Fabrication of Two-dimensional p-n-junctions Formed by Compensation Doping of p-modulation Doped GaAs/In$_y$Ga$_{1-y}$As/Al$_x$Ga$_{1-x}$As Heterostructures

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For two-dimensional p-n-junctions, i. e, coplanar two-dimensional p- and n-regions, interesting properties have been predicted theoretically, e. g., the capacitance should depend only very weakly on the applied reverse bias and the depletion length should depend linearly on the reverse bias [1,2]. Also, the capacitance of these junctions should be very small so that they might be interesting for high speed devices. The fabrication of such diodes is quite difficult because it requires the realization of a two-dimensional electron gas (2DEG) in direct vicinity of a two-dimensional hole gas (2DHG). We achieved this by locally overcompensating the p-doping of a modulation doped heterostructure with implantation of n-type dopants. In this paper we report on the first capacitance measurements on a two-dimensional p-n junction.

As base material, a C-doped pseudomorphic GaAs/In$_{0.1}$Ga$_{0.9}$As/Al$_{0.33}$Ga$_{0.67}$As heterostructure was used. The In$_{0.1}$Ga$_{0.9}$As channel had a distance of 180 nm from the surface. At room temperature, the hole density was 7×10^{11} cm^{-2} and the mobility was 200 cm^2/Vs. The sheet resistance of the 2DHG is approximately 30 kΩ. The Si atoms were introduced by focused ion beam (FIB) implantation employing an ion energy of 60 keV and a dose of 1.3×10^{13} cm^{-2}. These implantation parameters resulted in a 2DEG in the implanted region with an electron density of 5×10^{11} cm^{-2}, a mobility of 4100 cm^2/Vs, and a sheet resistance of 3.2 kΩ at room temperature. The presence of a 2DEG without parallel conduction was checked by magnetotransport measurements and C(V) spectroscopy [3]. The diodes fabricated consisted of two adjunct rectangles containing a 2DEG and a 2DHG, respectively. Three different lengths l (60 µm, 120 µm, 180 µm) for a constant width of w = 150 µm and three different widths w (150 µm, 200 µm, 300 µm) for l = 60 µm have been prepared. A schematic sketch of the of the device geometry is shown in the insert of Fig. 1.

In Fig. 1, an I-V characteristic measured at room temperature for a two-dimensional p-n-junction with w = 150 µm and l = 60 µm is shown. One clearly sees the characteristic diode behavior with a very low current under reverse bias condition and a huge increase of the current for forward bias. For reverse bias up to 20 V, the current is below 10 nA and no signs of junction breakdown can be detected up to a reverse bias of 50 V. In forward direction, the current is significantly larger reaching ~10 µA at 1.3 V forward bias. For higher forward bias, the current is no longer limited by the junction itself but by the series resistance of the neutral regions, especially by the high resistance of the 2DHG with its - compared to the 2DEG - low carrier mobility. The forward current through the diode scales well with the width of the junction whereas the current in the region where it is limited by the series resistance decreases with increasing length of the junction as expected from geometrical considerations.

In Fig. 2, the inverse of the capacitance squared as function of the reverse bias at 4.2 K is shown for three different widths of the junction. The capacitance scales within 10 % with the junction width, which coincides with the upper limit of our estimate of residual capacitance that might contribute to the data. One sees a slight decrease of the capacitance with increasing reverse bias, but the dependence is much weaker than the square root dependence observed for three-dimensional junctions. We fitted the data with an expression given in [2] and the agreement between theory and experiment is good.

Optical beam induced current (OBIC) measurements were performed to investigate the depletion length as function of the applied reverse bias. Due to the limited resolution of the experiment (4 µm), the expected linear dependence could not be confirmed but an upper limit for the depletion length of 4 µm at 20 V reverse bias could be determined. Taking the carrier densities of the junctions fabricated into account, this upper limit agrees well with the theoretical predictions of [1].

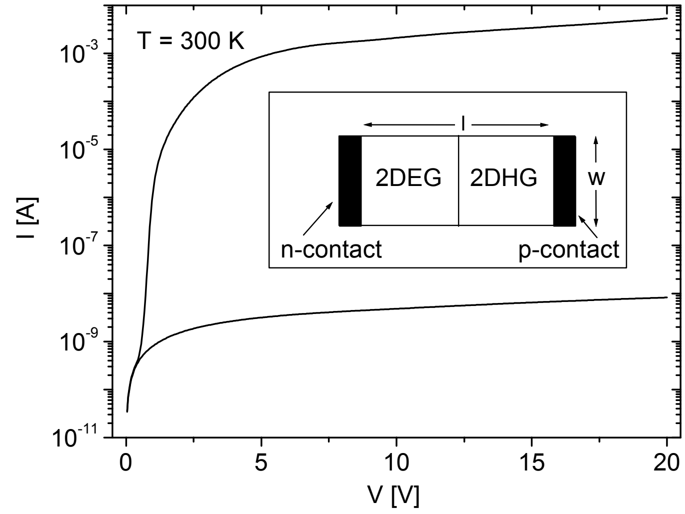

Figure 1: I-V characteristics of a two-dimensional diode with l = 60 µm and w = 150 µm measured at room temperature. The device geometry is shown in the insert. The measurements were performed in the dark.

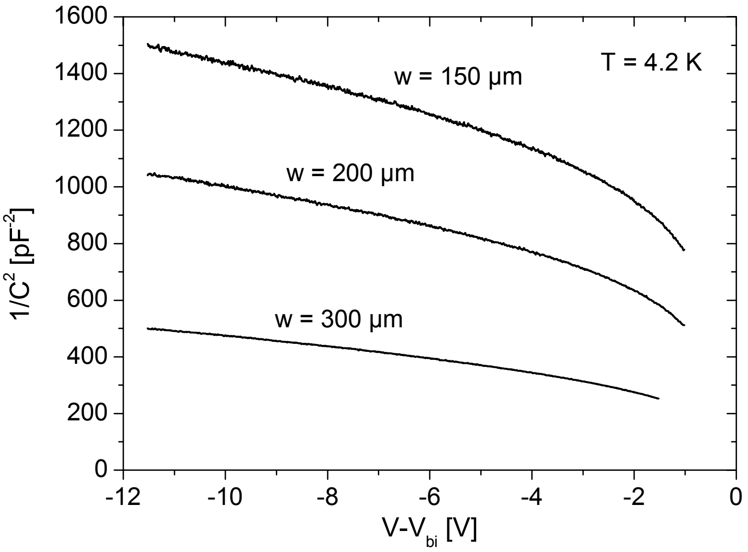

Figure 2: $1/C^2$ versus applied reverse bias V corrected for the built in voltage V_{bi} (1.52 V at 4.2 K) for two-dimensional p-n-junctions with various width w. As can be clearly seen, the voltage dependence is much weaker than the linear dependence observed in three-dimensional diodes.

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