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Invited
A New Route to Reduce Remote Impurity Scattering in Modulation Doped Quantum Wells with Very High Conductivity

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1. Introduction

Two-dimensional electron gases (2DEG) with ultrahigh conductivity are important for both fundamental research and for applications in low-noise and high-frequency devices [1]. However, remote impurity scattering (RIS) at the randomly distributed dopants becomes one of the main limitation for achieving high conductivities. We proposed a new concept for the reduction of RIS in GaAs single quantum wells (SQW) at high carrier concentrations thereby significantly increasing the conductivity [2]. In this presentation we review the applicability of our concept for GaAs as well as (InGa)As SQW and address some critical issues for HEMT application.

2. Concept to reduce remote impurity scattering

To get enhanced conductivity the fluctuations of the scattering potential (FSP) caused by the randomly distributed remote dopants have to be smoothed. For this approach we use barriers consisting of short period AlAs/GaAs superlattices (SPSL) instead of ternary ones. The superlattice period is chosen short enough to get the X-like conduction-band states the lowest energy states in the AlAs sequence of the SPSL. At high enough doping concentration these states become occupied with heavy mass X-electrons which are located close to the doping layer (Fig.1). The heavy mass of the carriers provides a high screening capability. Additionally, their Bohr-radius a_B as well as their nominal distance from the doping layer is smaller or nearly equal to the average distance between the Si-dopant atoms. Therefore, the X-electrons can be very easily localized at the minima of the fluctuating potential smoothing the FSP. As a result with X-electrons in the SPSL the mobility of the electrons in the GaAs SQW can be considerably increased.

Configuration of layer structure

The structures were grown by solid-source molecular beam epitaxy on GaAs (001) substrates. The free carriers in the 10 nm GaAs or (InGa)As SQW are provided by remote δ-doping with Si. The barriers of the SQW consist of several periods of 4ML AlAs / 8ML GaAs SPSL. Single Si δ-doping sheets with a doping concentration of N^{2D} were placed on both sides of the SQW into a GaAs layer of the SPSL at a spacer distance d_S. The low-temperature magnetotransport properties were studied on samples with Hall-bar geometry including a Ti/Au gate electrode to change the electron density.

Low temperature magnetotransport

In the case of a GaAs SQW we already reported about a very high mobility of $\mu \approx 120$ m^2/Vs at surprisingly high electron densities n up to $1.4 \cdot 10^{16}$ m^{-2} in the one subband mode without any parallel conductivity [2]. In the InGaAs SQW the alloy scattering is dominating. However, for SQW with electron densities as high as possible the spacer distance d_S should be low and RIS may become important. To demonstrate the suppression of RIS by X-electrons for the (InGa)As SQW we carried out magnetotransport measurements at low temperature. Figs.2a,b show the dependence of the components of the resistivity tensor ρ_{xx} and ρ_{xy} on the magnetic field. Fig.2b represents sample S1 with X-electrons being present on both sides of the SQW, while Fig. 2b shows sample S2 were the X-electrons on the surface side of the SQW are removed by etching away a

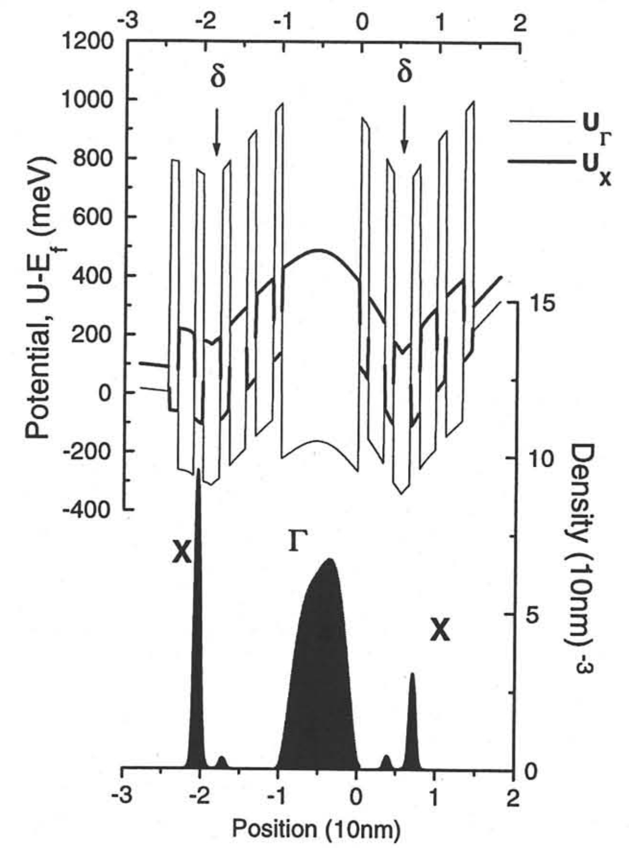

Fig.1 Potential and charge distribution of a $In_{0.2}Ga_{0.8}As$ SQW clad by GaAs/AlAs SPSL. δ marks the position of the doping layer $N2D \approx 4 \cdot 10^{16}$ m^{-2}. Calculation according to [3].

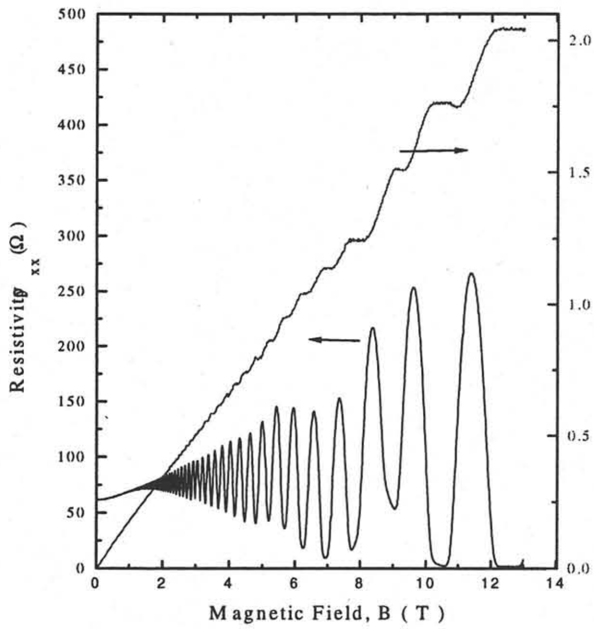

Fig.2a Magnetic field dependence of ρ_{xx} and ρ_{xy} at T=0.33 K in $In_{0.2}Ga_{0.8}As$ SQW with X-electrons on both sides of the QW- sample S1, $N_{2D} \approx 4 \cdot 10^{16}$ m-2, $n_{SdH} \approx 3 \cdot 10^{16}$ m-2 and $0.7 \cdot 10^{16}$ m-2 for the first and second 2D sublevel, respectively.

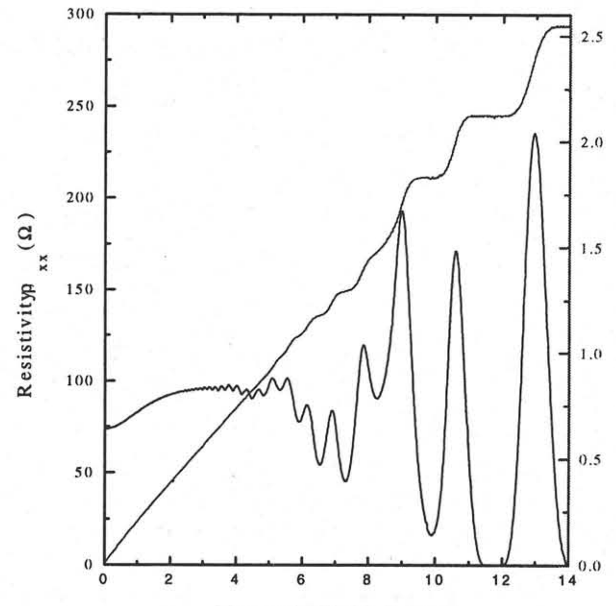

Fig.2b Magnetic field dependence of ρ_{xx} and ρ_{xy} at T=0.33 K in $In_{0.2}Ga_{0.8}As$ SQW with X-electrons removed from one side of the QW-sample S2, $n_{SdH} \approx 2.9 \cdot 10^{16}$ m-2 and $0.6 \cdot 10^{16}$ m-2 for the first and second 2D sublevel, respectively.

thin surface layer. An analysis of the SdH oscillations reveals two occupied subbands n_0 and n_1 with similar occupation in both samples. The Hall mobilities $\mu_H = \rho_{xy}/\rho_{x}$ which we expect to be mainly determined by alloy scattering are similar for the two samples, too. Significant differences are seen in the amplitude of the SdH oscillations which contains information about the single particle relaxation time τ_S. In contrast to the sample S2, τ_S is higher by a factor 4.5 in the sample S1, containing X-electrons on both sides of the SQW, which indicates the suppression of the RIS by X-electrons in the barrier.

Application in HEMT devices

We show that the layout of the HEMT and the processing methods have to be adapted to the special properties of the system with X-electrons. First, X-electrons may form a conducting channel parallel to the electrons in the SQW. We have investigated the temperature dependence of the conductivity of the X-electrons in the SPSL. The conductivity decreases by an exponential law when lowering the temperature. This promises applications for temperatures as low as 77K. Second, the usual switching function of the transistor comprises the depletion of the X-electrons by the gate voltage. This lowers the external gain and the screening properties of the X-electrons may get lost. A special gate design is necessary to keep the screening properties of the X-electrons. Third, the SPSL appears to be a source for additional serial resistance when feeding in the current from the contacts to the active layer. To overcome this, additional recess etching steps below the Ohmic contacts are necessary.

3. Conclusions

In conclusion, we have shown that the impurity scattering in remotely doped GaAs and (InGa)As SQW can be reduced effectively by the presence of heavy-mass X-electrons in the direct vicinity of the doping atoms in the barrier. These X-electrons exhibit an extremely high screening capability and are able to smooth the potential fluctuations, caused by the random distribution of the dopants. At low temperatures they are localized and do not contribute to the conductivity. This opens powerfull possibilities for device applications. With a special design HEMT structures can be improved for operation at temperatures up to 77K.

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References

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3) K.-J. Friedland and R. Zimmermann unpublished. The calculations are performed by the one-dimensional self-consistent solution of the Schrödinger and Poisson equations in the effective mass aproximation, including exchange and correlation interaction energy.