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ELECTRIC BREAKDOWN IN POLAR SEMICONDUCTORS

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ABSTRACT: Using the criterion given by de Alba[1] for the stability of the solutions of Boltzmann's equation, it is shown that for some kind of polar semiconductors, like InSb, CdS and ZnO, the existence of a critical breakdown field is established when we use an upper-cut-off for the wave number in the phonon spectra.

It is known that some polar semiconductors like InSb, CdS and ZnO, exhibit piezoelectric properties with varying degrees of intensity[2,3]. The first quoted material has been extensively studied in the literature[2]; in particular, the influence that the different scattering mechanisms produce on the stability of the Boltzmann equation describing the electron cloud motion has been analyzed. Depending on the temperature range, the relative importance of the various mechanisms manifests itself. At low temperatures T, in CdS and ZnO the piezoacoustic scattering is predominant, and as the temperature raises, the optical phonons start playing a more important role[3]. This scheme is assumed to be valid at low applied field F, but there is some doubt about its validity at higher fields. In the case of InSb, Ehrenreich[4] has estimated that optical polar scattering is determinant in the $200°$-$500°$

range, but this result is also restricted to low values of F. We could ask then, what would happen at high F and T. Sladek[5] has shown that, at least to explain the electron energy loss mechanism in InSb, it was necessary to assume that at 4.2° the piezoacoustic scattering is responsible for most of that energy loss. On the other hand, large mobility changes in an electric field have been detected in CdS and ZnO, and it has been found that the carrier heating is not responsible for this. The non-ohmic behaviour has been shown to arise from the generation of acoustic flux from the carriers[6], which takes place when the drift velocity exceeds the sound velocity. This usually happens at a field F where the carrier heating is manifested, so that both effects could not supposedly be separated. We pretend to show here that the carrier heating is not relevant for the existence of a critical breakdown field F_c.

Now, all this discussion about the relative importance of the scattering mechanisms is basic to test the various theoretical predictions about μ, the electron mobility, in a given sample of material at a given temperature and field range. It is the purpose of this note to study the intrinsic breakdown properties of these materials at any T and F, when the electrons are scattered indistinctly by themselves, by acoustic, piezoacoustic or optical phonons.

We assume that the motion of the electron cloud is described by the Boltzmann equation

$$(\partial f/\partial t) = (\partial f/\partial t)_F + (\partial f/\partial t)_e + (\partial f/\partial t)_{ph} \, , \qquad (1)$$

where the F, e and ph subscripts denote the interaction with the field, the electrons and the phonons, respectively.

For the transition probability rate per unit time we use

$$P_{\binom{a}{e}}(\mathbf{p}\,;\mathbf{p} \pm \mathbf{q}) = (2\pi/\hbar)\,B(q)\binom{\bar{n}}{\bar{n}+1}\,\delta\big(E(\mathbf{p} \pm \mathbf{q}) - E(\mathbf{p}) \mp \hbar\omega(q)\big) \, , \qquad (2)$$

where $\bar{n}$ stands for the equilibrium phonon distribution function and $B(q)$ is the squared matrix element of interaction between electrons and phonons of wave number q and frequency ω.

Now, de Alba[1] has generalized the breakdown criterion first proposed by Herrera, de Alba and Martínez[7]; we shall use de Alba's generalized criterion here. This criterion demands that a sufficient condition for the stability of the Boltzmann equation is that

$$eF < \lim_{p \to \infty} \sup \{ - (\partial E / \partial p_z)^{-1} (dW/dt)_{ph} \} , \tag{3}$$

where $(dW/dt)_{ph}$, which is the rate of change in energy of an electron with momentum p, is calculated as in reference (8).

This result is quite general, valid for any distribution function and energy shape in **p**-space and, in this connection, is independent of T and of the usual assumptions on the form of the distribution function, which are usually field dependent[9]. We can also see that the interelectronic collisions do not affect the existence of the critical field, as given in eq. (3).

For the $B(q)$'s we use the following expressions:

Acoustic[10)] $B_{AC}(q) = B_{AC} \cdot q$

Piezoacoustic[3)] $B_{PA}(q) = B_{PA} \cdot q^{-2}$

Polar optical[11)] $B_{PO}(q) = B_{PO} \cdot q^{-2}$,

where B_{AC}, B_{PA} and B_{PO} are given in the references. Now, for the acoustic case alone, it has been shown[7] that no finite upper limit exists for the breakdown field, unless the Debye cutoff is used for the phonon spectra. It was assumed in reference 7 that the energy bands were parabolic in the electron pseudo-momentum p. Later, de Alba[1] obtained a similar result using Kane's expression[12] for a non-parabolic energy band in InSb, assuming that only the electron scattering by optical phonons is present. It was to be noted that for parabolic bands the breakdown appeared even without cutoff. From all that has been said for the previous case, we can see immediately, without making any calculation, that the piezoacoustic interaction produces exactly the same results as those obtained for the polar optical case, since the squared matrix element has the same analytic dependence on q in both cases. Hence, we conclude that we will always get a finite breakdown field when proper use of the cutoff in the phonon spectra is considered, and the question about the relative importance of the scattering mechanisms, at least in the limits of the intrinsic electric breakdown of the material, is more clearly formulated.

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RESUMEN

Usando el criterio dado por de Alba[1] para la estabilidad de las soluciones de la ecuación de Boltzmann se demuestra que, para algunos semiconductores polares, como InSb, CdS y ZnO, la existencia de un campo crítico de rompimiento está íntimamente conectada con el uso de un límite superior para el número de onda en el espectro fonónico.