[5] N.S. Krylov and V.A. Fock, Zh. Eksp. Teor. Fiz. 17, 93 (1947).
[6] L.A. Khalfin, ZhETF Pis. Red. 3, 129 (1966) [JETP Lett. 3, 81 (1966)]; Dynamic Mass Filter and the Problem of $K_L \to 2\pi$ Decay, Paper at Session of the Division of Nuclear Physics of the USSR Academy of Sciences, 1967.
[7] L.A. Khalfin, Dokl. Akad. Nauk SSSR 115, 277 (1957) [Sov. Phys.- Dokl. 2, 232 (1958)]; Zh. Eksp. Teor. Fiz. 33, 1371 (1958) [Sov. Phys.-JETP 6, 1053 (1959)]; Quantum Theory of Decay of Physical Systems, Dissertation, FIAN, 1960.
[8] G. Hohler, Zs. Physik 152, 546 (1958).
[9] R.I. Oakes, Preprint DESY, 17/53 (1971).
[10] L.A. Khalfin, Non-exponentiality of the Decay Law, Mass Filter, and the Problem of CP-invariance, paper at Session of Division of Nuclear Physics, USSR Academy of Sciences, 1968.

DISCRETE LEVELS IN RANDOM FIELD OF SOUND WAVES AND A NEW MECHANISM OF NONLINEARITY OF THE SOUND AMPLIFICATION COEFFICIENT

V.L. Bonch-Bruevich
Moscow State University
Submitted 18 March 1972
ZhETF Pis. Red. 15, No. 9, 553 - 555 (5 May 1972)

A number of authors have shown experimentally and theoretically that the forbidden band of a disordered semiconductor is "jammed" with discrete levels (see, e.g., the review article [1]). An investigation of the behavior of the carriers in a random field shows [2] that this circumstance is due not to some concrete singularities of the structure of glasses or liquids, but to the very existence of spatial fluctuations of the potential - regardless of their physical origin. In this sense, one should include among the disordered materials also those (perhaps even ideally crystalline ones) with sufficiently large Maxwellian relaxation times [3], and also substances in which a sufficiently intense low-frequency acoustic field with random phases of the component harmonics has been produced. Indeed, if the essential frequencies are low compared with the reciprocal values of the free path time and of the Maxwellian relaxation time, then the energy U of the interaction between the carriers and the acoustic field can be regarded as a static quantity; the random character of variation of U in space is ensured by the randomness of the phases. Such a formulation of the problem is meaningful under conditions where sound is amplified by a stream of electrons, when by virtue of the very structure of the absorption coefficient (see, e.g., the review [4]) only waves in a limited range of frequencies and wave vectors are effectively amplified[1]. We shall henceforth have in mind precisely such a group of waves with a central wave number q_0.

Obviously, the discrete fluctuation levels which arise in the random phase under consideration can play the role of ordinary traps (the influence of the latter on the sound amplification coefficient is considered in [5, 6]). This will be the situation if the corresponding time of electron capture turns out to be small compared with the time that the given group of waves stays in the crystal (this condition imposes a limitation only in the case of motion of acoustic phonons; it is necessary here also that the domain, as is usually the case, be of macroscopic dimensions over which self-averaging of the considered random quantities can occur). The difference compared with the ordinary traps consists, however, in the fact that in this case (a) the traps are produced by the noise itself, and their number is determined by the strength of the sound P

[1] We are referring, of course, to incoherent waves, i.e., to the amplification of noise.

(defined as the density of the acoustic energy flux averaged over the period), (b) the discrete levels of the traps are continuously distributed in the forbidden band.

The last circumstance is not fundamental from the point of view of interest to us, while the first denotes that we have here a specific nonlinearity mechanism which comes into play at a sufficiently large sound strength.

To understand the resultant phenomena, we consider the case of "pure noise," when the random phases of the compounded harmonics have a uniform circular distribution. The random field produced by the deformation or piezoelectric potential turns out to be Gaussian [7], and the mean square of the potential energy of the carriers, ψ_1, is proportional to P. Namely, we denote by E_1, d, s, ε, and h respectively the constant of the deformation potential, the crystal density, the velocity of the amplified sound, the dielectric constant of the medium, and the piezoelectric constant (with dimension $J\text{-}Coul^{-1}cm^{-1}$). Then $\psi_1 = (E_1/ds^3)P$ in the case of interaction via a deformation potential and $\psi_1 = (2\pi eh/\varepsilon)^2(P/ds^3q_0^2)$ in the case of piezoelectric interaction.

In accordance with the statements made above, we can assume that $q_0^{-1} \gg 2\pi\hbar/\sqrt{mT}$ and $q_0^{-1} \gg \hbar(2m\psi_1^{1/2})^{-1/2}$, where T and m are the temperature (in energy units) and the effective carrier mass. This means that the concentration of the free and bound carriers can be calculated with the aid of the quasiclassically-calculated density of states [8, 9]. Further, substitution of typical parameters into the formulas for ψ_1 yields $\sqrt{\psi_1} \simeq 10^{-2}$ eV at $P = 10^5$ W/m^2 and $q_0 = 10^5$ cm^{-1}.[2] Consequently, under typical experimental conditions $\sqrt{\psi_1} \ll F$, where F is the energy difference between the bottom of the conduction band and the Fermi level (the latter, by assumption, lies in the forbidden band; for concreteness we are considering an n-type sample). We assume also that $F \gg T$. All the levels lying below F capture electrons effectively, and the levels above F are practically free. The relation between T and $\sqrt{\psi_1}$ can be arbitrary; interest attaches, however, to the cases $T \sim \sqrt{\psi_1}$ and $T \ll \sqrt{\psi_1}$. Namely, let $|F - \psi_1/T| \gg T$. We assume for simplicity that the degree of filling of the "true" traps does not change when P changes (this is a definite assumption concerning their location in the band). We then readily obtain for the concentration of the free carriers:

a) at $F_0 \gg \psi_1 T^{-1}$

$$n \approx n_0 \left\{1 - \frac{4\psi_1^2}{(2\pi T^3 F^s)^{1/2}} \exp\left[\frac{F_0}{T} - \frac{F_0 T}{4\psi_1} - \frac{T^2 F_0^2}{4\psi_1^2}\right]\right\}$$

b) at $F_0 \ll 4\psi_1^2 T^{-3}$

$$n \approx n_0 \exp\left\{\frac{\psi_1}{2T^2} - \frac{2\psi_1}{T^2}\left(\frac{F_0}{T}\right)^{1/2} + \frac{F_0}{T}\right\}.$$

Here n_0 and F_0 are the values of the corresponding quantities at P = 0.

Using the well-known expressions for the gain and the lattice sound-absorption coefficient as functions of n, we can easily calculate their explicit dependences on P for a given nonlinearity mechanism. In particular, in case (b) the gain of the sound decreases exponentially with P. By virtue of the very

[2] We note that the value of $\sqrt{\psi_1}$ is in a certain sense large: according to [2], the upper limit ν of the total concentration of the discrete levels amounts in this case to $\simeq 3.3(m/m_0)^{3/2} \times 10^{18}$ cm^{-3}. For GaAs this yields $\nu \simeq 6 \times 10^{16}$ cm^{-3}.

strong character of this decrease, we can expect the considered nonlinearity mechanism to turn out to be significant if not dominant at a large sound strength.

Obviously, the effect should be particularly noticeable at low temperatures. We note in this connection that motion of acousto-electric domains in CdS at $T \gtrsim 60°K$ was observed in [10], but no domains were produced at $T \lesssim 40°K$. It is necessary, however, to have additional data on the experimental conditions of [10] (in particular, concerning the strength of the sound) to be able to judge the possible role of the effect considered above.

[1] H. Fritzsche, J. Non-Cryst. Sol. 6, 49 (1971).
[2] V.L. Bonch-Bruevich, Zh. Eksp. Teor. Fiz. 61, 1168 (1971) [Sov. Phys.-JETP 34, 623 (1972)].
[3] V.L. Bonch-Bruevich, Proceedings, Ninth International Conference on Semiconductor Physics, Leningrad, Nauka, Vol. 2, 160 (1969).
[4] V.L. Gurevich, Fiz. Tekh. Poluprov. 2, 1557 (1968) [Sov. Phys.-Semicond. 2, 1299 (1969)].
[5] Yu.V. Gulyaev, ZhETF Pis. Red. 5, 419 (1967) [JETP Lett. 5, 342 (1967)].
[6] R. Katilyus, Fiz. Tverd. Tela 10, 458 (1968) [Sov. Phys.-Solid State 10, 359 (1968)].
[7] E.V. Burtsev, Phys. Stat. Sol. 50, No. 2 (1972).
[8] V.L. Bonch-Bruevich, J. Non-Cryst. Sol. 4, 410 (1970).
[9] M.J. Dyakonov, A.L. Efros, and D.L. Mitchell, Phys. Rev. 180, 819 (1969).
[10] W. Bauhofer and F. Siebert, Phys. Lett. 38A, 17 (1971).

CONCERNING ONE POSSIBLE USE OF THE IR LASERS FOR HIGH-TEMPERATURE HEATING OF A SUPERDENSE PLASMA

F.V. Bunkin, P.P. Pashenin, and A.M. Prokhorov
P.N. Lebedev Physics Institute, USSR Academy of Sciences

Submitted 21 March 1972
ZhETF Pis. Red. 15, No. 9, 556 - 559 (5 May 1972)

1. The main advantage of the laser method of high-temperature plasma heating, as is well known, is the possibility of attaining exceedingly high values of the specific energy input into the substance at low irradiation durations. In this method, the problem of confining the high-temperature plasma is eliminated in principle, since inertial confinement (IC) can be used because of the very short duration of energy supply. At the same time, the use of IC, with simultaneous requirement that the plasma be heated until the nuclear fusion energy exceeds the laser-pulse energy E consumed in heating, calls for a minimum required energy $E_{min} \sim 1/N_i^2$.[1)] Such a dependence of E_{min} on N_i indicates

[1)] Actually, from the condition of three-dimensional IC it follows that the volume V of the heated substance should satisfy the relation $\gamma V^{1/3} \simeq v_i(T)t$, where $v_i(T)$ is the average thermal velocity of the ions, t is the IC time, and the coefficient $\gamma < 1$ characterizes the degree of IC of the plasma. The minimal energy is

$$E_{min} \simeq 3kTN_i V = 3kT(v_i/\gamma)^3 N_i t^3.$$

The condition that the nuclear-fusion energy yield exceed the energy $3kTN_iV$ after a time t takes the form $N_i t > A(T)$ ($A \simeq 0.6 \times 10^{14}$ cm^{-3}sec for a 50% mixture of deuterium and tritium at $T = 10^8$°K). We then obtain

$$E_{min} > 3kT(Av_i/\gamma)^3 N_i^{-2}. \qquad (1)$$