Multipurpose Microspheres-Fiber Laser

Abstract:

Doped silica microspheres are used to build a novel, rugged, and tunable laser system. The injected microspheres into a hollow fiber are pumped externally and their emission is collected along the cladding of the fiber.

Summary

A technological revolution is occurring in the field of fiber lasers and fiber communication. On the other hand, the optical properties of solid microspheres and aerosol droplets have impacted several areas of science and engineering. Both technologies are merged together to build a novel laser system of microspheres in a hollow fiber. Solid microspheres and liquid droplets show nonlinear optical effects, such as second and third harmonic generation, four wave mixing, two photon absorption, stimulated Raman scattering, and lasing phenomena. Many of these effects are observed with laser intensities, which are orders of magnitude less than that required by threshold conditions for interactions in macroscopic bulk media. This could be attributed to the following reasons:

1. The front surface of the microsphere acts as a thick lens to enhance the internal intensity of the input laser radiation,
2. The spherical shape of the droplet acts as an optical cavity to provide feedback at specific wavelengths corresponding to whispering gallery modes or morphology dependent resonance (MDR).
3. The small mode volume and long photon storage time leads to a strong resonant buildup of energy in micro scale volumes which significantly reduces the threshold for lasing and for nonlinear optical effects to occur.

The most interesting finding in these microspheres research activities is the existence of resonance peaks in linear and nonlinear optical spectra. Such resonance peaks are dependent on particle morphology, size, shape, and refractive index of the particles. These resonance peaks are referred to by several names, such as, structural resonance, whispering gallery modes, creeping waves, circumferential waves, surfaces modes, and virtual modes. All of these names refer to the same phenomenon of morphology dependent resonance (MDR), which has already been described and predicted precisely by electromagnetic theory and Lorentz-Mie theory since 1908. Whispering-gallery-mode lasers have been demonstrated from the early days of lasers. Lasing has also been reported in ethanol droplets doped with Rhodamine and on polystyrene spheres covered with rhodamine. Pure silica microspheres have been demonstrated in our laboratory to provide a permanent system that combines relatively small mode volumes with the highest Q's ($>2x10^9$) corresponding to photon storage times of the order of one microsecond.

The resonance peaks become more prominent when the particle size approaches and exceeds the wavelength of the laser used and the refractive index of the particle is greater than that of the surrounding medium. Microspheres confine light both spatially through their tiny volumes and temporally that is described by the quality factor (Q), which is the photon storage time, normalized with respect to the frequency of oscillation. Light within the microsphere is confined by continuous total internal reflection near the cavity perimeter. Silica microspheres are of interest for a variety of studies ranging from fundamental physics such as cavity Quantum Electrodynamics to more applied areas such as low threshold and narrow line-width lasers, as well as high sensitivity transducers for biochemical sensing. Kwok et-al [1] observed lasing in laser-coumarin 460 dye -doped in ethanol droplets due to two-photon absorption from an input laser at 629.6 nm. Enhanced lasing emission from dye doped 2.6 μm polystyrene spheres have also been observed by Sheng et- al [2]. Microspheres monodispersity gives each particle the same optical properties when exposed to laser light. The work on microdroplets and solid microspheres has remained in most part a mere laboratory tool. Our novel system of merging the solid microspheres science and the fiber technology to build a laser system is the first of its kind to our knowledge.

Our results on dye-doped microspheres showed the potential for lasing actions from silica microspheres doped with rhodamine-6g laser dye. We examined several sizes of silica and polystyrene microspheres ranging between 5-20 microns. The spectral features of radiation emitted by the microspheres were examined using a 1200-grooves/mm, 750 mm spectrometer with a computer-controlled deriver using Lab View software. The second harmonic from a Q-switched Nd:YAG laser at 532-nm and operating at 10Hz excited the particles in 1mm optical path length cuvette. The microspheres were purchased at a concentration of 1% solid in a viscous fluid to slow down the sedimentation process.

The spectral data of silica microspheres show more prominent equally spaced laser lines. The whispering gallery modes are 5nm equally spaced and peaked at 565.5nm for the 12-micron spheres while they are 4nm equally spaced and peaked at 563.5 nm for the 5-micron spheres. The criteria for lasing at a pumping energy above the threshold energy, is when the perimeter of the sphere equals multiple numbers of the fluorescence waves ($2\pi r=N\lambda$), where N is the number of modes. The modes are spaced by spacing=$c/(2\pi rf)$ apart, where f is the ratio of index of refraction of the sphere to the refractive index of the hosting fluid. The threshold for lasing in silica microspheres doped with rhodamine 6g occurred at about 2.3×10^4 W/cm^2.

System design

There are two distinctive means of pumping the microspheres inside the hollow fiber. In the first design, the proper size microspheres for a specific band are injected into a hollow double cladding fiber. The inner cladding is used for pumping the spheres and the second cladding for collecting the lasing emission from the microspheres. In the second design, the microspheres doped with lasing materials are injected into a single cladding hollow fiber. The pumping in this case is not guided along the fiber as in the first design but it will be a side pumping through the transparent cladding. The fiber is rapped in multilayer on a hollow Pyrex glass cylinder and the pumping xenon lamps are mounted inside and outside the cylinder. One end of the fiber will be sealed and coated with a highly reflective coating to allow the lasing energy from the fiber to come out from only one end of the fiber.

References:

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