에바네슨트파에 의해 증폭된 전반사의 양자이론

Quantum Theory of Amplified Total Internal Reflection by Evanescent Wave

Chang-Woo Lee, Jaewoo Nho*, Wonho Jhe
Center for Nearfield Atom-Photon Technology, Seoul National University, Seoul, Korea
*Inha University, Incheon, Korea
elfie@mulli.snu.ac.kr

The amplification method using evanescent wave coupling has a long history and has been widely used as a new lasing method, especially, in the waveguide optics(1). In particular, it has been observed experimentally that when the light wave propagating in a dielectric medium is totally reflected at the planar interface between the dielectric and a pumped active medium, the reflectance may be greater than unity, i.e., amplification is possible(2). There were several attempts by other authors to explain this enhanced internal reflection (EIR) classically(3). They commonly introduced a complex refractive index for the active medium with its imaginary part being negative, and this scheme was also used to describe an amplification process in a waveguide having active-cladding region(4). However these theories are phenomenological, using macroscopic constants, and therefore a microscopic theory is needed to understand EIR in a fundamental level.

Even though there is a quantum theory of evanescent field(5), the stimulated emission process was not treated by a quantum-mechanical method, thus overlooking the possible interesting behavior of an atom coupled to the evanescent wave. Therefore we present a quantum-mechanical description of light amplification by the stimulated emission of the evanescent photon mode and shows that the cavity QED effect which is absent in the classical theory might be crucial in EIR or general evanescent-field amplifiers (EFA). Moreover, our theory is a lasing theory that is absent in the usual text book, hence offers a deeper understanding of the photon mode concept in the evanescent-field-present system.

Using the quantized field of Carniglia and Mandel (triple mode), we have calculated the spontaneous emission rate (Einstein's A coefficient), and derived optical gain formula or reflectance of EIR.

$$I/I_0 = 1 + \int_{z>0} G \; dz$$

Here G is the evanescent-gain coefficient, and in the non-saturation limit of incident light wave

$$G_\alpha = G_0 \frac{A^0_{21}}{A_{21}} \frac{|\,\boldsymbol{E}_\alpha(\boldsymbol{r})|^2}{\cos\theta},$$

where α denotes the mode index (incident wave direction, polarization, and so on), G_0 is the ordinary gain coefficient of laser system, and $A_{21}(A^0_{21})$ is the modified (ordinary) spontaneous emission rate of an atom coupled to evanescent wave.

Our theoretical calculation shows good agreement, in the order of magnitude, with the previous experimental results.

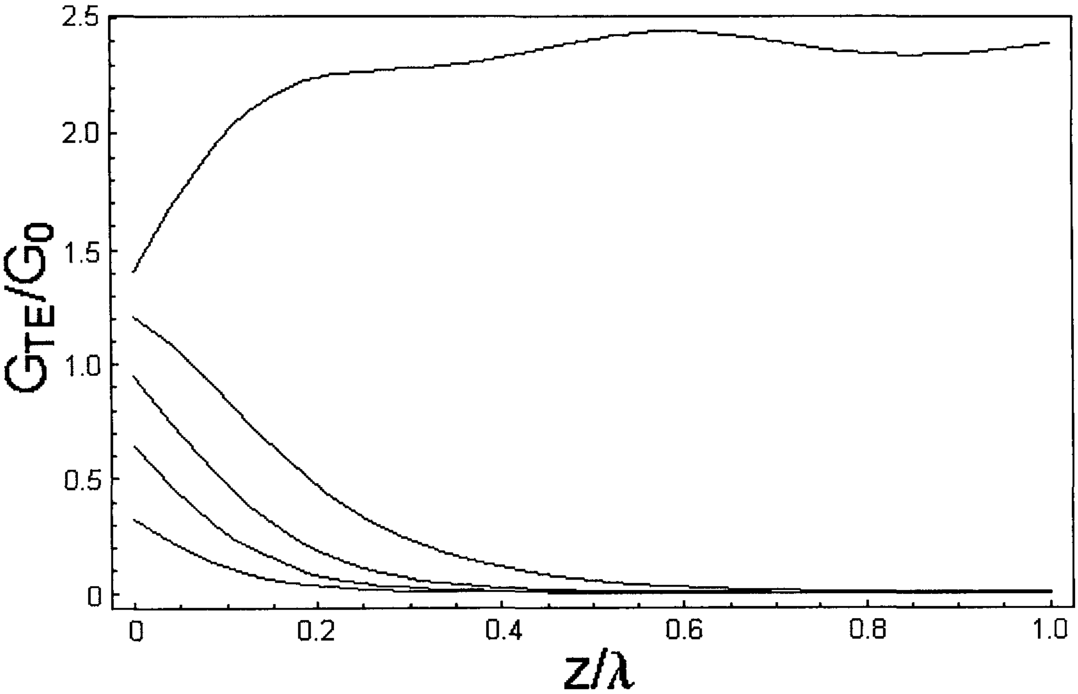

Fig 1. Gain coefficients of TE wave (s-polarization) according to z with incident angle $\theta = 80^\circ, 70^\circ, 60^\circ, 50^\circ, \theta_c$ from the lowest one. Note that the gain coefficient at $\theta = \theta_c$ has the smallest value at $z = 0$ due to the largest decay rate at that boundary.

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