Report on the Project
"Nonlinear Optical Switching in Composite Optical Microresonators"

Dr. Tatiana Murzina
Physics Department of M.V. Lomonosov Moscow State university

During the visit to IFAC-CNR, "NelloCarrara" Institute of Applied Physics R (Florence) the main efforts were aimed at the experimental studies of the light-induced switching of the Whispering Gallery Modes (WGM) in optical microspheres covered by a nonlinear polymer. The main idea was to perform the consecutive studies of this effect and to figure out the possible ways for the optimization of the all-optical switching in this type of devices. For the implementation of this idea an experimental set-up was used shown in Figure 1.

The main idea of such a setup was to combine high spatial and temporal interaction of the light propagating in the optical microspheres as WGMs and an intense pump pulsed beam which can cause the fast Kerr-like switching of the WGMs of the microsphere.

As a probe beam for the excitation of the WGM a semiconductor an external-cavity laser tunable in the spectral range of 1.55÷1.6 μm and with 300 kHz linewidth (Tunics Plus) was used. The probe laser wavelength could be changed precisely around a resonance by a few GHz. The light from the probe laser was coupled in and out of the WGMR by means of a home-made tapered fiber with the minimum waist of about 3 μm in diameter. The light transmitted through the coupler-WGMR system was monitored at the output of the taper using an amplified InGaAs photodiode detector connected to an oscilloscope.

A titanium-sapphire laser operating at the wavelength of 800 nm, with the pulse width of 100 fs, mean energy up to 250 mW and the gain 80 MHz was used. The radiation of Ti-sapphire was sent to an optical fiber and then focused on the surface of the microsphere in a spot of about 30 microns in diameter. The pump intensity on the sample was varied by a set of appropriate color filters. Fig. 1 shows a scheme of the laser set-up.

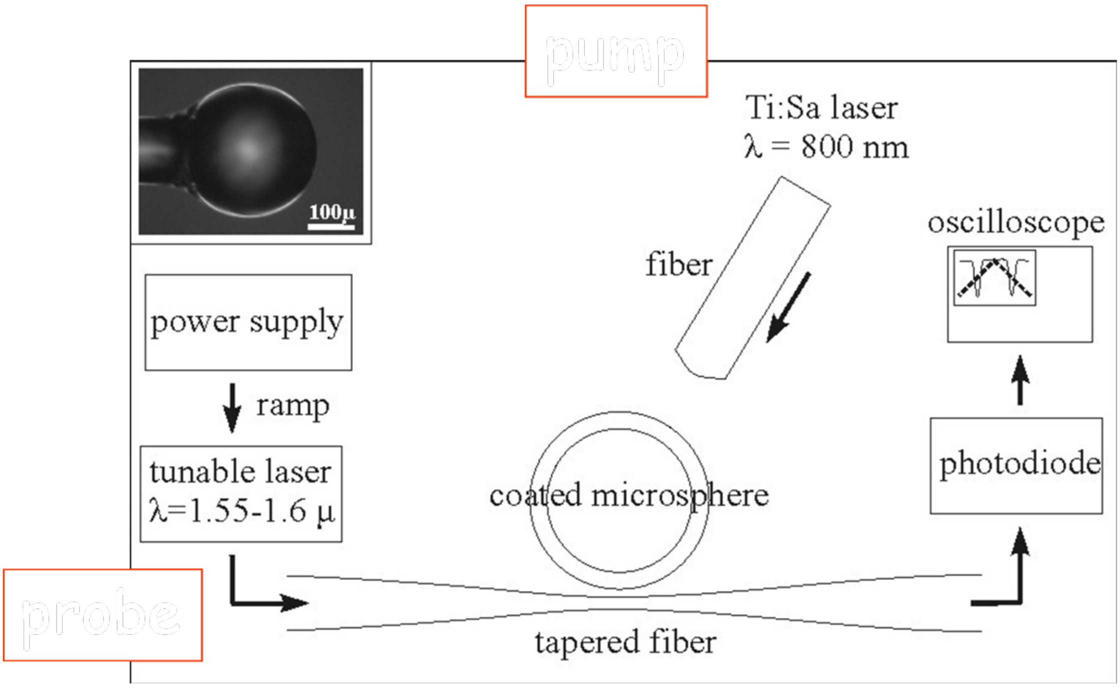

Fig. 1. The scheme of the pump and probe laser measurements with the fused quartz microsphere.

The samples under study are fused quarts microspheres of the diameter of 200-300 microns fabricated on the tip of a standard telecom fiber by using a fiber fusion splicer (FITEL S182K) and stored afterwards under the vacuum conditions. A polymer was deposited on the microsphere surface by dip coating in PF(o)n (0.1 mg/ml in toluene) followed by a drying in the until the total solvent evaporation. According to the structural measurements, the thickness of the polymer film was about several dozens of nanometers. Another set of measurements was performed for the analogous solution with PMMA.

1. The quality factor of the WGMs *Q* was obtained by measuring the resonance linewidth of the WGM modes around probe laser wavelength. A typical spectrum measured for the case of bare microspheres is shown in Figure 2. It can be seen that the *Q* factor of more than 10^8 is obtained. We have also checked that the quality factor decreases down to 10^6 after the polymer coating.

2. Pump-induced effects on the WGM in as-prepared microspheres were studied. No effect was seen, i.e. the WGM resonances were not shifted as the averaged pump power was increased up to 30 mW. Thus we may assume that the Kerr nonlinearity of quarts or the thermal heating effects were insufficient in that case.

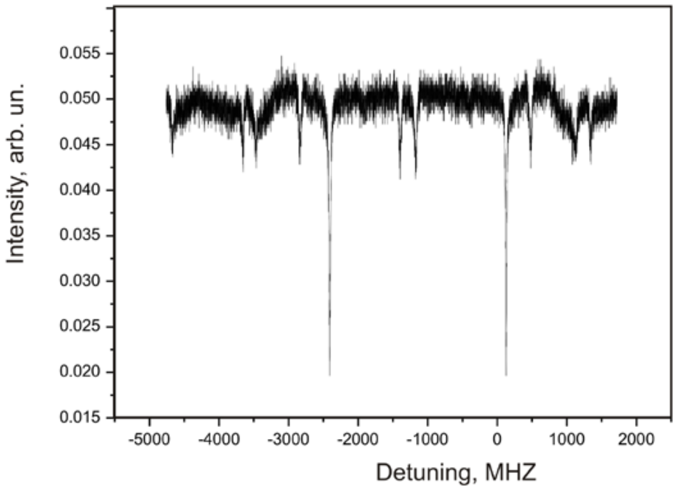

Figure 2. Typical WGM spectra measured for a bare microsphere.

3. Typical WGM spectra of polymer-coated microspheres in Fig. 3 and corresponds to the *Q* value of about 10^6. We have found that the decrease of the quality factor of coated microsphere is not much sensitive to the thickness of the coverage: it did not change within the experimental accuracy after a set of dipping and drying cycles. This is consistent with our expectations that the polymer layer closest to the microsphere surface plays the key role in the decrease of the WGM quality factor.

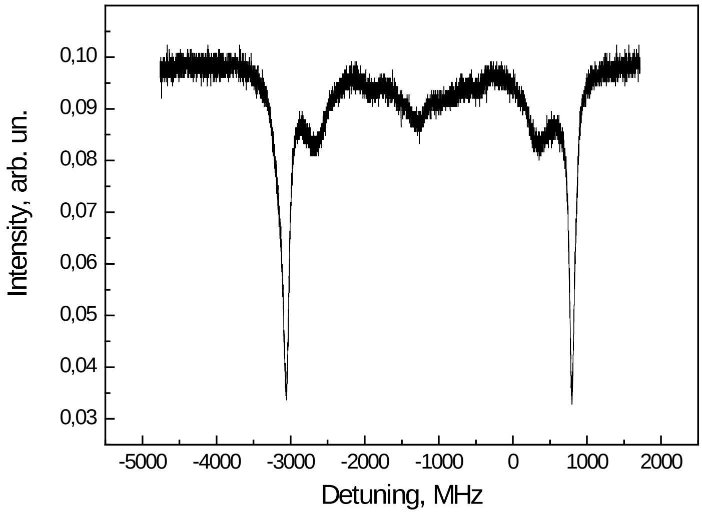

Figure 3. Typical WGM spectra measured for a polymer-coated microsphere.

Besides, similar effect in the Q factor was observed for the PMMA coverage. Thus we may conclude that the composition of the covering layer is not so important for the influence on the WGM conditions.

4. Pump-induced effects in WGM in polymer-coated speheres.

On the contrary to bare microspheres, we observed that a spectral shift of the resonant WGM in polymer-coated microspheres was observed. A typical dependence of the spectral shift of the resonances is shown in Fig. 4. Qualitatively similar dependencies were measured for the 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.

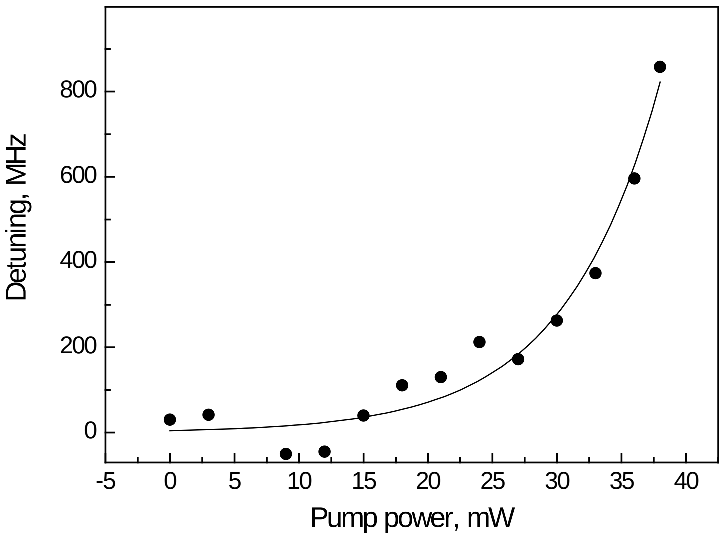

Fig. 4. Pump power dependence of the detuning of WGM in polymer-coated microspheres for mode-locked regime of the Ti-sapphire pump laser.

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 layer, 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 larger pump powers as compared with our previous studies. What we see was that the slow switching at low pump powers is close to a linear dependence, while for larger intensities it follows a square-type dependence as can be seen from Figures 4 and 5.

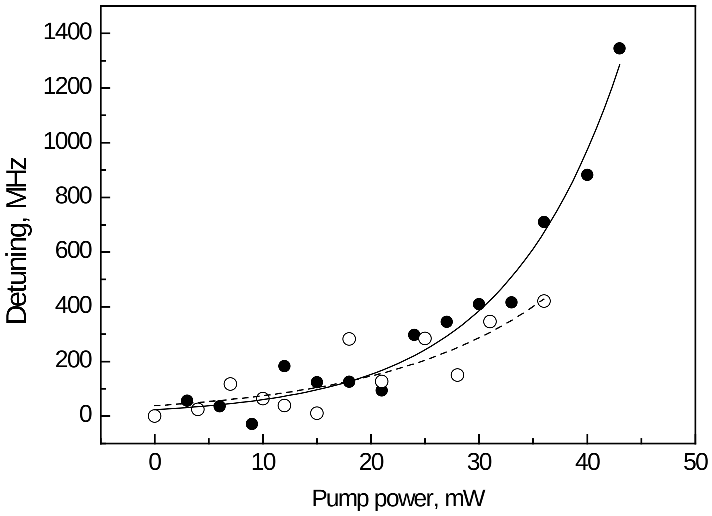

Fig. 5. Pump power dependence of the detuning of WGM in polymer-coated microspheres for mode-locked (filled circles) and continuous wavelength (open circles) regime of the Ti-sapphire pump laser.

This may be due to the appearance of higher-order temperature induced nonlinearities and the corresponding changes in the refractive index under high pump intensity.

In order to distinguish between these two mechanisms we would suggest to perform similar measurements for a number of specimen used as coverage layers for the microspheres: with high and low values of the Kerr nonlinearity.