Velocity resonance as a method of selective excitation of surface waves in solids

V. N. Anisimov, V. Yu. Baranov, O. N. Derkach, A. M. Dykhne,
D. D. Malyuta, V. D. Pis'mennyĭ, B. P. Rysev, and A. Yu. Sebrant

(Submitted 27 September 1985)
Pis'ma Zh. Eksp. Teor. Fiz. **43**, No. 1, 13–15 (10 January 1986)

Theory shows that different surface waves can be selectively excited in solids by moving a light beam along the surface at the "group" velocity of the corresponding perturbations. This theory is tested experimentally in the particular case of the evaporative waves.

1. One of the mechanisms of excitation of various surface waves is the decay of a wave that strikes the surface, the excited wave being one of the decay products of this decay. This process occurs as an instability of a stationary, homogeneous, incident wave. The amplitude of the excited wave increases exponentially as it propagates, providing a highly efficient excitation. If, however, there are several decay channels in such a process, the wave that is excited is the one whose growth rate peaks for a particular experimental geometry. The weak channels in this case are suppressed.

We wish to propose a method of surface-wave excitation which is free of the constraint indicated above. For definiteness, we assume that pumping is accomplished by an electromagnetic wave. If the beam aperture is finite, the waves (decay products) will leave the part of the surface illuminated by pumping at a group velocity. As a result, the instability growth rate will decrease or become completely suppressed. By moving the beam along the surface at a velocity u corresponding to a group velocity of propagation of perturbations we can track these particular perturbations and facilitate their rapid buildup. In other words, the growth rate of the decay into a given channel as a function of the beam velocity has a maximum at u_0. We can thus selectively stimulate the buildup of waves in a weak channel and, in particular, excite waves which cannot be produced in practice in a stationary beam at any intensity of incident light.

These arguments are of a general nature and are applicable to waves of any nature.

A theory of such a process was derived by Dykhne and Rysev[1] for the decay of light into a surface plasmon and surface sound.

We will study the velocity resonance described above by using as an example the evaporative periodic structures that are excited by light (see Ref. 2, for example). By using this example we can demonstrate that there is an optimum tracking velocity even when the propagation velocity of an excitable wave is zero.

2. The equations for the slow amplitudes of a surface electromagnetic wave $\epsilon(x,t)$ and a surface-relief "wave" $h(x,t)$ are

$$\frac{\partial \epsilon}{\partial x} + \Gamma\epsilon = ibh^*E, \quad \frac{\partial h}{\partial t} = a\epsilon^*E. \tag{1}$$

Here E is the field of the incident wave, and a and b are constants which depend on the properties of the material and the kinematics of the decay. If the incident wave is a stationary homogeneous wave ($E = \text{const}$), we find from Eqs. (1) a dispersion equation

$$\omega = DI/(\Gamma - ik), \quad D = \frac{4\pi}{c} a^*b, \tag{2}$$

where I is the intensity of the incident wave. The instability growth rate peaks at $\Gamma = k$ and the group velocity at this value of k is

$$u = DI/2\Gamma^2. \tag{3}$$

This is the velocity at which the perturbations leave the interaction zone if the aperture of the incident wave is finite. If the focus is moved at this velocity, the instability growth rate will peak. In the case of a moving finite focus an explicit expression for the instability growth rate can easily be obtained by expressing the

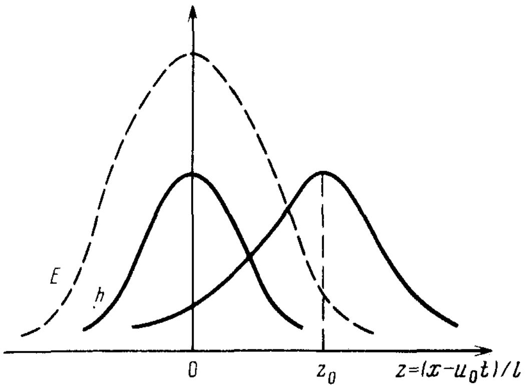
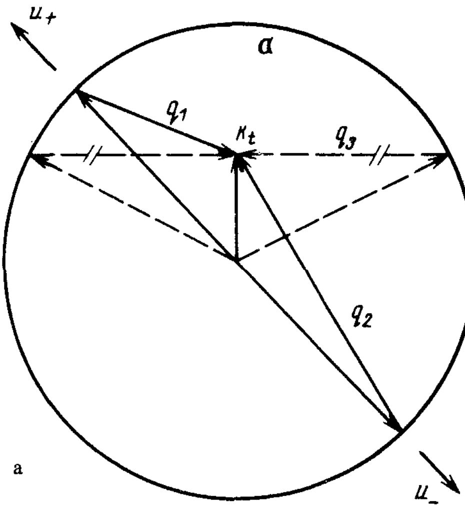


FIG. 1. $z_0 = \text{arctan h } [(1 + \Gamma l)^{-1}]$; the direction of u_0 is the same as the direction of propagation of surface electromagnetic waves.



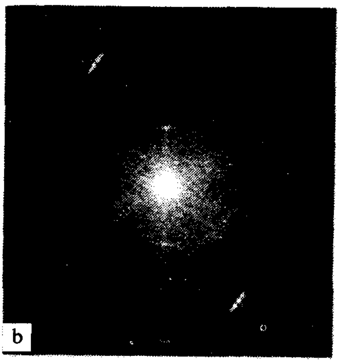


FIG. 2. (a) k_t—Projection of the vector of the reflected wave; $u_\pm$ —two opposite directions of motion of a spot. The dashed line shows the kinematics of formation of a degenerate grating q_3. (b) Reflections from the grating q_2. (c) Reflections from the grating q_1.

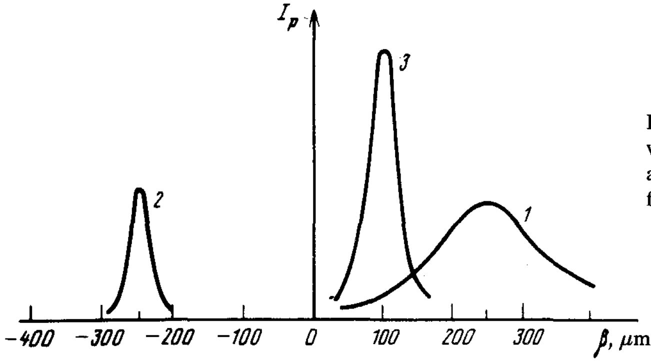


FIG. 3. 1, 3—$N = 15$; 2—$N = 50$, where N is the number of steps above which reflections higher than first-order reflections appear.

pump field in the form $E = \sqrt{I}\{\cosh[(x - ut)/l]\}$. Equations (1) can be solved exactly in this case; the instability growth rate as a function of the scanning velocity can be expressed in the form $\omega'' = \sqrt{2DIu} - (\Gamma + 1/l)u$. The maximum velocity is $u_0 = DI/2(\Gamma + 1/l)^2$. In the limit $l \to \infty$, this velocity is the same as the group velocity of propagation of the perturbations (3).

At the maximum velocity the amplitudes are qualitatively described in Fig. 1. The maxima E and h coincide only at this velocity.

3. The velocity resonance described above was studied experimentally in the particular case of the excitation of the evaporative gratings on a thin organic film covering a metallic substrate. Nitrocellulose film ~ 1 μm thick is deposited on the surface of a copper mirror which is bombarded by CO_2 laser pulses (5 μs in duration and 1 J/cm^2 in intensity; p is the polarization) at different angles of incidence θ. The irreversible nature of the film evaporation has made it possible to create pauses of arbitrary duration between the individual pulses. During these pauses, the sample is moved in adjustable translation steps, β, by a mechanical translator (the step accuracy is better than 5 μm, the diameter of the focus is ~ 1 mm). The sample is displaced along a straight line which forms an adjustable angle φ with the incidence plane. The development of gratings during the bombardment was determined from the Bragg reflections produced by a He-Ne laser ($\lambda = 0.63$ μm).

4. The laser bombardment intensity was chosen in such a way that there would be no gratings in the case of a stationary focus, regardless of the number of pulses.

To demonstrate the selective excitation of the different gratings, we changed the direction of the translation and its step. Figure 2a shows the kinematic scheme which corresponds to the law of conservation of a two-dimensional pulse during the decay (a normal pulse is not conserved because of the presence of an interface). The scheme includes three decay channels which can compete with each other if the direction of motion of the focus, $u_{\pm}$, is the same as the direction of propagation of surface electromagnetic waves (SEW)K_{SEW1} and K_{SEW2}. Channel 3 corresponds to a decay through which two degenerate gratings are formed, q_3 and $-q_3$. Figures 2b and 2c show the Bragg reflections corresponding to gratings q_2 and q_1. Figure 3 shows typical intensities of the reflections corresponding to the three gratings versus the magnitude of the translation step. In particular, we see that the decay channels change selectively as a function of the magnitude and direction of the translational velocity.

We believe that the method proposed by us can be used to excite various surface waves.

[1]A. M. Dykhne and B. P. Rysev, Proceedings of the Sixth All-Union Conference on Nonresonant Interaction of Light with Matter, Palanga, September, 1984, p. 434.

[2]V. V. Bazhenov, A. M. Bonch-Bruevich, M. N. Libenson, *et al.*, Izv. Akad. Nauk SSSR, Physical Series, **46**, 1186 (1982).

Translated by S. J. Amoretty