A STUDY OF ION MOTION IN STRAINED AND UNSTRAINED CRYSTALS OF SOLID hcp 4He

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A STUDY OF ION MOTION IN STRAINED AND UNSTRAINED CRYSTALS OF SOLID hcp ^{4}He†

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Résumé.- On démontre que les mesures de mobilité pour plusieurs cristaux de même volume molaire se décrivent par une formule empirique qui indique l'existence d'un tenseur anisotrope de mobilité, caractérisé par des énergies d'activation différentes pour le mouvement suivant l'axe c et dans le plan basique. Les cristaux déformés présentent des oscillations quasi-périodiques (de courant) dont les périodes moyennes dépendent du champ et de la température.

Abstract.- Mobility measurements on a number of crystals grown at the same molar volume are fit with an empirical formula which suggests an anisotropic mobility tensor characterized by different activation energies for motion along the c axis and in the basal plane. Strained crystals exhibit quasi-periodic current bursts with a field and temperature dependent period.

There is a considerable discrepancy between values of the activation energies reported in the literature for positive ion motion in solid ^{4}He /1-4/ and these values are not accurately reproductible for crystals grown at the same molar volume in a given laboratory. On the other hand, the activation energy for positive ion motion in isotropic bcc ^{3}He is a smooth function of molar volume /3/. We report here a study of the activation energies on a number of crystals grown at the same molar volume and of ion motion in virgin (unstrained) and strained crystals.

The mobility was extracted from the space charge limited I-V characteristics /2/ $I = \frac{9\varepsilon\mu A}{32\pi} \frac{V^2}{L^3}$, of a diode filled with solid He. Severe strains were introduced by locally melting some solid around a heater located behind the diode. For all virgin crystals the current was linear in V^2 for small voltages and the time for the current to reach its steady state value after a change in diode voltage was on the order of the transit time. Severely strained crystals exhibited the following properties : (1) the current increased more rapidly than quadratically with voltage, (2) the time for steady state to be established was much greater than the transit time, and (3) quadi-periodic current bursts were observed for positive ion currents.

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The first two observations are believed to be associated with charge trapping on defects. The trap depth and the density of trapped charge is a function of the applied electric field. Current bursts are shown in Figure 1 for various fields at 1.3 K. The frequency of the bursts increases with applied field and increasing temperature. Current increases as large as 3 % for a time $\sim\frac{1}{4}$ of the transit time were observed.

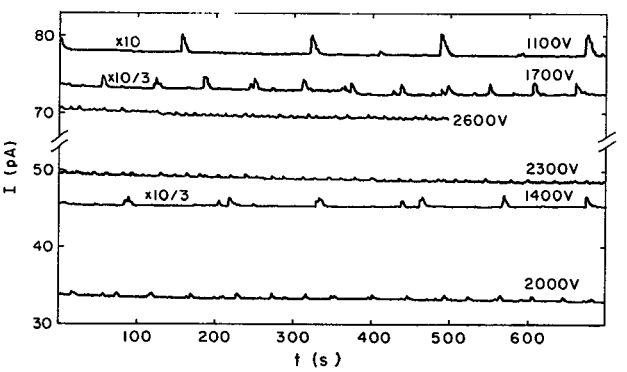

Fig. 1 : Plots of current versus time exhibiting periodic bursts for positive ions on a strained crystal at 1.3 K and V_m = 20.48 cm^3.

Both species of ions exhibit a range of apparent activities obtained from a plot of $\ln\mu$ vs T^{-1} on crystals grown at the same molar volume. Positive ion data on five crystals grown in the pressure range 458-465 psi [20.54 cm^3/mole] are shown in figure 2. The data are fit with a mobili-

ty of the form

$$\mu = \mu_1 e^{-\Delta_1/T} \cos^2\theta + \mu_2 e^{-\Delta_2/T} \sin^2\theta \qquad (1)$$

where each crystal is characterized by a given value of θ, and the parameters are $\mu_1 = 0.0071$, $\mu_2 = 0.185$ cm^2/Vs, $\Delta_1 = 10.2$ K, and $\Delta_2 = 17.8$ K.

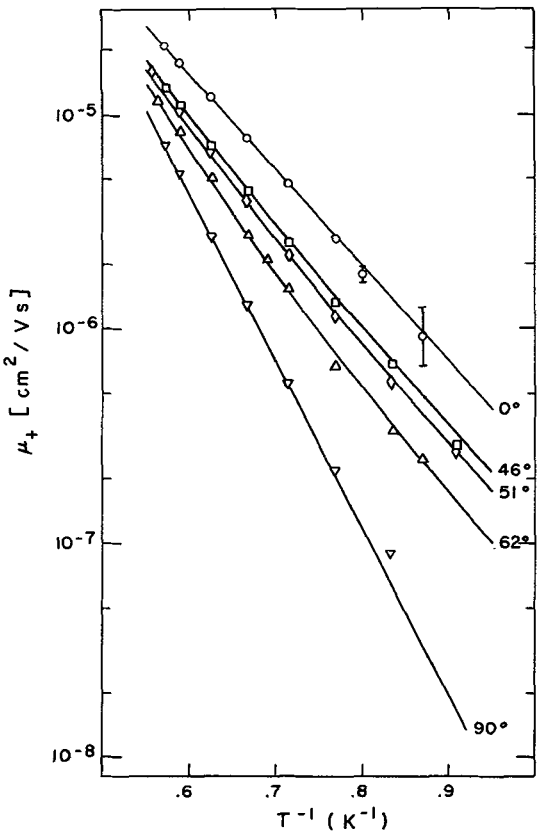

Fig. 2 : Positive ion mobility versus inverse temperature for a series of crystals grown in a narrow range of pressures. The pressures and apparent activation energies Δ obtained by fitting the high temperature part of the curves are 0-461 psi, Δ = 10.2 K; □ - 458 psi, Δ = 11.8 K; ◊ -465 psi, Δ = 12.4;Δ -464.5 psi, Δ = 13.4 K; ▽ -459 psi, Δ = 17.8 K. The solid lines are given by Equation (1) with the parameters given in the text. The values of θ for a best fit are given in the figure.

Negative ion data at this molar volume can be fit by equation (1) with the values μ_1 = 17.5, μ_2 = 1.50 cm^2/Vs, Δ_1 = 25.4 K and Δ_2 = 20.7 K. A discrepancy does exist in that the negative ion data are fit with different values of the parameter θ than the positive ion data for two crystals.

The data suggest an anisotropic mobility tensor. An anisotropic mobility tensor in a hcp crystal has diagonal elements of the form of equation (1) where $\mu_1 e^{-\Delta_1/T}$ is the mobility along the c axis, $\mu_2 e^{-\Delta_2/T}$ is the mobility in the basal plane, and θ or $(\frac{\pi}{2} - \theta)$ is the angle between the c axis and the applied field. We are unable to identify which term is associated with the c axis. Nor can we determine whether we have spanned the range of θ , but the data cannot be fit well by extending the range of the positive ion activation energies by more than 1 K.

Both ion structures may be expected to be slightly anisotropic due to a difference in lattice constants. It has been suggested that the negative ion, a charged void of ∿10 Å radius, moves by adatom diffusion along the void surface /2/. The activation energy to create adatoms depends on the crystal plane and this process could explain an anisotropic mobility tensor for the negative ions. If vacancies are responsible for positive ion motion, a different activation energy for motion in the basal plane and along the c axis might suggest that vacancies must be thermally activated over a barrier to tunnel into the positive ion core from one direction. We note that the thermal conductivity is highly anisotropic in hcp ^{4}He /5/.

The abrupt leading edge of the current pulses suggests a simultaneous release of charges from many traps in strained crystals with a recharging of the traps as the current decays to steady state. One feedback mechanism in the space charge current limit is the release of charges from traps located near the collector. The extraction of this charge from the crystal together with charge being replaced at the cathode leads to an enhancement of the total (space charge plus applied) field in the rest of the crystal which could release further charge from field dependent traps. This requires, however, a periodic coherent expulsion of trapped charge over a large area of the collector.

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