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DYNAMICS OF DEFECTS NEAR MELTING OF CLASSICAL 2D ELECTRONS

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Abstract. A slow dynamical response of a classical 2D electron system is observed in the vicinity of the liquid-solid transition. The R.F. absorption data, analysed in the framework of the dislocation mediated melting model, yield a precise determination of the defect core energies.

Introduction.

The theory of melting in 2 dimensions driven by the unbinding of dislocation pairs in the crystal (Kosterlitz Thouless (KT) model[1]), is remarkably supported by the experiments performed with electrons trapped at the gas-liquid interface of helium[2,3,4,5]. All these studies emphasize the crucial part assigned to the defects in the transition mechanism, but very little is known about the dynamics of these defects. The long time response on crossing the liquid-solid transition gives some information on the dislocations.

Experiments.

We detect collective modes of the 2D electron system with a wide band RF spectrometer. A guard ring electrode produces a modulation δn of the electron density n, in the KHz range and a phase sensitive detector (PSD) selects the transmitted RF power at the modulation frequency ω_{mod}.

The experiment is based upon the modification of the collective modes on crossing the liquid-solid transition. Of particular interest is the local mode appearing in the solid phase, where an electron vibrates in the potential well of the deformed helium surface, at frequency ω_0.The longitudinal frequency for a wavevector k is then modified from $(\frac{2\pi ne^2}{m}k)^{1/2}$ in the liquid phase to $(\frac{2\pi ne^2}{m}k+\omega_0^2)^{1/2}$ in the solid phase. This *discontinuous* change of the longitudinal frequency is obtained in the limit of steady equilibrium. If the temperature is kept constant at the non perturbed melting value T_m, the modulation makes the system cross the transition with frequency ω_{mod}, which is seen as a frequency modulation in the longitudinal response. The output signals displayed on Figures (1a) and (1b) show that the electron modes do not follow a sudden crossing of the freezing transition. The phase lag θ between excitation and detection at ω_{mod} results in an out of phase signal S_2 in a narrow temperature interval around T_m. Analysing the S_2 amplitude, we obtain the relation $tg\theta=\omega_{\mathrm{mod}}\times\tau(n)$, where the time τ, lying in the 10 μsec range, obeys the equation: $\tau(n)\propto n^{-1}$ as displayed in Figure (2).

A model for dislocation equilibrium.

According to the KT theory, the binding of free dislocations into pairs is the central phenomena at freezing. Thus the equilibrium is determined by the dislocations, involving particle motion in the crystal. The lengh scale for this process is the mean distance between two dislocations (density n_d) : $L=(a^2/n_d)^{1/2}$ and we assume that the dislocation system reaches equilibrium when a particle covers this distance L. Following Fisher, Halperin and Morf (FHM)[6], the particle motion is diffusive, dominated by interstitial defects of density ρ_i, with a diffusion constant $D\simeq a^2\omega_D\rho_i$. The dislocation equilibrium time is then:

$$\tau_{\mathrm{calc}}\simeq(L)^2/D\simeq\frac{1}{n_d}\times\frac{1}{\rho_i}\times\frac{1}{\omega_D} \tag{1}$$

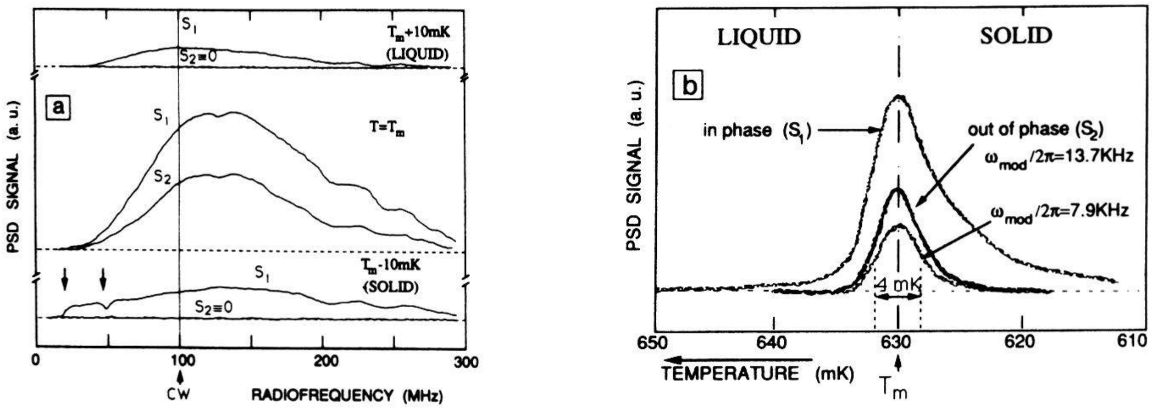

Fig. 1 **a)** *Detected signal as a function of the swept radiofrequency* ($n = 7.8\ 10^8\ \mathrm{cm}^{-2}$, $T_m = 630$ mK). *The arrows at 21 and* 48 MHz *show the first acoustic electron surface modes in the solid phase.* **b)** *Detected electron signal* ($n = 7.8\ 10^8\ \mathrm{cm}^{-2}$) *at fixed RF frequency* (100 MHz), *when the temperature is swept near* T_m. *The analysis of* S_2/S_1 *gives* τ_{exp}.

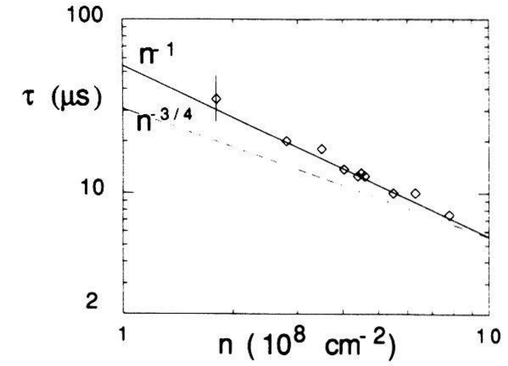

Fig.2 *Log-Log plot of the electron time equilibrium* τ_{exp} *as a function of the electron density showing the* n^{-1} *variation. The determination of* τ_{exp} *is less accurate for low density because the local mode frequency decreases as* $n^{3/2}$.

Thus, τ_{calc} depends on n through the Debye frequency $\omega_D \propto n^{3/4}$. FHM calculated the defect densities in term of the core energies E_c and E_i for dislocations and interstitials, which are proportional to the Coulomb energy $V_c = \mathrm{e}^2\sqrt{\pi n}$. Inserting their values in Eq.(1) gives $\tau_{\mathrm{calc}} = 3\ \mu$sec for $n = 6\ 10^8 cm^{-2}$, to be compared with $\tau_{\mathrm{exp}} = 10\ \mu$sec. It is worth noting that this difference can be removed through a small increase of E_c or E_i, of about 7%, which is within the uncertainties estimated by FHM.

Conversely, if we assume that the model is correct, this experiment appears to be a precise determination of the defect densities. Inserting τ_{exp} in Eq.(1), we get the sum $E_c + E_i = 13.5\ 10^{-2} V_c + \beta \log n$. The *small* logarithmic term which makes τ_{calc} to have the n^{-1} dependence of τ_{exp}, could indicate edge effects in the core energies.

Acknowledgements

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