PERFORMANCE CHARACTERISTICS OF MAGNETOPLASMON BASED SUBMILLIMETER WAVE NONRECIPROCAL DEVICES

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ABSTRACT

Results will be presented for nonreciprocal devices in the submillimeter range using magnetoplasmons on high quality n-type GaAs materials. Performance predictions are based on multi-layer canonical structures yielding both loss and dispersion data.

This is a report on our recent progress in a study of the feasibility of using surface magnetoplasmons on semiconducting substrates in signal processing devices such as isolators, phase-shifters, circulators and directional couplers, in the millimeter and submillimeter range.

A low loss semiconducting material such as n-type GaAs has been taken as the substrate material with a carrier concentration equivalent to a plasma frequency $\omega_p = 10^{13}$ rad/s and with a momentum relaxation time of the order of $\tau = 8 \times 10^{-12}$s. For the range of frequencies of interest to us, the interaction of the material with the applied electromagnetic field is well described by the local theory of plasmas (Drude model). The approximations introduced by this theory were described elsewhere.[1]

Anisotropy is induced when the material is exposed to a uniform d.c. magnetic field, yielding a cyclotron frequency of $\omega_c = 10^{12}$ rad/s. This value has been used throughout the calculations presented here.

An important achievement in connection with our computations was the utilization of a very reliable and efficient algorithm for finding the roots of the dispersion relation of the system, i.e., the values of the complex propagation constant yielded by complex solutions of a complex transcendental equation. This was obtained using Davidenko's approach.[2,3]

Two simple canonical structures have been studied[1] (see Figures 1a and 1b) and a third, more complicated one, is under consideration. The geometries of Figures 1a and 1b have been analyzed for both the isotropic and the anisotropic cases, with the d.c. magnetic field in the y-direction (Voigt configuration).

With regard to the latter situation, surface waves with nonreciprocal propagation characteristics are observed in the single GaAs interface case. A direct consequence is the field displacement effect that appears in the case of the semiconducting slab. This effect is analogous to that which was already observed in the case of anisotropic ferrite slabs in the microwave region[4,5,6], which led to the design of devices such as nonreciprocal isolators and differential phase-shifters.

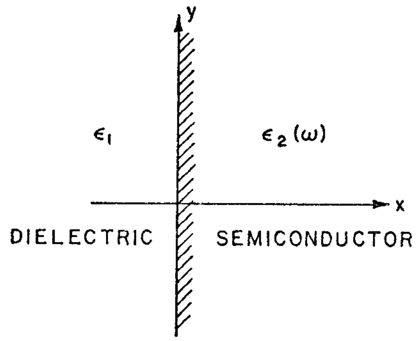

Figure 1a Single dielectric-semiconductor interface model.

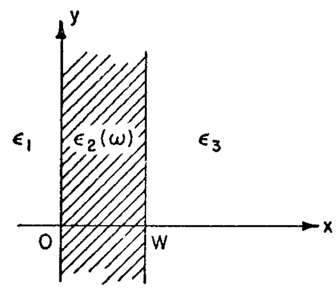

Figure 1b Semiconducting slab sided by dielectric.

Figure 2 shows the complete modal structure for the air-semiconductor (anisotropic) interface. The regions of interest of the ω - β diagram are essentially those where the effective dielectric constant of the n-GaAs is negative, that is, for $\omega < \omega_o^{(1)}$ and $\omega_\infty < \omega < \omega_o^{(2)}$.

The case of a slab of magnetized n-GaAs sided by air is presented in Figure 3 and can be viewed as two interacting air-semiconductor interfaces. Thus, the ω - β diagram of Figure 3 is closely related to that of Figure 2.[1] Notice the corresponding labelling of the different branches in both figures.

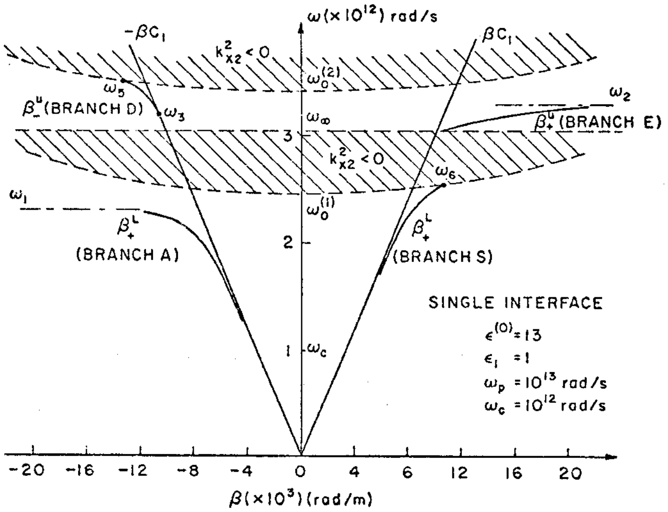

Figure 2 Dispersion diagram of single dielectric-anisotropic n-GaAs interface. The semiconductor is assumed to be lossless.

Since loss characteristics are of primary interest to us, however, collisions in the GaAs must be considered. Figure 4 shows the dispersion and loss characteristics for the same configuration as in Figure 3, for $\tau = 8 \times 10^{-12}$ sec. We observe that with increasing frequency all branches become highly attenuated as more electromagnetic energy then travels within the lossy slab.

Nevertheless, branches A and S both exhibit attenuations of 0.5dB/mm or less below 270 GHz and 370 GHz, respectively.

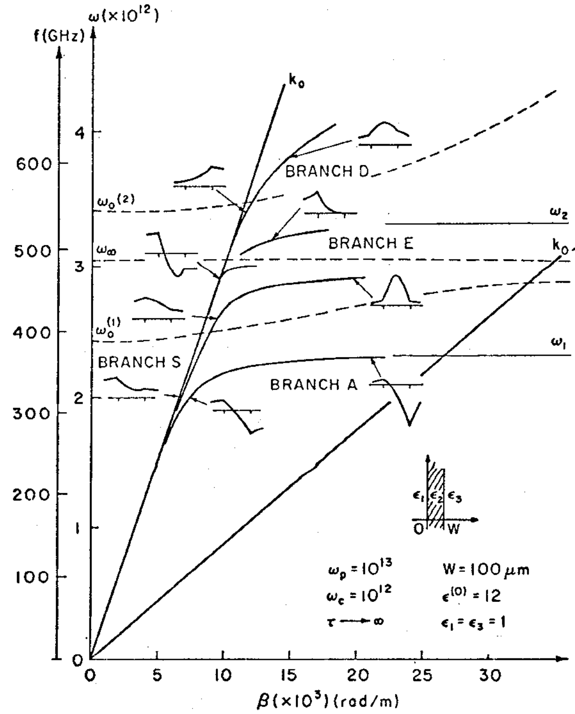

Figure 3 Dispersion diagram for the symmetrically loaded anisotropic n-GaAs slab. The semiconductor is assumed to be lossless.

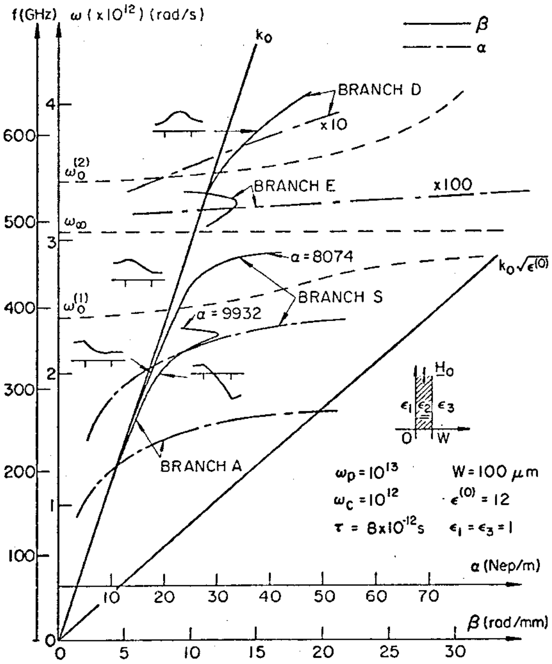

Figure 4 Same as for Figure 3. Losses in the semiconductor are now taken into account.

The prospective utility of this result becomes apparent when we load the sides of the semiconducting slab with different dielectric media so as to obtain nonreciprocal behavior. A typical result is shown in Figures 5 and 6, where it can be seen that branch S is now unidirectional. Notice that between 240 GHz and 340 GHz branch S has an attenuation of 0.5dB/mm or less while branch A is highly attenuated.

These results, therefore, offer a strong possibility for the design of nonreciprocal isolators. It must be added, however, that in the range of interest the fields extend quite far away from the slab into the higher dielectric constant region ($\varepsilon_1 = 4$).

Although the latter property could appear as a disadvantage in the design of isolators, it offers, on the other hand, interesting possibilities for the design of directional couplers and switches. Indeed, it can be shown that in a more complicated configuration, the extension of the field away from the GaAs slab into the higher dielectric constant region can be controlled. This is done by introducing another dielectric slab at a certain distance from the semiconducting region having a somewhat higher dielectric constant than that of the region between the two slabs.

Moreover, in a model that considers this second dielectric slab, a new branch is observed in the dispersion characteristics which is very similar to the dynamic mode already observed in the case of ferrites.[6] This mode also promises to be useful for isolator design.

For this reason, a study of a five-region canonical structure is in progress. This configuration is appropriate for the modelling of two rectangular dielectric waveguides embedded in a dielectric substrate, one of which is the semiconducting material.

It must be noticed that since the GaAs is lossy, most of the energy should be preferentially guided external to the GaAs slab. For an isolator it is desired that, making use of the field displacement effect, most of the energy travels within the semiconducting slab for one direction of propagation (thus suffering attenuation) while for the other propagation direction the energy is predominantly exterior to the semiconductor.

Dispersion and loss characteristics obtained so far for structures modelling isolators in the near-millimeter range, using currently available high quality GaAs materials, are encouraging.

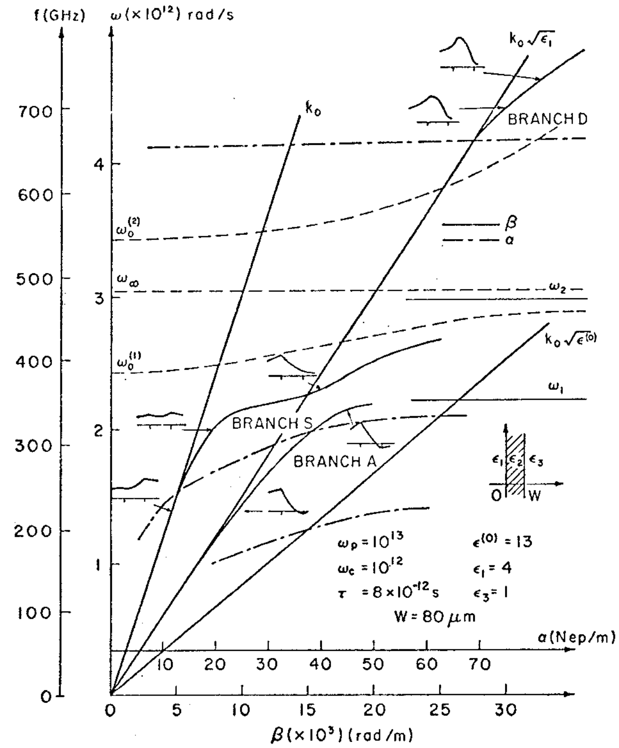

Figure 5 Dispersion diagram for the asymmetrically loaded lossy anisotropic n-GaAs slab.

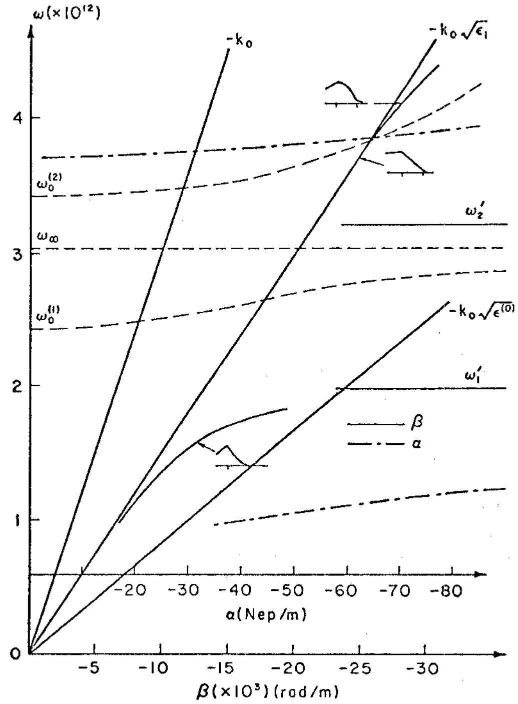

Figure 6 Same case as for Figure 5. Reverse propagation.

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