Edge effects due to propagation of surface IR electromagnetic waves along a metal surface

G. N. Zhizhin, M. A. Moskaleva, E. V. Shomina, and V. A. Yakovlev
Institute of Spectroscopy, USSR Academy of Sciences

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A new method of exciting IR surface electromagnetic waves (SEW) by means of a diaphragm is proposed. Excitation and disruption of SEW at the edge of a metal is observed and the effect of scratches of different width on SEW propagation is investigated.

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The method of excitation of surface electromagnetic waves (SEW) by means of a modified total-internal-reflection prism (MTIR) is well known.[1-4] The SEWs are non-radiative excitations with wave vectors greater than the wave vector of light in air and, in accordance with the law of conservation of momentum, SEWs cannot be excited by light incident on a smooth metal surface. It could be assumed that if a slit exists between the metal surface and a diaphragm (placed near the surface) which lies along the path of light incident on that surface at a glancing angle, a change in the wave vector of the light occurs at the edge of a slit and an SEW is excited at the metal surface.

We investigated the excitation of an SEW on the surface of a 0.3 μm thick aluminium film. This thickness which was much greater than the depth of penetration of an SEW into the metal. Radiation from a CO_2 laser was focused by a sodium chloride $f = 10$ cm lens on the metal surface without exciting an SEW. If razor blades were lowered by means of a micrometer screw to a point where the radiation was focused, SEWs occurred on the metal surface. The angle of incidence of light varied from 86 to 88° with the maximum effectiveness of excitation occurring at the latter. This method may also be used to convert SEWs into three-dimensional radiation. An optimal gap between the metal and blade (of several tens of microns) is observed for which the effectiveness of conversion of the incident radiation into an SEW is maximum. This gap coincides approximately with the optimal gap of a metal prism in the case of SEW excitation by an MTIR prism.

Investigation of the effect of the incidence angle of light in a prism and the gap between the prism and metal (in the case of SEW excitation by an MTIR prism) on the effectiveness of conversion of the incident radiation in an SEW showed that the optimum excitation angle is somewhat smaller than the critical. These experimental results are also confirmed by calculations which we carried out for the natural oscillations of the system " prism-gap-metal" for highly-conducting metals in the IR spectral region. Thus, waves under a prism are, strictly speaking, not surface but conventional plane waves that are partially converted into surface waves when they emerge from under a prism. Moveover, due to disturbance of the translational symmetry at the prism edge there occurs a jump in the wave vector which increases and becomes larger than for the case of light in air. It may be concluded that both in the case of SEW excitation by means of an MTIR prism and the excitation method proposed here one and the same mechanism is involved, namely the change in the field wave vector due to a perturbation of the translational symmetry at the edge of a barrier. Experimentally, the excitation by means of a diaphragm permits one to dispense with building a prism and to study specimen with smaller dimensions.

We shall now examine the edge of the metal surface along which an SEW propagates. At the edge, an SEW is easily disrupted and converts into three-dimensional radiation (this is well known[2,5] for the RF range). A process that is counter to SEW disruption may be achieved—excitation of an SEW by three-dimensional radiation incident on the surface edge. By focusing laser radiation on a metal edge we observed SEW excitation at a glancing angle of incidence, similar to excitation by means of a diaphragm.

If the metal surface is scratched (transverse metal bands are eliminated from the glass substrate with a sputtered metal layer), an SEW approaching a scratch boundary should be fully converted into three-dimensional radiation that propagates almost parallel to the surface. The reverse transformation of a three-dimensional wave into a surface wave occurs at the other scratch boundary. We experimentally observed attenuation of SEWs by scratches of different width on an aluminium film. Excitation and registration of SEWs was done by means of MTIR prisms. Figure 1 shows on the semi-logarithmic axis the dependence of intensity of radiation emerging from the sec-

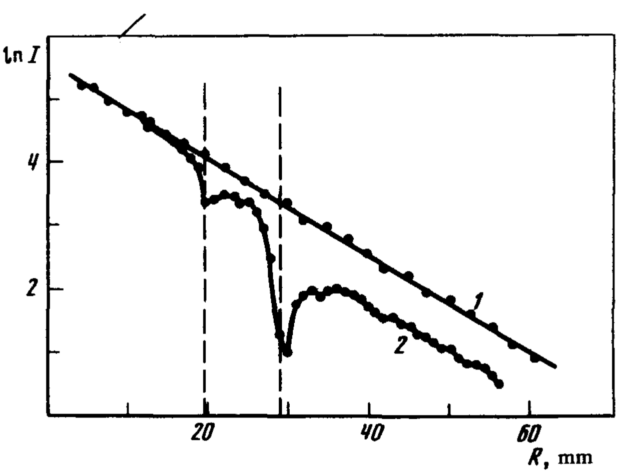

FIG. 1. Dependence of SEW intensity on distance between prisms: 1—SEW propagated along metal without scratches; 2—with scratches.

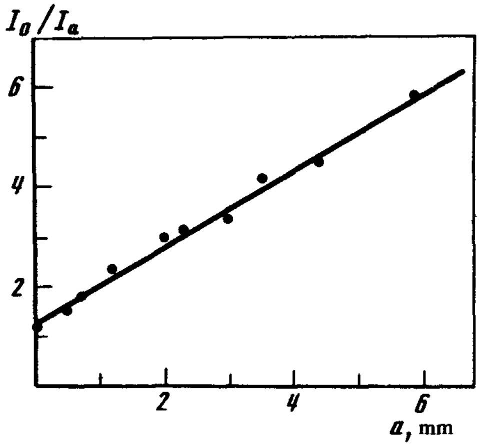

FIG. 2. Dependence of SEW intensity attenuation I_0/I_a on scratch width a on metal surface: I_0—SEW intensity without scracthes; I_a—with scratches of width a.

ond prism on the displacement of the output prism with respect to the fixed input prism. Two notches were made on the metal surface: 20-μm and 0.5-μm wide. The notch width was measured microscopically. When no scratches exist between the prisms, the intensity of radiation emerging from the prism decreases exponentially with increasing spacing between the prisms. The slope of curve 1 in Fig. 1 yields the SEW propagation length $L = 1.2$ cm at $\nu = 945$ cm^{-1}. If the output prism is located above a scratch, the intensity of radiation emerging at an angle that corresponds to SEW emergence falls off sharply (radiation, detached from the scratch edge, emerges from the prism at another angle). When the prism reappears above the metal, an SEW with a lower intensity is registered since not all the energy detached from the edge of the metal at one scratch boundary is converted into an SEW at the other boundary, a portion of the energy remaining in the form of the emitted wave. A similar intensity jump is observed at the second notch, except that it is more intense because of the greater notch width. The slope of the straight line in Fig. 1 remains unchanged past the nothces—since an SEW propagates along the same metal—while the curve drops by the amount of radiative losses.

Figure 2 shows the dependence of the SEW intensity attenuation on notch width. The slope of the straight line may be used to calculate the directivity of the beam that has detached from the metal edge, having assumed that a portion of the radiation which has reached the second notch boundary cannot be converted into an SEW because of beam divergence (since it turned out to be much too far from the metal surface). The divergence of the detached beam, estimated in this manner, was several degrees. Approximately the same value of divergence was obtained in the direct measurement of the directivity pattern of radiation detached from the metal edge.

The edge effects we studied may be useful in crystal-optics investigations of SEW.[2] The proposed methods of excitation and registration of SEWs that propagate along the metal surface may be used in the SEW spectroscopy alongside the MTIR method and, in many cases, replace the latter.

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