14-12

EDGE-GUIDED MAGNETOPLASMONS ON CURVED INTERFACES IN SUBMILLIMETER WAVE DEVICES

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ABSTRACT

We consider an interface between dielectric and semiconductor semispaces, curved along the direction of propagation and infinite in the transverse direction. The semiconductor is magnetically polarized in the Voigt configuration. We give approximate expressions for the loss due to curvature.

INTRODUCTION

With the investigation of the submillimeter wave range, interests are in the analysis and design of non-reciprocal components such as circulators, isolators and phase-shifters that will perform the same important role as those available at lower frequencies.

Over a certain frequency range, $\omega_o^{(1)}<\omega<\omega_6$ [1], the unidirectional propagation of surface magnetoplasmons along the interface between dielectric and magnetically polarized semiconducting half-spaces, shows a similarity with the propagation of edge-guided waves (EGW) which occurs at lower frequency on ferrite microstrips [2]. Therefore, all the various structures envisaged for ferrite loaded EGW devices are aimed to be transposed to the submillimeter wave range. With such a feature in mind, the case of a curved interface is studied and expressions for bending losses are derived under the assumption of large radii and low material loss.

THEORY

The two geometries considered are represented in Figure 1.a and b.

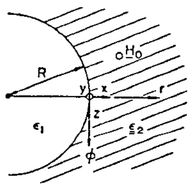

Figure 1.a

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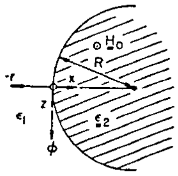
Figure 1.b



The TM modes interact with the anisotropic properties of the semiconductor magnetically polarized in the y-direction [1]. These modes have three components: H_y, E_ϕ, E_r. The electric field components can be expressed as functions of the transverse magnetic field through Maxwell's equations. Assuming a propagation factor $\exp[j(\omega t-v\phi)]$, the wave equation in cylindrical coordinates becomes the well-known Bessel equation:

$$u^2\frac{\partial^2 H_y}{\partial u^2} + u\frac{\partial H_y}{\partial u} + (u^2-v^2)H_y=0 \qquad (1)$$

where in the dielectric region: $u=u_1=k_o\sqrt{\epsilon_1}r$ or in the semiconductor: $u=u_2=k_o\mathrm{SIGN}[\mathrm{Re}\{\epsilon_e\}]\sqrt{\epsilon_e(\omega)}r$; The sign change is needed to insure bounded fields at infinity. The ratio of the Poynting vector S_r to the power carried by the mode P gives the power loss $2\alpha_{rc}$ per unit length of waveguide:

$$2\alpha_{rc}=\frac{2|k_i|}{|\epsilon_i|}\left[\frac{\beta}{\epsilon_1 k_1}+\frac{\beta}{\epsilon_e k_2}-\frac{n}{\xi\epsilon_e}\right]^{-1}\cdot f_c \cdot \qquad (2)$$

$$e^{-(\mathrm{Re}[U_i]\alpha\pi+2k_o n_i)R} \text{ where}$$

$$U_i=\ln\{\mathrm{abs}[\frac{1+k_i}{1-k_i}]\}-2k_i;\ k_i^2=\beta^2-k_o^2\epsilon_i$$

and $f_c=\mathrm{Re}[|\epsilon_e|/\epsilon_e]^{\frac{1}{2}}$; $\beta=v/R$

In the case of Figure 1.a, i=1, $f_c=1$, $n_i=0$ and U_1 is a positive value which increases monotonically with frequency. For constant radius, the power loss decreases as the frequency increases. Such behavior is to be expected since in this case the guide wavelength decreases, thus reducing the effect of curvature. It is also to be pointed out that if the dielectric permittivity increases, U_1 increases and so the power loss due to the curvature decreases, since the higher the dielectric constant, the more energy clings to the dielectric side of the interface and so the less radiation due to the curvature is likely to occur in the dielectric region.

If material loss in the semiconductor is taken into account, the propagation constant v becomes complex. Only the real part of each parameters in the factor in front of the exponential need to be taken if we consider low loss cases. This approximate formula show how the material loss affects the bending loss, which not surprisingly increases as the attenuation constant of the corresponding plane structure increases.

In the case of Figure 1.a, i=2, $\varepsilon_2=\varepsilon_e$ (effective permittivity of the semiconductor), $n_i=n_R=\mathrm{Re}[\sqrt{\mathrm{ABS}\{\varepsilon_e\}}]$ if $\varepsilon_e>0$ or $n_i=n_I=\mathrm{IM}[\sqrt{\mathrm{ABS}\{\varepsilon_e\}}]$ if $\varepsilon_e>0$. U_2 is positive and decreases from infinity (in the lossless case) to zero as the frequency increases within our range of interest $[\omega_0^{(1)},\omega_6]$. Therefore, R being constant, the power loss increases with frequency. This behavior is explained by the fact that the exponential factor in the semiconductor k_2 decreases with frequency, thus decreasing the energy on the semiconductor side of the interface. For negative values of the real part of the effective permittivity, the expression for the power loss is similar to (2) and differs only by the change from n_I to n_R.

RESULTS

The semiconductor is presumed to be a high quality, moderately doped n-type GaAs material, with a carrier concentration of $n \cong 10^{15} cm^{-3}$ which is equivalent to a plasma frequency $\omega_p=10^{13}$ rad/s. At liquid nitrogen temperatures (77 K), mobilities of the order of $2x10^5 cm^2/Vs$ which is equivalent to a momentum relaxation time of $8x10^{-12}$s can be obtained. Here, an hypotetic relaxation time of $100x10^{-12}$s has been considered to satisfy the assumption of low material loss. A biasing magnetic field of 3810 Gauss which is equivalent to a cyclotron frequency $\omega_c=10^{12}$ rad/s is assumed.

				α_{rc}[dB/mm] at R=2 mm	
ω [rad/s]	$50\lambda_g$ [mm]	α[dB/mm] @=10^{-10}s	ε_e	Figure 1.b lossless	Figure 1.b lossy
$1.5x10^{12}$	30	.37	-24.5	5.2	5.4*
$2.2x10^{12}$	18.5	.21	-2.3	1.2	1.4
$2.4x10^{12}$	16	.40	1.56	.054	.073

	Figure 1.a lossless	Figure 1.a lossy
	0	negl.
	0	negl.
	negl.	negl.

*.053 at R=40mm

Numerical examples show that bending loss in the semiconductor is negligible in the case of Figure 1.a and in the frequency range for which the effective permittivity is negative. Indeed, for these frequencies the exponential decay factor k_2 in the semiconducting region is larger than the one in the dielectric region and thus the energy clings more tightly to the interface on the semiconductor side, thus being only weakly affected by the curvature. Bending loss in the case of Figure 1.b, i.e., radiation into the dielectric region due to curvature effects, could be non-negligible. A more accurate analysis should be undertaken if small radii are considered. However, for most cases power loss due to curvature effects can be neglected in the case of Figure 1.a and also in the case of Figure 1.b provided that large radii ($R>50\lambda_g$) are used here. This limit value ensures that the curvature does not deviate by more than 1% from the straight direction, i.e., that we can use $v \cong \beta R$.

CONCLUSION

To conclude it is pointed out that interesting devices such as circulators, isolators, phase-shifters using edge wave-like surface magnetoplasmons should preferably be based on the structure represented in Figure 1.a where the curvature does not introduce excessive loss. Further work is needed to solve the dispersion relation more accurately and to allow extending such conclusions to the more general cases.

REFERENCES

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