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Spherical Leaky Wave Active Scattering

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In 1978, N. G. Alexopoulos and N. K. Uzunoglu(1) published a paper in which they extended the classical Mie theory for scattering of an electromagnetic plane wave from a dielectric sphere to include spheres with a complex dielectric constant which represents gain. These theoretical predictions of unbound scattering cross section were not observed experimentally until 1989 when Mendenhall, Stafsudd and Alexopoulos(2) reported observation of these predicted resonances in dielectric slabs with gain. Their experimental observations confirmed that the very large resonances predicted were real and that they corresponded to the interaction of the external electromagnetic plane wave with the radiative modes of the dielectric structure. The unbound resonances occurred when the gain of the dielectric object just exactly offsets the radiative loss of a particular radiative mode.

Dielectric spheres, like other dielectric objects, support two kinds of electromagnetic modes, i. e. those that radiate and those which do not.(3) These modes are sometimes referred to respectively as leaky(radiative) and trapped(bound). If the dielectric object is within a dielectric sea and the seas dielectric constant is greater than that of the object, then only radiative modes exist in this case. It is absolutely critical that no trapped modes should exist in order to observe undamped radiative modes. This is due to the practical fact of gain saturation. If a trapped mode exists, then no gain is required to make it lossless. If, however, spontaneous radiation from the gain medium feeds this mode, then it will grow exponentially with time, because its gain exceeds its loss, until saturation eventually reduces the gain. This value of gain will always be less than that necessary to turn on the lossless radiative modes. In this study, we show that anomalous scattering of a plane wave from active spheres corresponds to similar interactions with lossless leaky modes. The diameter of the sphere and the real part of the index of refraction determine the resonant frequencies while the imaginary part of the refractive index has a threshold value to make up for its radiation loss of the mode.

Individual spheres could be manipulated and placed in the center of the scattering apparatus as shown in Fig. 1. The pump energy to supply the population inversion (gain) came from a XeCl excimer pumped dye laser operating at the wavelength of 514nm. The pump intensity was 1.2MW/cm^2 in a pulse duration of 8-ns. The wavelength of the pump was chosen to correspond to the maximum of the absorption coefficient of the Rhodamine 6G dye. The broad normal fluorescence of the Rhodamine 6G dye is evident in Fig. 2. The details of the sharp emissions from the resonant modes of the sphere can be seen in Fig. 3. According to the behavior of the curve in Fig. 4, as the radius of sphere increases the threshold pump intensity decreases uniformly. These experimental results agree with the theory that using a ray model, the gain threshold should be inversely proportional to the radius of sphere.

The lossless radiative modes of a spherical active particle have been observed for the first time. We believe that earlier researchers were unable to observe these resonances because their experiments allowed the presence of the bound modes. If bound modes exist, their thresholds are always lower than the radiative, or unbound, modes. The unbound modes use the gain to increase their intensity and via saturation reduce the gain below the threshold values for the desired unbound modes.

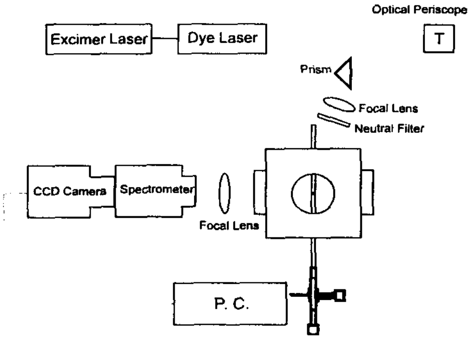

Fig. 1. The experimental arrangement for the measurement of the active scattering experiment.

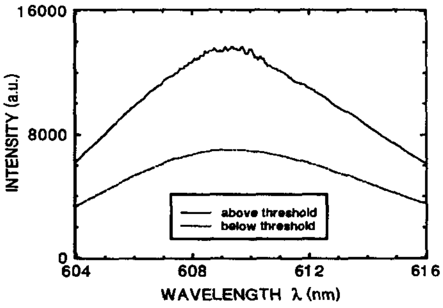

Fig. 2 Total emission spectrum for a dye sphere having dye concentration=2.0g/l, a=0.54±0.01mm.

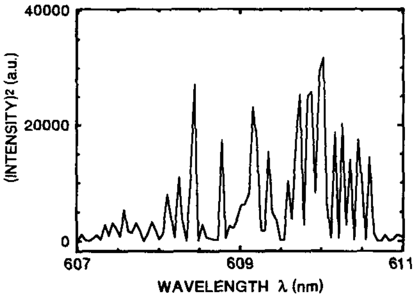

Fig. 3 Active scattering intensity for a sphere having dye concentration =1.8g/l and a=0.45±0.01mm.

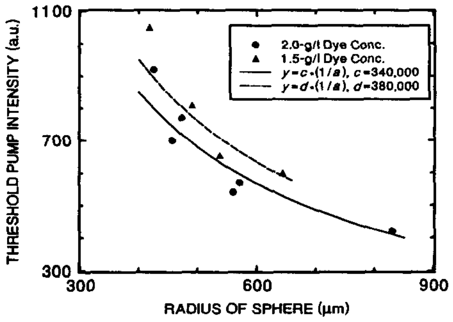

Fig. 4. Comparison of estimated relative threshold pump intensity as a function of radius.

References

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2. S. N. Mendenhall, O. M. Stafsudd, and N. G. Alexopoulos, "Resonant optical interactions in active dielectric films," J. Appl. Phys. **66**, 4645-4652 (1989).
3. J. A. Kong, *Electromagnetic Wave Theory*(John Wiley & Sons, Inc., New York 1985).