Surface-functionalized silica microsphere lasers

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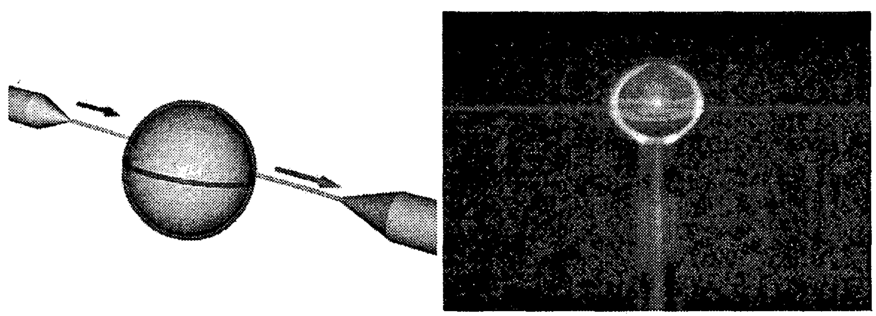
Abstract: Er-doped sol gel films are applied to the surface of silica microspheres to create low-threshold microcavity lasers. By varying the thickness of the applied sol-gel layer, both continuous wave and pulsating modes of operation are possible.

OCIS codes: (140.3500) laser, erbium; (140.4780) optical resonators

Microcavities formed by surface tension can exhibit quality factors in excess of one billion and are of interest in cavity QED, nonlinear optics, photonics and sensing. When silica microspheres are doped with rare earth ions, ultra-low threshold microlasers are possible [1,2]. In this work, ready-made microspheres of undoped silica serve as a base resonator structure and gain functionalization of the surface is performed using an erbium-doped sol gel film (see figure 1(a)). In addition to providing added flexibility in terms of dopant selection and doping concentration, it will be shown that the thin film nature of the gain layer has an important effect on laser dynamics.

The sol gel starting solution was prepared by hydrolyzing tetraethoxysilane in water under acid conditions (pH~1) with isoproponal as the co-solvent. $ErNO_3$ was added to achieve an Er concentration of approximately 10^{19} cm^{-3} in the final films [3]. The initial pure-silica microspheres (approx. 50~80 μm in diameter) were formed by heating the end of a tapered fiber tip with a CO_2 laser [4]. Multiple dipping of the spheres into the sol gel solution was used to build up a desired layer thickness. After every two cycles, the spheres were irradiated using the CO_2 laser to densify the sol gel layers.

Optical coupling to the spherical microcavities was performed using optical-fiber tapers [2]. Figure 1(b) shows representative excited-state emission observed when WGMs are pumped using a single-frequency, tunable external-cavity semiconductor laser emitting in the 980-nm band. Both continuous wave (cw) and pulsation mode (pm) operation were possible by controlling the sol gel coating thickness. When the doped shell is thick in comparison to the radial width of the mode excited in the 980-nm band, there will remain unpumped regions that can provide saturable absorption to the longer wavelength lasing modes. In addition to modifying the threshold characteristics, saturable absorption is known to modify lasing dynamics such that pulsation behavior is possible. CW laser operation was observed for coating thicknesses in the range of 1μm, while pm laser operation was possible for coatings in the range of 5μm.



(a) (b)

Fig.1. (a) Schematic of a thin film coated microsphere laser coupled using a fiber taper (b) Image of a WGM in the taper-sphere coupling zone.

Fig. 2 shows the laser output versus the pump power absorbed by the microsphere for cw operation. A corresponding laser spectrum is presented in the inset. The threshold was estimated to be around 28μW and the laser reaches an output power of 6μW. A laser output power of up to 10μW was observed for single mode pm operation. Figure 3 shows typical measured pulsation frequency plotted versus the square root of the laser output power for pm operation. The observed linear behavior is consistent with un-damped relaxation oscillations.

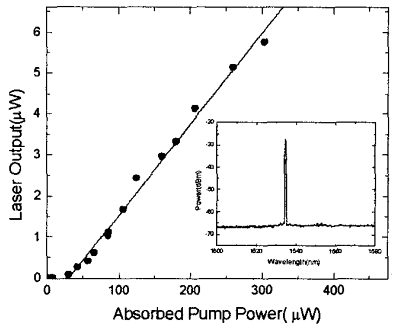


Fig. 2. Laser output power versus absorbed pump power in the microsphere laser. The inset shows a typical emission spectrum of the microsphere laser.

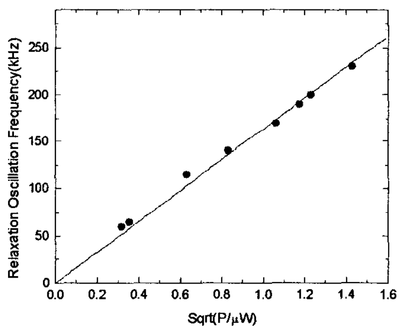


Fig.3. Pulsation frequency versus the square root of the laser output power P

In conclusion, we have demonstrated gain functionalization of silica microspheres using doped sol gel films. By varying the thickness of the doped sol gel films, both cw and self-pulsation operation are possible. This technique may also provide a way to achieve surface layers that target applications such as nonlinear optics in a micro-cavity [4]

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