Comparing measured and calculated local density of states in a disordered two-dimensional electron system

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Abstract

The local density of states (LDOS) of the adsorbate induced two-dimensional electron system (2DES) on n-InAs(110) is studied by low-temperature scanning tunneling spectroscopy. In contrast to a similar 3DES, the 2DES LDOS exhibits 20 times stronger corrugations and rather irregular structures. Both results are interpreted as a consequence of weak localization. Fourier transforms of the LDOS reveal that the k-values of the unperturbed 2DES still dominate the 2DES, but additional lower k-values contribute significantly. To clarify the origin of the LDOS patterns, we measure the potential landscape of the same 2DES area allowing to calculate the expected LDOS from the single particle Schrödinger equation and to directly compare it with the measured one.

Key words: Electron states at surfaces and interfaces; Weak or Anderson localization; Semiconductor compounds;

1. Introduction and Experimental Details

Two-dimensional electron systems (2DES) are intensively studied as a paradigmatic case for many-particle systems in disordered potentials [1]. They exhibit unique properties with respect to their three-dimensional counterparts such as weak localization or the quantum Hall effect [2]. Many experiments probed the macroscopic properties of a 2DES, but little is known about the underlying local density of states (LDOS). On the other hand, detailed predictions for the LDOS exist from theory [2,3] making it important to establish quantitative LDOS studies [4].

For this purpose, we use the adsorbate induced 2DES [5] on InAs(110) [6]. In contrast to usual heterostructures [7], this 2DES provides a spatial resolution of 5 nm well below characteristic length scales of the 2DES LDOS. Subband energies are determined by angle-resolved photoelectron spectroscopy (ARUPS), the disorder potential is measured using the lowest state of the tip induced quantum dot (QD) [8], and the 2DES LDOS is recorded by scanning tunneling spectroscopy (STS). Thus, for the first time, all ingredients of the Schrödinger equation (SE) are known and the output of the SE (LDOS) is measured. We found that the tendency of a 2DES to weakly localize results in strong and irregular LDOS corrugations in remarkable contrast to 3DES's, where only weak and regular corrugations are found [9].

The UHV-low temperature STM working at $T = 6$ K with spectral resolution in STS down to 0.5 mV is described in [9]. Degenerate n-InAs ($N_\mathrm{D} = 1.1 \times 10^{16}/\mathrm{cm}^3$) is cleaved in-situ at a base pressure of 10^{-8} Pa, which leads to a nearly defect free InAs(110) surface with a Fermi level $E_F = 5$ meV above the conduction band minimum. To induce the 2DES, Fe is deposited from an e-beam evaporator [6]. The Fe coverage is determined by counting the Fe-atoms and given with respect to the unit cell of InAs(110).

Topographic STM-images are recorded in constant current mode with voltage V applied to the sample. The dI/dV-curves are measured by lock-in technique

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(f = 1.5 kHz, V_{mod} =1.8 mV) with fixed tip-surface distance stabilized at current I_{stab} and voltage V_{stab}. The influence of the spatially changing tip-surface distance is checked to be of minor importance [9].

2. Results and Discussion

In Fig. 1a, we show one of the LDOS images recorded at 2.7 % coverage (in the absence of a QD). The spatial resolution (5 nm) is well below the Fermi wave length (23 nm). The total intensity corresponds to about 30 electronic states, but, since the scattering length and thus the localization length is larger than the image size, more states contribute with part of its intensity. In general, the LDOS images exhibit corrugations decreasing in length scale with increasing V and do not show the circular structures found in the InAs 3DES [9]. The corrugation strength defined as the ratio between spatially fluctuating and total dI/dV-intensity is 60 ± 5 %, i.e., 20 times larger than the corrugation strength in the 3DES (3 ± 0.5 %) [9].

Both results reflect the tendency of the 2DES to weakly localize [2]. Many different scattering paths containing each many scattering events contribute to the LDOS leading to more intricate patterns and the tendency for localization leads to the increased corrugation.

A Fourier transform (FT) of the LDOS (inset) reveals the distribution of contributing k-values. At low voltage a disk is visible in the FT, which at higher voltage is confined by a ring. At even higher voltages ($V > -40$ mV), we find that a second smaller disk appears indicating the occupation of the second subband. We can use these data to reconstruct the dispersion curve for the lower subband with good accuracy [5].

We next solve the SE for noninteracting particles numerically using periodic boundary conditions, the measured disorder potential and *no* adjustable fit parameter [11]. To construct the LDOS, the resulting squared wave functions are weighted with the known energy resolution of the experiment. The resulting LDOS for a particular energy is shown in Fig. 1a in comparison with the measured LDOS in Fig. 1b. The correspondence is reasonable, i.e. several features as the central ring structure or other smaller structures marked by arrows appear in both images. The FT's (insets) and the intensity distributions of the LDOS (Fig. 1c) show very good agreement demonstrating that the additional k-values in the FT's and the strength of the corrugation are indeed caused by the interaction with the potential disorder. Fig. 1d shows the cross correlation function between experimental and theoretical images. Oscillations on the length scale of the unperturbed electron wave length are found, which demonstrates quantitatively the reasonable agreement between calculated and measured patterns.

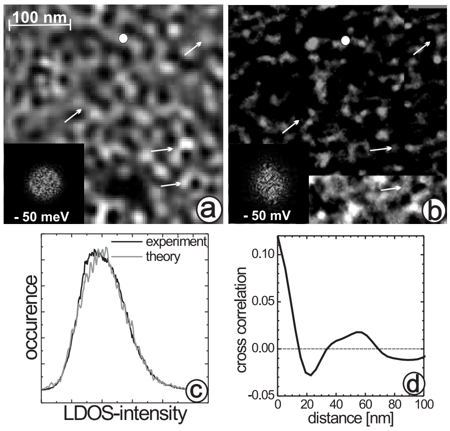

Fig. 1. (a) LDOS calculated from a potential landscape at $E = -50$ meV. (b) Normalized dI/dV-image of the same area; $V = -50$ mV, $V_{stab} = 100$ mV, $I_{stab} = 300$ pA. Insets are FT's. Dots mark identical sample positions as deduced from constant current images. (c) Intensity distribution of the LDOS in (a) and (b); for the sake of comparison the experimental curve is stretched by 5 %. (d) Cross correlation function between experimental and calculated image.

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