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Terahertz waves propagation through an inhomogeneous collisional magnetized plasma slab

Z. Rahmani*, H. Moradi

Department of Laser and Photonics, Faculty of Physics, University of Kashan, Kashan, Islamic Republic of Iran

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ABSTRACT

Propagation of terahertz waves through an inhomogeneous collisional magnetized plasma layer is studied. The plasma has bell-like electron density distributions, but collision frequency is constant. The transmission, reflection and absorption of s-polarized wave obliquely incident on the plasma slab, are found using the impedance matching method. Here the external magnetic field is uniform and its direction is perpendicular to inhomogeneity direction and parallel with the plasma surface. The effects of the incident wave characteristics, such as frequency of the electromagnetic wave and its incident angle, and plasma parameters, such as the inhomogeneity coefficient, cyclotron frequency and collision frequency on transmission, reflection and absorption are investigated.

1. Introduction

Many investigations have been done about the interaction between electromagnetic (EM) waves and plasmas because of its widespread applications in many fields, such as plasma physics, radio wave propagation, plasma diagnostics with microwaves, plasma stealth, and air chemistry [1–8]. A plasma layer by carefully adjusting of the plasma parameters, such as the collision frequency, electron density profile, thermal velocity of electrons and external magnetic field strength can be tuned to behave as a good reflector or as a good absorber [9–13]. The metallic targets are easily detectable due to their highly reflecting nature. The reflection can be reduced by using the low observable techniques. Plasma is one of these choices for controlling the reflections from the surface. A collisional plasma, which has a complex dielectric constant, can be used as a good absorber of EM waves over a wide range of frequencies [14–16]. Vidmar [17] has shown that cold, collisional plasma generated at atmospheric pressure can be used as a broadband absorber.

Considering a plasma slab in entirely homogenous form is an ideal status and almost all of laboratory and natural plasmas seen in the practical situations are nonuniform. In the majority of literatures, in order to investigate of inhomogeneous plasma layer, it is divided to very thin homogenous sub-slabs so that in each sub-slab, plasma properties are constant. Then reflection, absorbtion and transmission coefficients of the plasma in multilayered form are recursively obtained [18,19]. The most of these investigations are limited in the microwave or gigahertz frequency range. In recent years, terahertz waves have found applications in different fields, such as physics, material science, electrical engineering, chemistry. In addition, new researches show its applications in biology and medicine. With sensing THz applications and short-range communications possible in the 10- to 100-μm range, the technology and applications for waves are growing rapidly [20]. There are a number of communications applications where THz waves will provide new capabilities and also applications in explosive

* Corresponding author.
E-mail address: z.rahmani@kashanu.ac.ir (Z. Rahmani).

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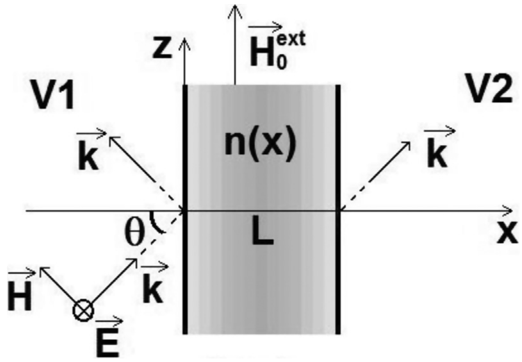

Fig. 1. Geometrical configuration of the considered problem for S-polarized EM wave obliquely incident on the plasma slab surrounded by vacuum.

and biochemical agent detection, mine detection, high-resolution through-the-wall imaging, etc. [20]. Many experimental and theoretical works are organized on the interaction of terahertz waves and plasmas [21–23]. Some investigations indicate that increasing the carrier frequency to terahertz band is a potential way to solve the blackout problem [24]. The effects of layer size, electron density profile, and collision frequency on the propagation of THz waves through an unmagnetized microplasma are analyzed numerically in reference [25].

In this paper, the propagation of terahertz waves from an inhomogeneous collisional magnetized plasma slab immersed in an external uniform magnetic field will be investigated. The novelty of the present work is that interaction between an inhomogeneous plasma slab and terahertz waves has been studied as a general problem without dividing the slab into uniform sub-slabs and inhomogeneity effect is entered in dielectric permittivity matrix of plasma slab. On the other hand, unlike the earlier works in this field, the incident wave frequency has been considered in terahertz range. In previous papers the electromagnetic wave is normally incident to plasma layer whereas in this paper, the effect of the incident angle of THz wave will be considered. In addition, the effects of the inhomogeneity coefficient, the external magnetic field, collision frequency and the frequency of the incident wave on transmission, reflection and absorption are studied by theoretical analyses.

2. Configuration and basic equations of the problem

As shown in Fig. 1, we have supposed a plasma layer with thickness L that is bounded by two semi-infinite vacuum regions from the right and left.

Here the plasma is considered as cold collisional magnetized inhomogeneous. A plane and monochromatic terahertz wave with linear polarization is incident on the plasma surface from vacuum region $V1$. Moreover we assume that the frequency of the incident wave is sufficiently high so that the ions remain immobile in the plasma, and thus the current of the system is given by the electron conduction current. As seen in Fig. 1, the external steady-state magnetic field $\vec{H}_0^{ext}$, is assumed along the z-axis and plasma density varies along the x-axis. Similar to the majority of actual plasma, the electron density profile is considered bell-like profile as [26]

$$n_e(x) = n_{e0}[1 - \chi(x - L/2)^2] \tag{1}$$

where L is the plasma slab thickness, n_{e0} is the maximum density of electrons at $x = L/2$, and χ is a constant parameter. Furthermore, we assume that the transmitted electromagnetic wave is s-polarized as the following form

$$\vec{E} = (0, E_y(x), 0)\exp(ik_z z - i\omega t), \vec{H} = (H_x(x), 0, H_z(x))\exp(ik_z z - i\omega t) \tag{2}$$

where $\omega = 2\pi f$, f is the incident wave frequency and the k_z represents the wave vector component along the z-axis. In this work we use from the impedance matching (IM) method to study EM waves propagation through inhomogeneous plasma slab. This method is extensively applied in engineering to study the propagation of EM waves in plasma layers [15,22]. In IM method the continuity conditions of the tangential components of the electrical and magnetic fields at boundaries are applied to obtain the reflectance, transmittance and absorbance coefficients of plasma slab. By introducing the local wave impedance as $Z = E_t/H_t$ and applying Maxwell's equations to obtain the field components, the wave impedance in the region V1 can be expressed by:

$$Z_{v1}(x) = Z_v \frac{\exp(ik_x x) + r\exp(-ik_x x)}{\exp(ik_x x) - r\exp(-ik_x x)}, \tag{3}$$