TITLE: Unconventional Landan States in the Quantum Well with Embedded Self-Arranged Quantum Dots

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# Unconventional Landau states in the quantum well with embedded self-arranged quantum dots

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**Abstract.** It have been found that that the presence of InA self-arranged quantum dots strongly modify the structure of Landau levels in a host GaAs quantum well.

It was shown recently that the presence of InA self-arranged quantum dots (QD) in a host GaAs quantum well containing a two-dimensional electron gas strongly effects the electron transport [1], dramatically modifies the cyclotron resonance [2], and even more in the presence of quantum dots electron system exhibits metal-insulator transition in zero magnetic field otherwise not observable [3]. In this work we demonstrate with the help of the tunneling spectroscopy that QD also modify the structure of Landau level states in the quantum well.

The structure for the present studies was the same double barrier AlGaAs/GaAs/AlGaAs heterostructure as used before [4] containing layer of InAs QD in the center of the well, which was confirmed by photoluminescence spectroscopy. In equilibrium the dots is normally charged with electrons from contact layers.

After application of the high enough voltage bias to the structure the accumulation layer adjacent to the barrier is formed which serves as two dimensional emitter. In normal to the barriers magnetic field electrons tunnel into empty Landau level states in the well. If all tunneling electrons have the same energy, which happens if only ground Landau level is occupied in the two-dimensional emitter, the tunneling spectra measured at different biases give direct mapping of the density of states in the quantum well. The energy of the states is related with bias voltage by approximately linear dependence.

Figure 1 shows tunneling current versus magnetic field at different biases obtained when only ground Landau level is occupied in the emitter. Peaks correspond to the tunneling into Landau states in the well. The oscillations is periodic in reverse magnetic field and it is easy by simple analysis to determine the relation between peak on the curve and the number of the corresponding Landau level. The most interesting feature of the data is that some of the peaks (for example one indicated by arrow) are transformed from the well defined peak into the shoulder and then again to the peak with bias voltage.

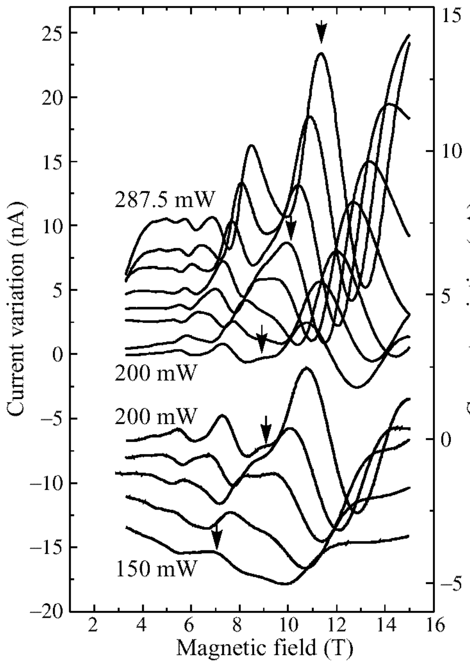


**Fig. 1.** Tunneling current variation with magnetic field at different voltage biases $V_b$. Curves are shifted arbitrary in vertical direction. The lower set of the curves for bias voltage range from 150 mV to 200 mV (right scale). The upper set for the range from 200 mV to 287.5 mV (left scale). Bias voltage step between curves is 12.5 mV for both sets. Arrows indicate the peak which transformation with magnetic field is discussed in the text.

Figure 2 shows the fan diagram of the observed peaks, that is the dependence of the peak position on the voltage scale versus magnetic field. The solid circles indicate position of the well defined peaks when the open circles indicate position of the shoulders. It is obvious that in magnetic fields defined as $B_1^*$ and $B_2^*$ unusual perturbation with Landau levels take place. In these magnetic field the area of the ground Landau level state in the well is approximately equal to $2S$ and $3S$, where $S = 12\,\text{nm} \times 12\,\text{nm}$ is the average area of the quantum dots known from the electron microscopy studies.

At the moment we do not have exact model of the observed influence of the quantum dots on Landau levels. We could propose that in the bias voltage region where the features were found the dots is still charged by electrons and in fact arrange in the well layer of

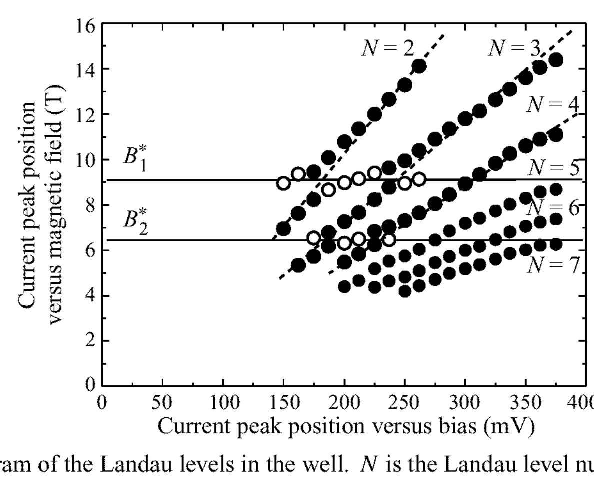


**Fig. 2.** Fan diagram of the Landau levels in the well. $N$ is the Landau level number. Other details in the text.

the approximately equal size randomly located antidots. There also must exist clusters of 2, 3 and more antidots. Evidently that one should expect some kind of interaction in the structure when the area of clusters becomes commensurate with the area of cyclotron orbits. It should be expected also that some features will appear in tunneling spectra when area of ground state Landau level becomes equal to $S$ which happens in magnetic field about 18 T. This value was out of magnetic field range used in our studies.

In conclusion, we demonstrate with the help of the tunneling spectroscopy that that the presence of InA self-arranged quantum dots modify the structure of Landau levels in a host GaAs quantum well. It could be proposed that some new commensurate type effect have been found in our studies.

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