Extended Abstracts of the 1993 International Conference on Solid State Devices and Materials, Makuhari, 1993, pp. 721-723 **PD-2-7**

Fabrication and Characterisation of Direct Schottky Contacts to Two-Dimensional Electron Gas in GaAs/AlGaAs Quantum Wells

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Schottky contacts to the edge of a two-dimensional electron gas in a GaAs/AlGaAs system have been manufactured using a newly developed in-situ etching and electroplating technology. The authors show that electroplating takes place selectively on the edge of the quantum well. I-V and C-V measurements have been made in order to compare the diodes with conventional Schottky diodes. The good agreement of theoretical predictions and experimental results demonstrates that we have indeed produced a Schottky contact to a 2-DEG.

1. Introduction

In recent years intensive efforts have been made in order to fabricate quantum-effect devices, many of them exploiting the extremely high mobility and other transport properties of low dimensionally confined electron gases at very low temperatures. While the quantum effects themselves are fairly well understood, both theoretical and technological aspects of the formation of contacts to quantum structures are rarely dealt with. Theoretically, contacts are medelled as "ideal electron reservoirs" and experimentally they are realised by ohmic contacts whose effects on electron waves are not quite clear. Some recent theoretical considerations by Petrosyan and Shik[1] seem to indicate that contact formation depends considerably on the dimensionality of the system. To this regard, Schottky contacts seem to provide a clearer view since they can be fabricated avoiding complicated metallurgical reactions and the possible degradation of the quantum structure during the annealing of ohmic contacts.

As a first attempt to form Schottky contacts to quantum structures and to clarify the transport mechanism, we have developed an in-situ electrochemical technology for the formation of Schottky contacts to 2-DEG in a GaAs/AlGaAs quantum well. Using the theory outlined by Gelmont et al.[2], we could confirm that a contact to a 2-DEG has definitely been formed. The behaviour of our diodes is similar to that of recently published microwave-mixer diodes using an InGaAs/GaAs quantum well system[3].

2. In-situ electrochemical contact deposition

In contrast to e-beam evaporation Schottky contact formation by electroplating is known to cause less damage to the semiconductor surface, resulting in a more homogeneous current flow, less recombination etc. It has also been shown that the removal of native oxides by electrolytic etching and the in-situ deposition of Pt Schottky contacts to GaAs in the same electrolyte result in very low density of deep level defects[4] and in oxide free interfaces[5].

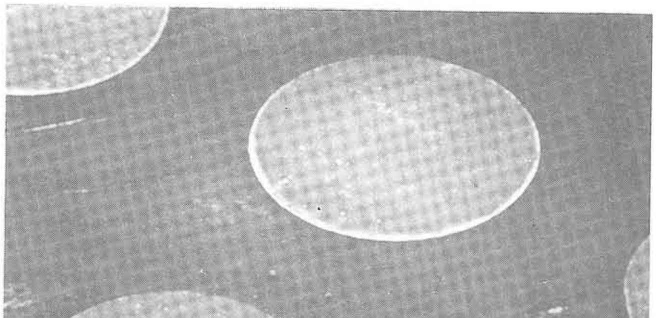

Fig.1: Circular dots deposited onto GaAs through holes in an epitaxial AlGaAs layer

Contact formation to the extremely small area of the edge of a 2–DEG by a Schottky contact with a controlled metal–semiconductor interface becomes possible when we take advantage of the fact that both electrolytic etching and metal deposition will principally occur on the best conducting parts of a sample. In order to demonstrate this we etched holes into an epitaxial $Al_{0.3}Ga_{0.7}As$ layer grown on a n–doped GaAs wafer. After manufacturing a backside ohmic contact the cleaned sample was exposed to an electrolytic bath of 200ml 1N–HCl with 1g of H_2PtCl_6 and etched with electric pulses of 0.2µs length. Immediately afterwards we deposited Pt by applying electric pulses of 0.5µs length and 1V potential difference with respect to the electrolyte. A more detailed description of this technology is given by Wu[5]. As Fig.1 shows, only the GaAs areas are selectively electroplated.

3. Fabrication of Schottky/2–DEG diodes

The quantum well structure used in our experiments was grown by MBE and is shown in Fig.2. A 10nm GaAs quantum well is embedded between $Al_{0.3}Ga_{0.7}As$ barriers. Electron supply is accomplished by a δ–doped Si layer. AuGeNi ohmic contacts to the quantum well were evaporated and annealed. A hole was etched in a distance of 20µm of these contacts by wet etching with $NaOH{:}H_2O_2{:}H_2O$ (10:1:200). We then deposited Schottky contacts to the edge of the 2–DEG using the technology described above. About 50,000 etching pulses and 75,000 deposition pulses were applied. We found that the Pt deposition indeed starts at the edge of the quantum well, but then rapidly spreads along the less conducting adjacent surfaces. The 75,000 deposition pulses produced a 5µm wide line as shown in Fig.3. Finally Au contact pads were evaporated for better contacting of these fine lines. A cross section of the diode structure is given in Fig.2.

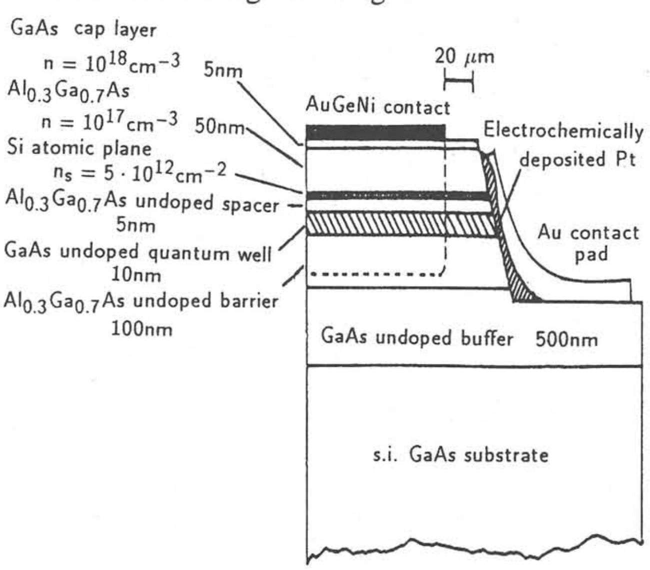

Fig.2: Cross section through a Schottky/2–DEG diode

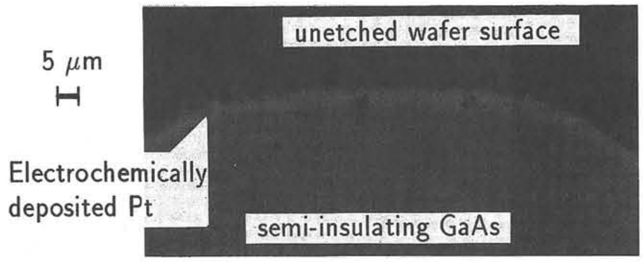

Fig.3: Fine Pt line produced by electrodeposition onto the 2–DEG

4. I–V and C–V characteristics

The results of I–V measurements of the manufactured diodes are shown in Fig.4. They resemble I–V characteristics of usual Schottky diodes with an ideality factor n of 1.4 to 1.6. The series resistance of 250Ωmm was expected from the Hall measurements of the quantum well. Although Petrosyan and Shik[1] give a theoretical limit of n=1 they also point to the fact that their result may not be true for any geometrical configuration of the contact. Hence, the reason of the fairly high ideality factor is not yet clear. At low voltages a shunt conductivity can be seen. Using the Richardson constant for bulk GaAs a barrier potential of 0.7V was calculated. These two results are in agreement with similar diodes reported elsewhere[3]. As the mechanism of barrier formation is yet to be examined, a reason for the low barrier voltage compared to usual Schottky diodes can not be given. The reverse breakdown voltage was higher than 25V.

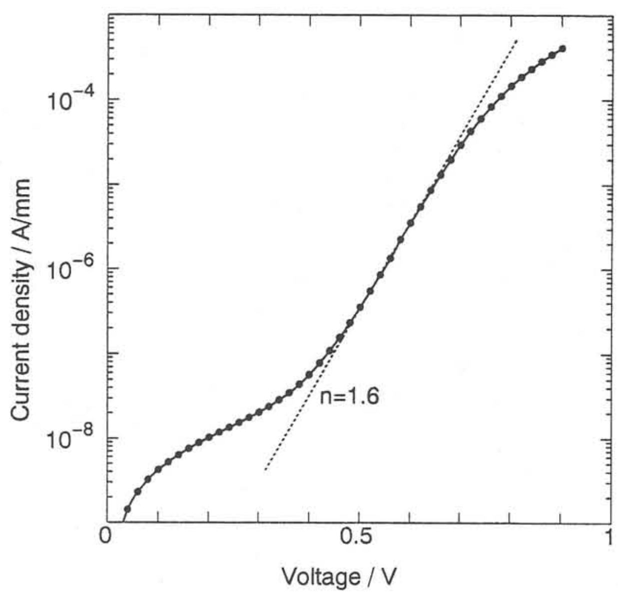

Fig.4: Forward I–V characteristics of a 100µm wide Schottky/2–DEG diode

The result of capacitance-voltage (C–V) measurements indicated that a linear relationship between $1/C^2$ and the voltage, typical for Schottky contacts to bulk material does not exist. The decrease is much steeper and in fact almost exponential (Fig.5). Gelmont et al.[2] have given a formula for the capacity of a p(3–DEG)–n(2–DEG) junction which can be used for Schottky contacts as well and can be reduced to $C \sim \ln(V_{bi}-V)^{-1}$ for large contact areas. As shown in Fig.6 our C–V measurements agree very well with this relation when we assume a built-in voltage of 0.74V. This shows that we have indeed produced a Schottky contact to the quantum well.

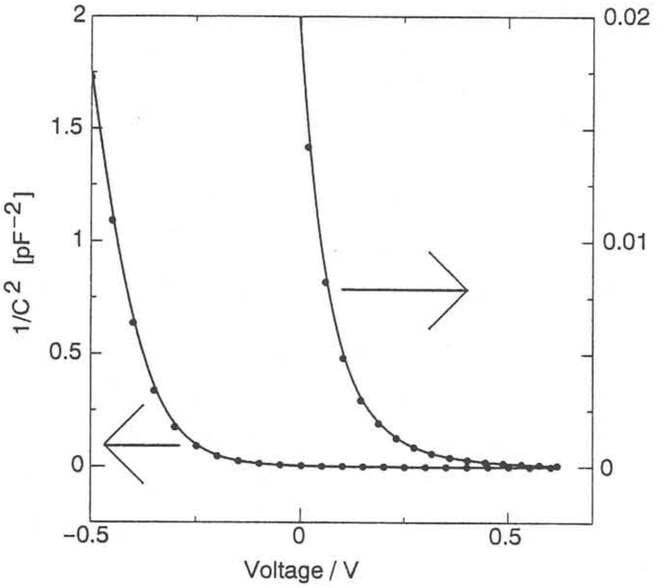

Fig.5: $1/C^2$ versus voltage of a 100μm wide diode shows a nonlinear decrease

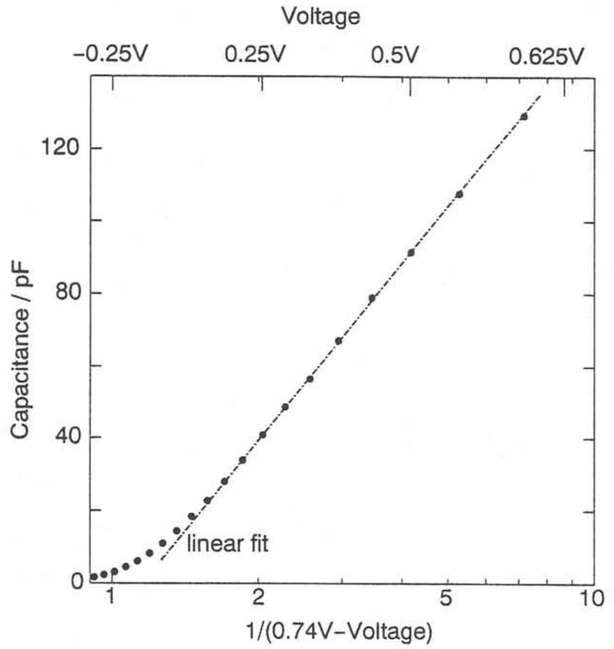

Fig.6: The same C–V measurement result shows a linear dependence on $\ln(V_{bi}-V)^{-1}$ as theoretically predicted

5. Conclusions

We could demonstrate that Schottky contacts to two-dimensional electron gases can be produced by selective deposition of Pt in an in-situ electrochemical etching and electroplating process. This enables us to investigate the contact mechanisms to 2–DEG. We could show that the characteristics of the diodes thus fabricated agree with the theory. Aside from fundamental interests related to quantum transport, such Schottky contacts to edges of quantum wells may find applications in mixer diodes for highest frequencies[3] which could be integrated in MMICs. The selective deposition technology can be used to contact separately very close quantum wells, and thus may lead to an entire new generation of devices.

6. Acknowledgments

One author (G.Schweeger) is grateful to Hitachi Co. for sponsoring his research activities.

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