Surface-Coupled Microsphere Resonators

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Abstract: A novel micro-optical amplifier is evaluated experimentally and theoretically. Comprising a microsphere (onto which a gain medium is tethered) and a plasmonic surface, this micro-optical system is capable of amplifying Raman emission generated internally to the microsphere.

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Recently, a new micro-optical amplifier was proposed [1] in which light is coupled into the whispering gallery modes (WGMs) of a spherical microresonator by placing the microsphere onto a plasmonic substrate. Virtually all previous microresonator work has relied on coupling power into the resonator with a tapered optical fiber or a prism [2, 3]. The proximity of the plasmonic surface, and its design, serve to efficiently couple optical power into, and out of, the microresonator. The experiments and theory reported here demonstrate that this micro-optical system is capable of serving as an amplifier in the visible.

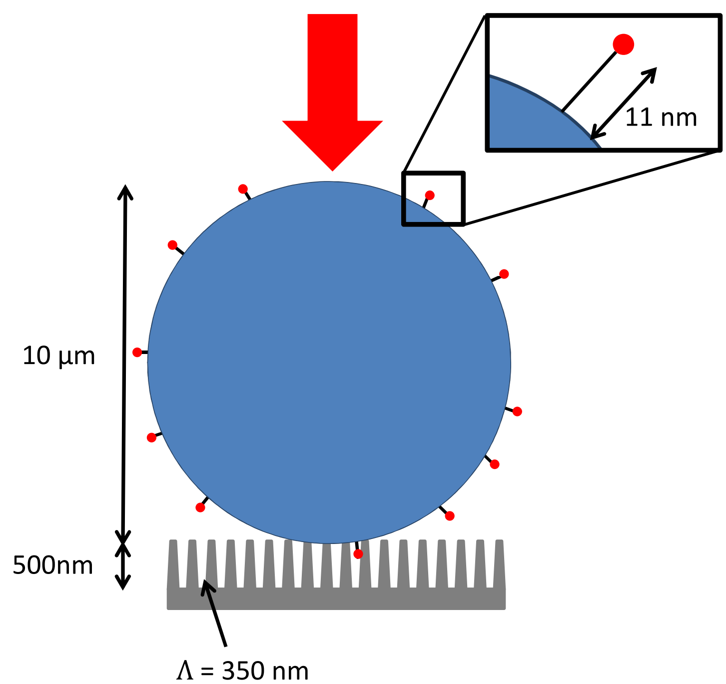

Fig. 1. Experimental setup (not to scale). The pump laser is incident on the top of the sphere, which is covered in dye molecules and sitting on a square array of silver or gold nanocones. The cones are 500 nm tall and the period of the structure is 350 nm. Dye molecules are suspended 11 nm from the surface by the biotin-avidin bond.

A diagram illustrating (in cross-section) this resonator/plasmonic system is shown in Fig. 1. Polystyrene microspheres 2 μm or 10 μm in diameter serve as the resonator. Dye molecules are suspended 11 nm from the surface of the microsphere with a biotin-avidin tether, and the microsphere is then placed on a plasmonic substrate comprising replica-molded nanocones or nanocylinders coated with thin films of gold or silver. The completed samples are illuminated with the focussed output of a He-Ne (632.8 nm) or frequency-doubled Nd:YAG (532 nm) laser. Focussed to a nominal spot size of 1.1 μm on the microsphere, this pump radiation was provided by a commerically-available Raman microscope. Emission from the sphere that is collinear with the pump beam is collected by a 50x objective and delivered to a spectrometer.

Representative data are presented in Figure 2 for the 640-745 nm spectral range for a microsphere to which the dye known as Dylight 650 is tethered. The pump wavelength is 632.8 nm and the plasmonic surface is coated with 80 nm of gold. Data are shown for several values of the pump power and, at lower values, the presence of WGMs in the scattered flourescence is clear. The measured mode spacing of 9.8 nm near 650 nm is consistent mode numbers around $m = 78$.

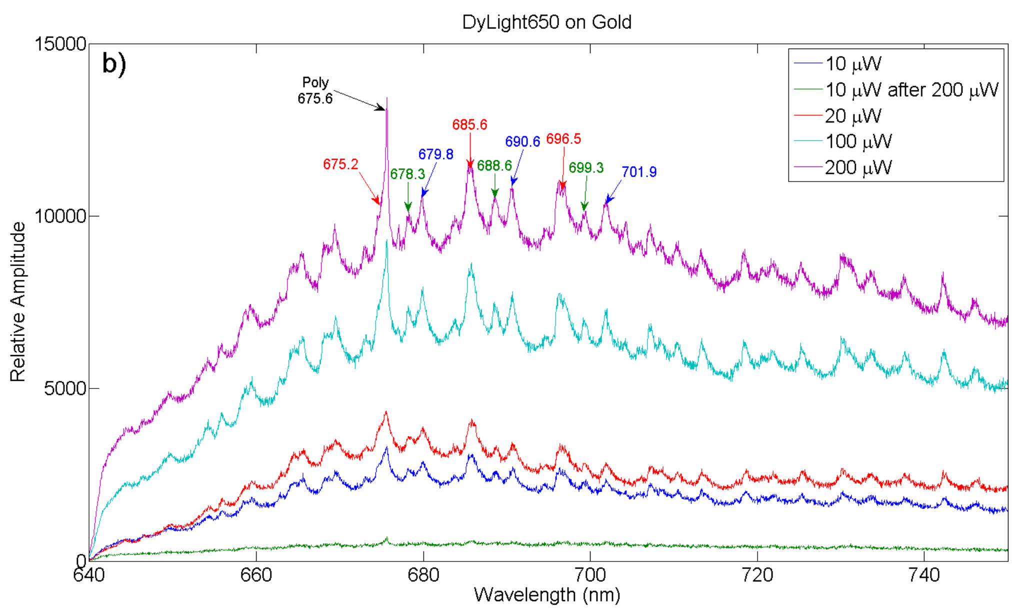

Fig. 2. **a)** Spectrum of polystyrene spheres on silver excited at two different points on its surface at 100 μW power. **b)** Spectrum of polystyrene spheres on gold excited with varying powers at the same point. Note the green curve, which shows the spectrum recorded with 10 μW excitation after the sphere had been exposed to 200 μW. In both figures, Raman lines are identified with black arrows. WGM peaks corresponding to the same series of modes are identified with red, green, and blue arrows.

As the pump power is increased, a narrow feature at 675.6 nm and identified as a Raman line of polystyrene is observed. Also, blackbody emission from the spehre and plasmonic surface dominate at the highest incident pump power tested to date (80 kW-cm^{-2}). The disappearance of the WGMs as the pump power is increased apears to be the result of photobleaching of the dye. Calculations suggest thatt this system is lasing at lower pump powers, and the potential of this system as a micro-optical amplifier will be discussed.

References

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