# Density of states in MDS structures

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The density of states of a two-dimensional plasma in a random surface potential of the semiconductor component of a metal-dielectric-semiconductor (MDS) structure is investigated. The interaction of electrons, in which the reflection forces are taken into account, gives rise to a strong dependence of the density of states on the thickness of the dielectric layer.

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The electrons in metal-dielectric-semiconductor (MDS) structures, which are situated in the inversion layer at the surface of a doped semiconductor in a strong electric field normal to the surface, form a two-dimensional electron plasma in a random surface potential. The electron density in the inversion layer can be varied over a broad range by varying the applied electric field.

We shall examine a sufficiently dense plasma and assume that the mean free path $l = v_F \tau$ is such that $p_F l \gg 1 (\hbar \equiv 1)$. Under these conditions we can use the conventional diagram method.[1]

The interaction in a disordered, two-dimensional Fermi system was studied by Altshuler *et al.*[2] Specifically, they studied the effect of interaction of Fermi particles on the density of states near the Fermi energy $|\Omega\tau| \ll 1$. Allowance for the Coulomb interaction in this energy region gives a correction for the density of states[1)]

$$\frac{\delta \nu(\Omega)}{\nu_0} = -\frac{1}{2\pi \epsilon_F \tau} \ln |\Omega\tau| \ln \frac{|\Omega\tau|^{1/2}}{D\tau K^2}, \qquad (1)$$

where $D = 1/2\, v_F^2 \tau$ and $K$ is the reciprocal screening length which is $K = 2\pi e^2 S \nu_0$ in the two-dimensional case, where $\nu_0 = m/2\pi$ is a single-spin density of states of the noninteracting particles and $S$ is the degeneracy multiplicity. The second logarithm in this formula, which contains the reciprocal screening length, is a consequence of long-range Coulomb interaction.

The electron interaction in the inversion-layer plasma differs from the Coulomb interaction[3]: the electrons are influenced by the image forces in the metal, which gives rise to the fact that the Coulomb interaction between them becomes a dipole interaction when the spacing between the electrons in the inversion layer is greater than the thickness $d$ of the dielectric layer.

We determine in this letter the behavior of the expression (1) for the density of states when the real interaction between electrons is taken into account.

The two-dimensional Fourier transform of the interaction potential of electrons, with allowance for the image forces, is[3]

  

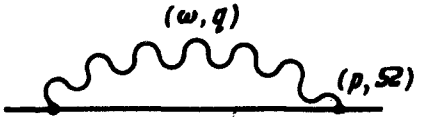


Fig. 1

$$\phi(q) = \frac{4\pi e^2}{q(\epsilon_1 + \epsilon_2 \coth dq)},$$

where $\epsilon_1$ and $\epsilon_2$ are the dielectric constants of the semiconductor and of the dielectric layer, respectively.

To determine the density of states, we must calculate the exchange diagram (Fig. 1). The solid lines here correspond to the Green's function of free particles, which is averaged over the impurities

$$G(\Omega, p) = \frac{1}{\Omega - \epsilon(p) + \mu + i\dfrac{\operatorname{sign}\Omega}{2\tau}}.$$

In the region of small transferred frequencies and momenta, $|\omega\tau| \ll 1, D\tau q^2 \ll 1$, the vertex part with an integrated impurity ladder is[2]

$$\Gamma(q, \omega, \Omega) = \frac{\theta[\Omega(\omega - \Omega)]}{\tau(Dq^2 - i|\omega|)} + \theta[\Omega(\Omega - \omega)].$$

The renormalized interaction in this frequency and momentum region has the form

$$v_s = \frac{\phi(q)}{1 + \phi(q)\Pi(q, \omega)},$$

where $\Pi(q, \omega) = s\nu_0 Da^2/Dq^2 - i|\omega|$ is the polarization operator.

The exchange diagram gives a correction for the density of states

$$\delta\nu(\Omega) = -\frac{1}{\pi}\operatorname{sign}\Omega \cdot \operatorname{Im}\int\frac{dp}{(2\pi)^2} iG^2(\Omega, p)\int\frac{d^3q}{(2\pi)^3}\Gamma^2(q, \omega, \Omega)\, v_s G(\Omega - \omega, p - q).$$

Since the main contribution in the integral over $q$ comes from the region of the diffusion pole of the vertex part $\Gamma$, $q$ may be assumed to be equal to zero in the argument of the Green's function. The integrals over $p$ and $q$ are uncoupled, and further integration is carried out in a straightforward manner.

An analysis showed that the density of states near $\epsilon_F$ depends greatly on the thickness of the dielectric layer $d$. In the energy region $|\Omega\tau| \ll (l/d\,\epsilon_1/\epsilon_2)^2\,(1 + 2Kd/\epsilon_1 + \epsilon_2\,\epsilon_1/\epsilon_2)$, for $|\Omega\tau| \ll 1$ the energy-dependent correction for the density of states is

$$\frac{\delta\nu(\Omega)}{\nu_0} = \frac{1}{2\pi\epsilon_F\tau}\ln\frac{2Kd}{\epsilon_2}\ln|\Omega\tau|. \qquad (2)$$

This correction comes from the dipole part of the interaction potential. The expression (2) is valid so long as $|\delta\nu(\Omega)| \ll \nu_0$.

If the thickness of the dielectric layer is sufficiently large, so that $(l/d\ \epsilon_2/\epsilon_1)^2 (1 + 2Kd/\epsilon_1 + \epsilon_2\ \epsilon_1/\epsilon_2) \ll 1$, then in the energy region $(l/d\ \epsilon_2/\epsilon_1)^2 (1 + 2Kd/\epsilon_1 + \epsilon_2\ \epsilon_1/\epsilon_2) \ll |\Omega\tau|$ we obtain

$$\frac{\delta\nu(\Omega)}{\nu_0} = -\frac{1}{2\pi\epsilon_F\tau} \ln|\Omega\tau| \ln\frac{|\Omega\tau|^{1/2}}{2D\tau\frac{K}{\epsilon_1+\epsilon_2}},$$

in agreement with the result obtained in Ref. 2 for the Coulomb potential for $\epsilon_1 = \epsilon_2 = 1$.

We have not analyzed the Hartree diagram and the renormalization of the vertex part by the impurity "fan." They are important for processes with a large momentum transfer and hence do not give a second logarithm (3), but are small as compared with (2) with respect to the gas parameter $K/p_F \ll 1$.

In conclusion, I deeply thank A. G. Aronov and B. L. Al'tshuler for the formulation and useful discussion of the problem.

[1)]Equation (1) differs from expression (10) in Ref. 2 in that it has a sublogarithmic factor in the second logarithm which is written incorrectly in Ref. 2.

1. A. A. Abrikosov, L. P. Gor'kov, and M. E. Dzyaloshinskiĭ, Metody kvantovoĭ teorii polya v statisticheskoĭ fizike (Quantum Field Theoretical Methods in Statistical Physics), Moscow, 1962. [Translated from the Russian by D. E. Brown. English translation edited by D. ter Haar, Oxford, New York, Pergamon Press, 1965].
2. B. L. Altshuler, A. G. Aronov, and P. A. Lee, Phys. Rev. Lett. **44**, 1288 (1980).
3. A. V. Chaplik, Zh. Eksp. Teor. Fiz. **62**, 746 (1972). [Sov. Phys. JETP **35**, 395 (1972)].

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