determine the power dependence of optical scattering, the wavelength of the pump laser was fixed at a point on the transmission curve of the resonator which had the highest slope. Then the input power was varied. To facilitate these measurements, the input polarization was controlled with a fiber based polarization controller at the input of the resonator waveguide (Fig. 1(b)). The measured scattering intensity as a function of input power for the TE and TM polarization at 778.18nm and 778.34nm wavelengths is shown in Fig. 2(b) and 2(c) respectively. For the 90º detection geometry (Fig. 1(b)) in our set up, scattered light from the TE and TM modes of the ring resonator corresponds to MD and ED scattering respectively. Surprisingly, the magnetic (TE) mode scattering is comparable in intensity to the electric (TM) mode (Rayleigh) scattering, but its apparent dependence on input intensity is quadratic (Fig. 2(b)).

3. Summary

The use of a high-Q micro-ring resonator structure fabricated using nanoimprinting has allowed us to investigate nonlinear magnetic response of polystyrene for the first time using only a few mW of input power. Observations of magnetic (TE) scattering reveal magnitudes comparable to linear electric (TM) scattering over the measured intensity range and are consistent with second-order magneto-electric scattering previously observed only at much higher input intensities in bulk materials. Because nanoimprinting is adaptable to other polymers, these results should provide a platform for the comparison of nonlinear magnetic properties in numerous materials without requiring large sample volumes or high power laser systems.

4. Acknowledgement

This research was supported by the MURI Center for Dynamic Magneto-Optics (FA9550-14-1-0040) at the University of Michigan.

5. References

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