SELF-RESONANT LSA OSCILLATOR DIODE OF RECTANGULAR CROSS-SECTION

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In two recent publications [1, 2] *Rode* has proposed an interesting operating mode of the LSA diodes. In this self-resonant mode the semiconductor bulk of negative conductivity operates as an open cavity resonator and therefore the oscillation frequency is determined by the device geometry rather than by an external resonator.

The configuration investigated by *Rode* was a circular cylinder of linear homogeneous, isotropic material with negative conductivity. The exact calculation to obtain the lowest eigenfrequency of this geometry in the E mode is possible and the result is

$$fd = \frac{c}{\pi} \varrho', \tag{1}$$

where d is the diameter of the cylinder, c the velocity of the light in free space and ϱ' the smallest real root of the transcendental equation:

$$\sqrt{\varepsilon} J_0'(\sqrt{\varepsilon}\varrho')/J_0(\sqrt{\varepsilon}\varrho') = H_0^{(1)'}(\varrho')/H_0^{(1)}(\varrho') , \tag{2}$$

where we have the relative permittivity $\varepsilon = \varepsilon_L + j(\sigma/\omega\varepsilon_0)$.

Unfortunately, the cylindrical geometry is unusual for practical applications. The usual geometry for the active layer of the LSA diodes is a rectangular prism. Among the planar geometries the active planparallel layer was investigated in detail only [3—9]. *Chawla* and *Coleman* [6] (whose letter was quoted by *Rode* [2]) as well as *Giannini* et al. [9] fixed the real part of the relative permittivity as $\varepsilon_L = 12$.* For the lowest real eigenfrequency they got the frequency by thickness product as

$$fL = 4.86 \cdot 10^9 \text{ cm/s}.$$

* This is the value of the relative permittivity of GaAs.

This result is far from Rode's fd product. Using Fig. 2 of [1] we have the value of $\varrho' \cong 0.24$ with $\varepsilon_L = 12$. Therefore

$$fd \cong 2.3 \cdot 10^9 \text{ cm/s}.$$

The exactly calculable lowest real eigenfrequencies of the rectangular but open (planparallel) layer and the closed but edgeless cylinder are relatively far from each other. This fact is unconvenient for estimating the eigenfrequency of the rectangular prism from the results given above. In the following we show that the lowest eigenfrequency of a rod with square cross-section and of nega-

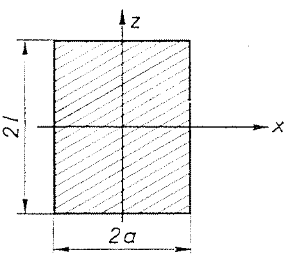

Fig. 1

tive conductivity is far nearer to Rode's result than to the result in [6] and [9]. Thus, we shall apply the geometrical optical considerations of *Vainshtein* [10]. Let the cross-section of an infinite rod be as given in Fig. 1. The only component of E inside the rod is parallel with the y axis. Let it be chosen inside the rod in the following form:

$$E_y = A f_x (k_x x) f_z (k_z z) e^{-j\omega t} \tag{3}$$

where

$$k_x^2 + k_z^2 = k^2 \varepsilon\mu \tag{4}$$

k being the wave number in free space.

Outside the rod the electromagnetic field is represented by an outward travelling plane wave. For example in the region $x > a$, $|z| < l$

$$E_y = A_0 e^{jk_x^0 x} f_z (k_z z) e^{-j\omega t} \tag{5}$$

where

$$k_x^0 = \sqrt{k^2 - k_z^2} = \sqrt{\frac{k_x^2 - k_z^2(\varepsilon\mu - 1)}{\varepsilon\mu}}\,. \tag{6}$$

From Maxwell's equations and the continuity conditions of the fields on the surface $x = a$, $|z| < l$ we have the equation:

$$\frac{f_x'(k_x a)}{f_x(k_x a)} = j\mu \frac{k_x^0}{k_x} \tag{7}$$

and similarly

$$\frac{f_z'(k_z l)}{f_z(k_z l)} = j\mu \frac{k_z^0}{k_z} \tag{8}$$

is also valid where

$$k_z^0 = \sqrt{k^2 - k_x^2} = \sqrt{\frac{k_z^2 - k_x^2(\varepsilon\mu - 1)}{\varepsilon\mu}}\,. \tag{9}$$

Looking for the most homogeneous distribution of the field corresponding to the lowest eigenfrequency we may suppose that

$$f_x\,(k_x\,x) = \cos\,(k_x\,x) \tag{10}$$

and

$$f_z\,(k_z\,z) = \cos\,(k_z\,z)\,. \tag{11}$$

Supposing furthermore that $a = l$ and because of the symmetry $k_x = k_z$ is valid, from Eqs (6) to (11) the dispersion equation has the following form ($\mu = 1$).

$$\tan\left(\sqrt{\frac{\varepsilon}{2}}\,ka\right) = -j\sqrt{\frac{2-\varepsilon}{\varepsilon}}\,. \tag{12}$$

The deduction given above neglects the diffraction. This fact involves that Equ. (12) has real k solutions substituting real $\varepsilon > 2$. This phenomenon is the consequence of the total reflection on the inner surfaces.

Taking into consideration this fact we look for the $f \cdot 2a$ product with $\varepsilon = \varepsilon_L = 12$. With this value we get

$$ka = \frac{1}{\sqrt{6}}\,\text{arc tan}\sqrt{\frac{10}{12}} = 0.302$$

and

$$f \cdot 2a = \frac{c}{\pi}\,ka = 2.89 \cdot 10^9 \quad \frac{\text{cm}}{\text{s}}\,.$$

This result shows that Rode's exact lowest eigenfrequency is a good approximation in the case of a rectangular parallelepiped geometry of the LSA diode, if the diameter d is chosen to be equal to the length of the sides of the square cross-section.

Summary

Several results on the eigenfrequency of the self-resonant linear active open cavity resonator with circular cylindrical geometry were applied to the LSA diode operation in recent papers. It is shown here that the exact value of frequency obtained in this way is a good approximation for the real LSA diode geometries that, however, are inaccessible to exact treatment.

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