APPLICATION OF THE METHOD OF LINES TO THE ANALYSIS OF SURFACE PLASMON TRANSVERSE DISTRIBUTION IN THE WAVEGUIDE STRUCTURE OF A LONG-WAVE SEMICONDUCTOR LASER

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At present, great interest is attracted to and much effort is undertaken worldwide in the development of coherent sources operating in the far and medium IR wavelength bands. This problem is topical because these lasers can be used in high resolution spectroscopy, gas analysis systems and so on. The list of existing semiconductor lasers operating at wavelengths mentioned above, is actually limited to devices of two types: *quantum cascade* and *fountain* lasers. The most impressive results have been demonstrated for the quantum cascade lasers (QCL) [1,2]. Difficulties revealed under the creation of the QCL are associated both with the necessity for growing a rather complex quantum-well structure and with making the waveguide layers with good confinement of light within the active region. The founders of the QCL (Prof. F.Capasso's group) have proposed to utilize a metallizing layer as one of confining layers [2]. A larger transverse-optical mode confinement factor was reached in a waveguide with excited *surface plasmons* (SP) in comparison with that of traditional dielectric guiding structures.

At the wavelength of visible and near infrared spectrum, the surface plasmon waveguide structures, as a whole, cannot compete with conventional dielectric ones because of high optical absorption in the metal. On the other hand, for a wavelength approaching the far-infrared ($\lambda > 15$ μm) band, the region of dielectric active layer occupied by the energy flow is greatly extended. The loss is reduced to acceptable value, allowing the creation of semiconductor QCL [2].

Here, we present the results for the transverse distribution of surface TM-mode (plasmon) in a finite-width waveguide of long-wavelength semiconductor lasers. Either a structure of multiple quantum wells with variable period separated by injectors, like as in the QCL, or an intervalley-hot-electron-transition (IVHET) structure, proposed by the researchers from the Institute of Physics of Microstructures of Russian Academy of Sciences (N.-Novgorod) [3] may be used as an active region in these lasers.

For the determinancy, let us consider the IVHET laser. It is assumed in the model of the laser that the active region is formed by a superlattice of alternating layers of GaAs (80 A^0) and AlAs (20 A^0). The total width of active region approximates 1 μm. The waveguide (confining) layers are made from AlAs and Au. It is important for the considered structure, that the amplification is only possible for the waveguide eigenwaves that have an electric field component directed across the active layer, i.e., for TM modes (like as in the QCL). Using the data on plasma and damping frequencies from [4], we obtained the real and imaginary parts of dielectric constant for gold at a wavelength of 10 μm: $\varepsilon'_{Au} = \mathrm{Re}\,\varepsilon_{Au} \approx -5000$; $\varepsilon''_{Au} = \mathrm{Im}\,\varepsilon_{Au} \approx 1000$. The Method of Lines (MOL) developed by Prof. R.Pregla [5], was applied to the analysis of field transverse pattern. All simulations were performed for geometrical and electrical parameter values listed in the Table below.

Parameters of waveguide structure

Layer	Width, μm	Reε	Imε
Substrate (GaAs)	100	12.2	0
Waveguide (confining) (AlAs)	5	9	0
Active (GaAs+AlAs)	1	11.5	0.3
Metallization (Au)	0.05	-5000	1000

A principal peculiarity of the MOL is that the values of field are found out at the lines directed across the structure layers, but not at the rectangular grid nodes. The solution along the lines may be obtained analytically. Consequently, in the framework of the MOL, discontinuous fields may be investigated; that is practically impossible by using the grid methods.

The distribution of power density in the cross-section of analyzed surface-plasmon waveguide is shown with the equal level lines in Fig.1. The X- and Z - axes are directed along the width of the waveguide and across the layers of the structure, respectively. The origin of Z-axis is superposed with the inner boundary of metallization. In the case in question, as distinct from a conventional dielectric waveguide, the power density is greatly non-homogeneous in the Z direction and has the breaks at the boundary of the metallized and the waveguide AlAs layers. For clearness, the following Fig.2. displays the graph of power density profile along the Z-axis. The origin of power density breaks is evident - these are due to the jumps of the transverse component of electric field at the boundaries of layers with different values of dielectric constant. The field of the surface plasmon poorly penetrates into the waveguide (confining) layers. That is why the confinement factor for the structure under analysis is as high as 0.65.

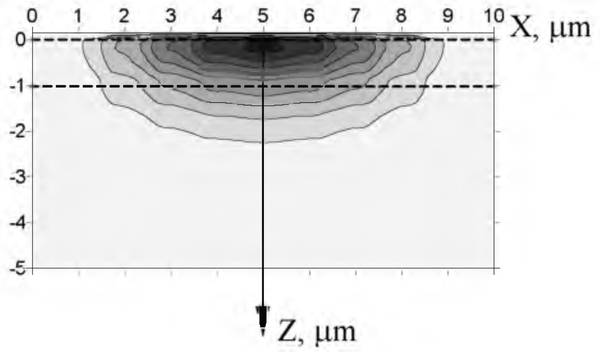

Fig.1. .Distribution of power density in cross-section of laser. The boundaries of active region are shown by dotted lines.

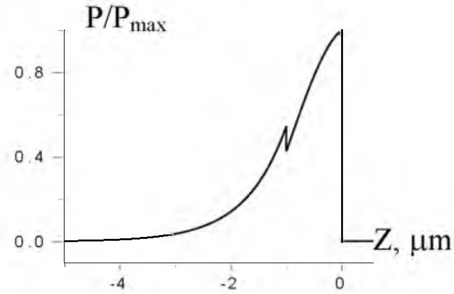

Fig.2. The profile of power density across the structure layers. There are the breaks at Z = 0, -1.

This value is approximately 3 times greater in comparison with the confinement factor for purely dielectric waveguide. However, an additional simulation shows that the surface-plasmon field is more considerably dumped by propagation in comparison with the conventional TM-modes. Namely, the loss coefficient value is of about 50 cm^{-1} and 2 cm^{-1}, respectively. (Analyzing the losses, we took into account, at first, absorption in metal and, secondly, the losses caused by longitudinal field component in the active layer. Drude's absorption in an undoped confining AlAs layer was not taken into consideration).

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