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Solid and hollow whispering gallery mode resonators for all optical switch

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Abstract. Whispering-gallery-modes resonators (WGMR) are effective switching devices when either coated or filled with non-linear material. We present examples of all-optical switching of hybrid WGM using polyfluorene, a methacrylate azobenzene and an acrylate derivates. We have studied the Kerr non-linear effect and thermal nonlinearities in a such hybrid systems.

1 Introduction

Dielectric spherical WGMR are compact and high-quality optical resonators which lead to a significant enhancement of the efficiency of nonlinear-optical processes. In this work we present our investigation on the all-optical switching of WGM in silica microspheres and microbubbles with different types of coatings or fillings. π-conjugated polymers and azo-dyes are exciting nonlinear-optical materials and their suitability for nonlinear devices has been well-known for more than a decade. We tested a Kerr or π-conjugated polymeric material (polyfluorene derivative, LSC-110), an azo-dye as Dimethyl-red-1-methacrylate (DR1M), DR1M combined with polyphaldehide (PPA) and an inert polymer based on an anionic copolymer made of metacrylic acid and methyl methacrylate. We also modeled the overlap of the coupled optical field with the polymer layer and verified the role of the probe field experimentally for both polymer coatings. Depending on the composition of the polymer, its state and the geometry of the light-WGMR interaction, different regimes of the switching can be attained: fast electronic Kerr switching, as well slow thermal modification of the WGM spectra that exist even for the CW mode of laser operation. Higher order induced nonlinearities were observed when the sensitivity of the mode was greater, due to a better confinement of the field. No effects were observed for bare microspheres or microbubbles.

2 Experiment results

The experimental set-up is based on two laser sources, pump and probe ones. A tuneable external-cavity laser with the linewidth of 300 kHz (Tunics Plus) was used as a probe for the measurements of the WGMR transmission spectrum. The probe laser could be finely swept at very low frequency around a resonance by a few GHz. The pump beam (Ti-sapphire, Mira 900F, Coherent, 780) was coupled to a single mode fiber with one end slightly spliced in order to achieve an effective lensing and placed at about 1 mm away from the microsphere. The pump illumination was covering an hemisphere of the WGMR. The pump wavelength of 780 nm was close to the two-photon resonance in PF(o)n. In the pulsed regime of the laser operation, the repetition rate is about 82 MHz and the pulse width is about 100 fs. A second laser was used as a pump beam, a filtered supercontinuum source (Superk Compact and Super K Select, NKT Photonics) in order to compare both regimes of switching. All-optical switching of WGMR was studied by comparing the transmission spectra of the microbubbles and microspheres in the absence and in the presence of the pump beam. The spectral shift of WGM was studied for various average values of the pump radiation intensity. In can be supposed that two main mechanisms can be involved in such a spectral shift: (i) third-order nonlinear Kerr effect, that leads to variation of the refractive index of a medium, (ii) linear thermal effects, that depend on the average power of the laser beam and (iii) thermal non-linearities. Thermal effects can originate from the dependence of the refractive index of the WGMR on the temperature as well as from the thermal expansion of the of both the polymer and the silica core of WGMR. To distinguish between these effects, the spectral shift of the WGMs was studied for the pulsed and CW regimes of the laser operation. The corresponding results are shown in the Figure1. It can be seen that in Figure1 a the light-induced detuning of WGM is linear in the average laser intensity, while their slopes are different. This difference should be attributed to the Kerr effect, as the thermal heating is the same for the CW and pulsed laser regimes. The inset of Figure1a shows the result of closed-aperture z-scan measurement on LSC-110 polymer film. On the contrary to bare WGMR, we observed that a spectral shift of the resonant WGM in hybrid WGMR was observed. Qualitatively similar dependencies were measured

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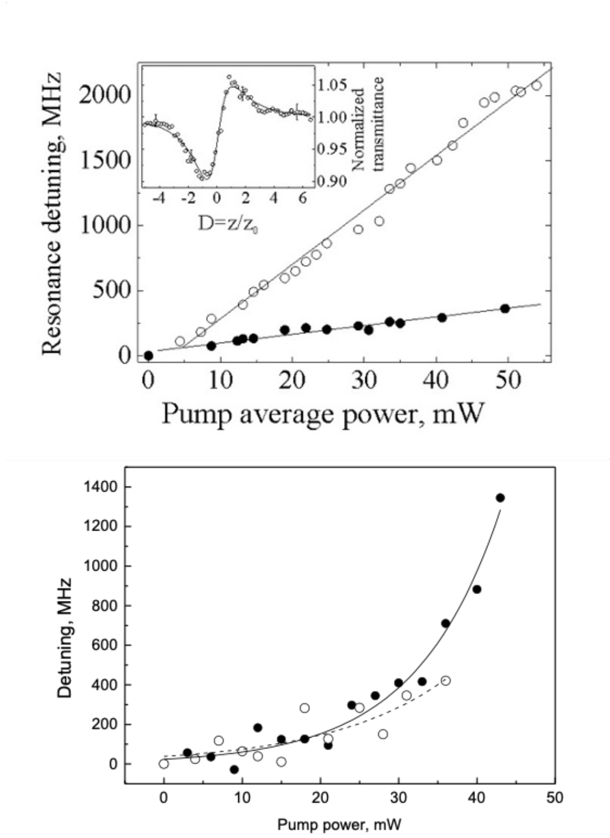

Figure 1. a) Dependences of WGM resonance shift on pump power for cw (solid) and pulsed (empty circles) laser regimes. Inset: closed-aperture z-scan measurement on LSC-110 polymer film; b) Dependences of WGM resonance shift on pump power for pulsed laser regimes for two different pump wavelengths: 1558 nm (solid) and 1600 nm (empty).

for pump wavelengths of 760 nm, 780 nm, 800 nm and 830 nm as well as for the probe laser wavelengths of 1550 nm, 1600 nm and 1640 nm. No drastic changes were observed in the character of the pump power induced WGM detuning. Two main temporal scenario of the switching dependencies were observed: fast and slow light-induced switching of the resonant modes. In the first case the light-induced effect was larger for the mode-locked regime if the Ti-sapphire, i.e. for larger peak pulse power. This is probably caused by the fast electronic Kerr-like nonlinearity of the polymer, as no such effects were observed for bare microspheres at the same pump power values. In some cases the switching time was evidently larger. While we had no possibility to perform direct pump-probe measurements, these discrepancies were evident by eye when analyzing a transmission spectra by oscilloscope. Besides, in that case the WGM detuning as a function of the pump power was nearly the same for mode-locked pump laser regime and for a CW one. Thus we have to consider that in that case fast Kerr nonlinearity was suppressed and the switching took place due to the temperature –induced nonlinearity in the presence of an intense pump laser beam. We studied the switching effects for high pump powers. The slow switching at low pump powers is a linear dependence (see Figure 1a), while for larger intensities it follows a square-type dependence as can be seen from Figure 1b). This is due to the appearance of higher-order temperature induced nonlinearities and the corresponding changes in the refractive index under high pump intensity.

3 Conclusions

In summary, an all-optical switching is observed for an ultrahigh Q spherical WGMR coated by a thin layer of n polyfluorene. A resonant frequency shift of about 2 GHz is observed under the pulsed optical pumping. Short switching time together with the estimations of the polymer nonlinear refraction index prove the role of the third-order nonlinear Kerr effect in the observed light-induced WGM detuning of the solid spherical WGMR.

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