Influence of a Magnetic Field on the Energy Flow of Surface Polaritons Propagating in Semiconductor Cylinders

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This work reports the influence of a dc external magnetic field on the polaritons propagating in cylindrical systems. We present numerical results for the dispersion relation and energy flow for surface polaritons modes propagating in hollow and massive cylinders made of GaAs and InSb.

1 Introduction

The energy flow plays an important role in the study of the transport properties by the analysis of the behavior of energy rate transported by the system. This work studies the propagation of the energy by polaritons propagating in coaxial semiconductor cylinders, submitted to a constant magnetic field. The cylindrical geometry presents some peculiarities that make it very different from the planar and spherical geometries. In a coaxial cylinder, the presence of new interfaces provokes the appearance of new branches in the dispersion relation, even if the magnetic field is absent[1]. The presence of a magnetic field applied on a semiconductor cylindrical system, causes significant alterations in the modes of propagation of polaritons. One of the main effects of the application of the field is to promote the decoupling between the electric transverse (TE) and the magnetic transverse (TM) modes, by the elimination of the TE mode [2].

2 The model

The system under consideration is an infinite coaxial cylinder of internal and external radii designated by **a** and **b,** respectively, submitted to a magnetic dc field applied parallel to the z-axes. The geometry of the system defines three different regions: Region I $(0 < r < a)$, region II $(a < r < b)$ and region III $(r > b)$ that we consider The infinite, homogeneous and isotropic as the vacuum. If the cylinder is not hollow, we have two optically active medium, characterized by a magnetic permeability μ_0=1.0 and dielectric tensor given by ε_j, where j=I, II, III [3]. The electromagnetic fields for the electromagnetic modes can be written as

$$\overrightarrow{E} = [E_r(r), E_\theta(r), E_z(r)]\, S_n \tag{1}$$

$$\overrightarrow{H} = [H_r(r), H_\theta(r), H_z(r)]\, S_n, \tag{2}$$

With

$$S_n = \exp\left[i\left(kz + n\theta - \omega t\right)\right] \tag{3}$$

Different from the spherical and planar geometry, we cannot find independent solutions for the transverse electrical (TE) modes (*Ez* = 0) and transverse magnetic (TM) modes (*Hz* = 0) in this case. Thus the fields in cylindrical systems are, in general, a linear combination of these two modes.

We consider the solutions of Maxwell's equations in cylindrical coordinates for polaritons propagating parallel to the axis of the cylinder, and using the usual boundary conditions that ensure the continuity of the electromagnetic fields at the interfaces we obtain the dispersion relation for the surface polariton modes. The energy flow is obtained by the calculation of the time average of the Poynting vector calculated for the three regions and it is given by

$$\begin{aligned}\langle S_j\rangle = \tfrac{\omega k}{8\pi}&\left[\left(k^2 - \tfrac{\omega^2}{c^2}\varepsilon_{1j}\right)^2 - \left(\tfrac{\omega^2}{c^2}\varepsilon_{2j}\right)^2\right]^{-2} \times \\ &\left\{\left\{\tfrac{n}{r}\varepsilon_{2j}k^2E_{zj} + \tfrac{dE_z}{dr}\left[\varepsilon_{1j}\left(k^2 - \tfrac{\omega^2}{c^2}\varepsilon_{1j}\right) + \tfrac{\omega^2}{c^2}\varepsilon_{2j}^2\right]\right\} \times \left\{\tfrac{n}{r}\tfrac{\omega^2}{c^2}\varepsilon_{2j}E_{zj} + \left(k^2 - \tfrac{\omega^2}{c^2}\varepsilon_{1j}\right)\tfrac{dE_z}{dr}\right\} + \right. \\ &\left.\left\{\tfrac{n}{r}\left[k^2 - \tfrac{\omega^2}{c^2}\varepsilon_{1j}\right]E_{zj} + \tfrac{\omega^2}{c^2}\varepsilon_{2j}\tfrac{dE_z}{dr}\right\} \times \left\{\tfrac{n}{r}\left[\varepsilon_{1j}\left(k^2 - \tfrac{\omega^2}{c^2}\varepsilon_{1j}\right) + \tfrac{\omega^2}{c^2}\varepsilon_{2j}\right]E_{zj}\right\} + k^2\varepsilon_{2j}\tfrac{dE_z}{dr}\right\}\end{aligned} \tag{4}$$

3 Conclusions

The result represented by Eq. (4) is completely general, so it can be applied for any coaxial cylinder and also includes the limit in which the internal radius goes to zero. The numerical results are obtained for the surface polaritons propagating in semi-conductors cylinders of GaAs and InSb,

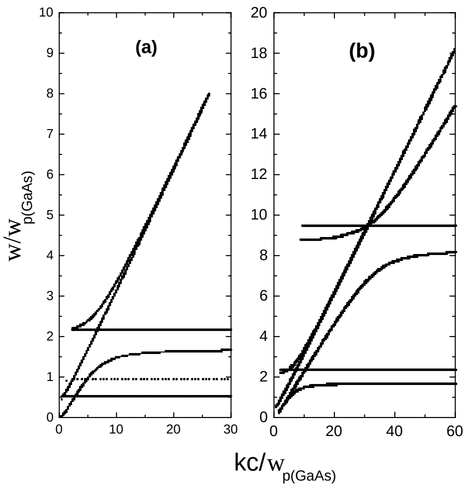

Figure 1. Dispersion relation: (a) Hollow cylinder made of GaAs; (b) Cylinder of InSb covered by a cladding of GaAs. The radii are: a=50nm and b=100nm. B=5000 G. The dotted line in Fig 1(a) corresponds to the case without external magnetic field. $\omega_{p(GaAs)}$ is the plasma frequency to the GaAs.

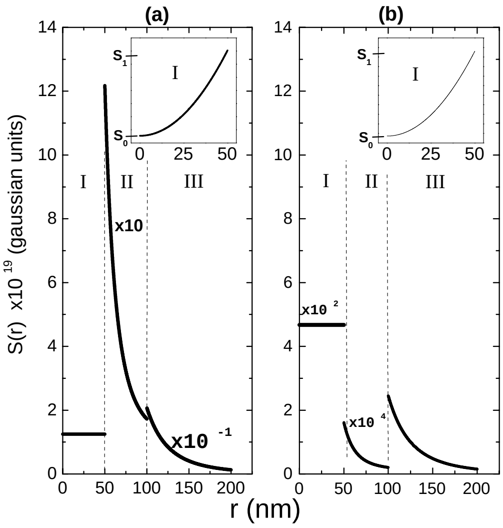

Figure 2. Energy flow, S(r): (a) Hollow cylinder made of GaAs; (b) Cylinder filled with InSb. ω/ω_p=10.0 and kc/ω_p=3.3. The magnetic field B=5000G. In detail the region I, where S_0=1.24883x10^{19} and S_1=1.24884x10^{19} in (a); S_0=4.675336x10^{21} and S_1=4.675338x10^{21} in (b).

whose effective mass and high-frequency dielectric constant, are, $m = 0.067 m_e$, $\varepsilon_\infty = 10.9$ for the GaAs, and $m = 0.0135 m_e$, $\varepsilon_\infty = 15.68$ for the InSb. The density of carriers, $n = 1.4 \times 10^{14}$ cm^{-3}, is the same for both materials. The results are shown in the Figs. 1, 2 and 3. In Fig. 1 we show the dispersion relation for two kinds of materials and in the Figs. 2 and 3 we show the energy flow. We study the effect of the magnetic fields whose maximum intensity

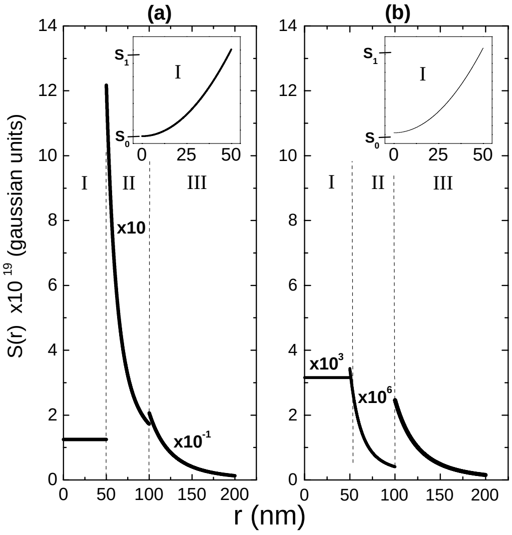

Figure 3. Energy flow, S(r): Hollow cylinder made of GaAs: (a) B=5000 G; (b) B=500 G. ω/ω_p=10.0 and kc/ω_p=3.3. In detail the region I, where S_0=1.24883x10^{19} and S_1=1.24884x10^{19} in (a); S_0=3.157236x10^{22} and S_1=3.157238x10^{22} in (b).

is 0.5T. The maximum values for the energy flow occur near the interfaces and in the intermediate region (**a** $<$ **r** $<$ **b**) the intensity is bigger than in the other regions. The internal energy flow can be positive or negative, in contrast of that it occurs in the field absence [4], where the energy flow is always negative inside the cylinder. The signal of the energy flow determines the propagation direction, what it is confirmed by the determination of the speed of transport of the energy, by the analysis of the dispersion relation [2]. The energy flow decreases when the external magnetic field increases. When we fill the cavity with another semiconductor (InSb), we observe that new modes appear in the dispersion relation and the energy flow presents intensity bigger than the hollow cylinder. The effect of an external magnetic field is to vanish the TE mode. Because of this decoupling the external dc magnetic field can be seen as a polarizer that eliminates the TE mode. We also observe the existence of one mode in low energy range ($\omega \rightarrow 0$ when $k \rightarrow 0$). This means that fields with magnitude almost constant in long regions of the hollow cylinder can be found.

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