원통형 유전체 광 증폭기에 대한 연구

Dielectric Cylinder Optical Amplifier

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The electromagnetic wave scattering from active objects has only recently attracted attention.(1)-(3) Theoretical studies have considered normal-incidence plane-wave interactions with active dielectric cylinders with the prediction of large enhancements in the scattered field for bound mode structures. According to the theory of the electromagnetic wave scattering from a dielectric cylinder, the eigenvector solutions are discrete and have both guided (non-radiative) and leaky (radiative) mode solutions. By using an anti-guiding (leaky) structure instead of a guided structure and scattering at oblique incident angles near critical angle, the scattering resonances predicted by theoretical studies were obtained for the first time. A fine-grained scan of the plane-wave incident angle α reveals the existence of discrete scattering resonances. The diameter and real part of the index of refraction determine the resonant conditions and the imaginary part of the refractive index has a threshold value to make mode up for its radiation loss. The cross coupling between transverse electric (TE) and transverse magnetic (TM) modes is clearly detected for both active and passive scattering as theoretically expected.

The propagation of a leaky waveguide mode in the cylindrical region is governed by $\exp[j(m\theta + pz)]$ where m is integer and p is the longitudinal propagation constant for the structure. The resonant leaky modes obey a gain condition and the resonant scattering angle given approximately by

$$1 - R_{21}\exp\left({g_q d}/{\cos\theta_{2q}} \right) = 0 \;, \quad \alpha_q = \arccos\left(\frac{n_{2r}\sin\theta_{2q}}{n_1} \right) \qquad q = 1, 2, 3, ... \qquad (1)$$

where R_{21} is the TE (TM) Fresnel intensity coefficient of reflection at the boundary, λ is the free-space wavelength of the mode, q is the mode index g_q is the required intensity gain coefficient. According to the result of theoretical calculation, scattering resonances are achieved at discrete plane-wave incidence angles α near the critical angle as shown in Fig. 1.

Experimentally, active scattering is achieved by exciting the laser dye with a short and powerful pump pulse while simultaneously scattering from the excited region with a 10 mW polarized He-Ne probe beam operating at a wavelength of $0.6328\mu m$. The pump beam is a 20-nS pulse from a XeCl excimer pumped dye laser tuned to $0.503\mu m$. By rotation of the polarizer both TE and TM scattered light was recorded. The detector system was mainly a photomultiplier tube (S-20). Fig. 2 shows the detected TM-polarized active and passive scattered intensities. Note that active scattering resonances occur at or near the angles that the passive scattering is minimized. Figure 2 also clearly supported the theory that predicted a cross coupling between TE- and TM-modes. Figure 3 shows the detected amplitudes for different pumping levels. Although the amplitude of active scattering decreases as the gain decreases, the resonant modes occur at almost same incident angles. Figure 4 illustrates the behavior of gain threshold of resonant mode as a function of the bore tube radius. As we expected, the gain required to excite the resonant modes should be higher for smaller bore tube than for larger one. Phase-matched resonant electromagnetic scattering from active dielectric cylinder has been observed. These resonances correspond to the phase-matched excitation of unattenuated leaky waveguide modes on the active cylinder structure. The cross coupling between TE and TM electromagnetic scattering from active circular cylinders has been experimentally observed.

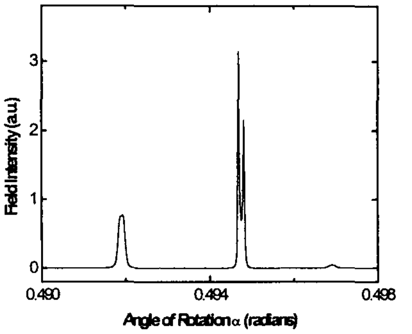

Fig 1. Electric-field intensity for the first TE mode as a function of scattering angle α for a cylindrical dielectric waveguide structure.

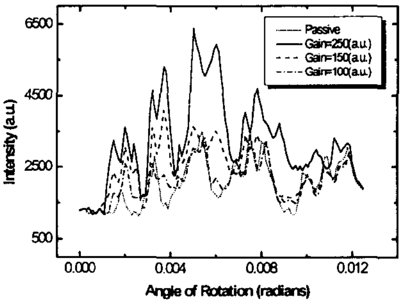

Fig. 3 Comparison of the TM-polarized active scattered intensity as a function of rotation angle near the critical angle with the TE-polarized incident probe for several pumping levels.

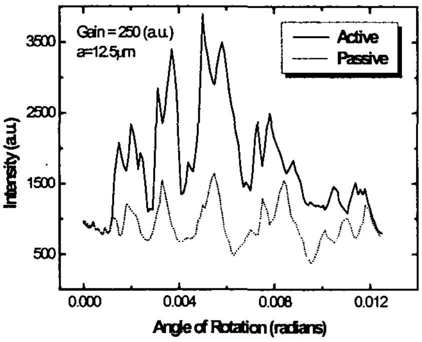

Fig. 2 Active and passive scattered intensities (TM polarization) verses angle of rotation near the critical angle with a TE-polarized incident probe for a 25-μ m-diameter cylinder.

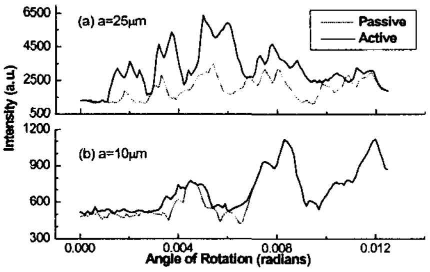

Fig. 4. A comparison of the active scattered intensity as a function rotation angle for different bore tube radii, (a) a - 25 μm and (b) a - 10 μm at the same pumping level (gain-250 a.u.).

References

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