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C-V and EBIC Study of Direct Schottky Contacts to Quantum Wells Formed by In-Situ Selective Electrochemical Process

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Depletion properties of direct Schottky/quantim well (QW) contacts formed by the *in-situ* selective electrochemical process were systematically characterized by the C-V and EBIC techniques. The EBIC images clearly showed that the barrier exists at the edge of the QW layer. It was found that the capacitance of the Schottky/QW contact depends linearly on $\ln(1/V_{bi}-V)$, where the V_{bi} is built-in voltage, and that the depletion width obtained from the EBIC measurements is proportional to the applied voltage. These results demonstrate that well-behaved depletion characteristics of the Schottky/QW systems can be realized. Preliminary results of the QW wire with the Schottky/QW barriers are also presented.

1. INTRODUCTION

We have recently shown that a Pt/GaAs Schottky interface with excellent qualities and a direct Schottky contact to quantum wells (QWs) with two dimensional electron gas (2DEG) can be made by our *in-situ* electrochemical process.[1,2)] The *in-situ* etched GaAs surface was very smooth, and no oxidized and disordered layer was produced at the interface. In addition, the unique feature of this process is that it allows selective and low-damage deposition of Pt only to the QW edge, as schematically shown in Fig.1(a). No other technique provides such a feature. This technique seems to be useful for formation of quantum structures. An example of quantum well wire (QWW) formation is shown in Fig.1(b). For design and fabrication of such a structure, one needs information on the depletion characteristics of direct Schottky contacts to the QW edge, that are expected to be different from those of three dimensional Schottky barriers. Theoretical prediction of the potential distribution in the Schottky/2DEG systems has recently been proposed,[3)] but no experimental approach is dealt with.

The purpose of this paper is to study and optimize the depletion characteristics of the Schottky/QW contacts formed by our *in-situ* selective electrochemical process. Depletion properties of the Schottky/QW contacts were characterized by C-V and electron beam induced current (EBIC) technique using a standard scanning electron microscope (SEM).

2. EXPERIMENTAL

Figure 2 shows the molecular beam epitaxy (MBE) grown QW structure and the cross-sectional view of the Schottky/QW barriers. Trenches were etched into the QW structure by wet etching. The trench surface was etched by anodic dissolution using avalanche pulses prior to the pulse plating of Pt in the same electrolyte. This process was found to form oxide-free and well-ordered metal/semiconductor interfaces.[1)] In addition, selective and direct contact formation to the edge of QW becomes possible by taking advantage of the fact that both *in-situ* electrolytic etching and metal plating take place selectively at the place with the lowest potential on the surface. The *in-situ* process realized the initial selective deposition of Pt seed at the edge of QW followed by

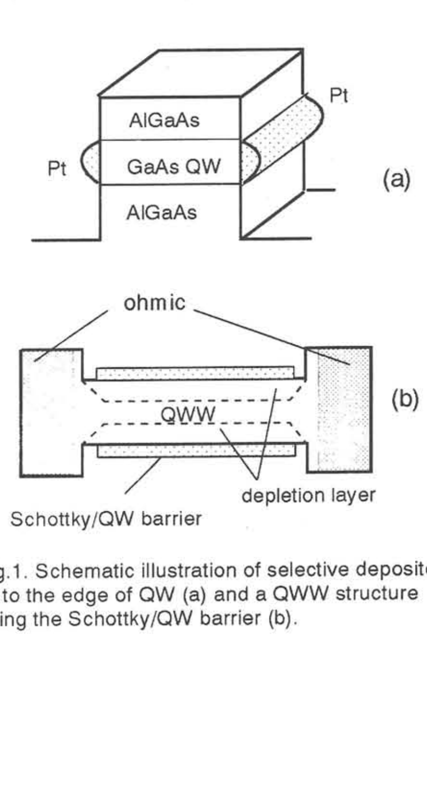

Fig.1. Schematic illustration of selective deposited Pt to the edge of QW (a) and a QWW structure using the Schottky/QW barrier (b).

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GaAs cap	1×10^{18} cm^{-3}	100Å
$Al_{0.3}Ga_{0.7}As$	5×10^{17} cm^{-3}	450Å
Si atomic plane	5×10^{12} cm^{-2}	—
$Al_{0.3}Ga_{0.7}As$	undoped	50Å
GaAs QW	undoped	200Å
$Al_{0.3}Ga_{0.7}As$	undoped	1000Å
GaAs buffer	undoped	5000Å
SI GaAs substrate		

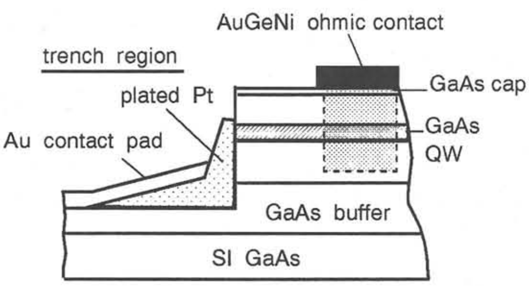

Fig.2. GaAs/AlGaAs QW structure and cross-sectional view of the Schottky/2DEG contact.

gradual spread of metal film over the surface of the exposed semiconductor. SEM observation showed formation of the deposited-Pt line after application of thousand plating pulses.

3. RESULTS AND DISCUSSION

The I-V behavior of the Schottky/2DEG diodes fabricated was similar to those of usual Schottky/bulk diodes with the ideality factor, n, of 1.4-1.6. Using the Richardson constant for bulk GaAs, a barrier height of 0.7eV was calculated.

On the other hand, the C-V results of the Schottky/2DEG contacts indicated that a linear relationship between $1/C^2$ and the bias voltage, typical for Schottky contacts to bulk material, dose not exist. This is in agreement with the theoretical analysis of Gelmont *et al.*[3] A junction capacitance for a 3-dimensional/2-dimensional contact system is given by the following expression when the half-depth of the 3-dimensional contact in the dimension vertical to a 2DEG, R, is much larger than the depletion width in a 2DEG:

$$C = \frac{2W\epsilon}{\pi}\left(\frac{qRn_s}{\epsilon} + \ln\frac{1}{V_{bi}-V}\right) \qquad (1)$$

where W is the anode width of the diodes, ϵ the dielectric constant of the semiconductor, n_s the sheet carrier concentration of a 2DEG and V_{bi} the built-in voltage.

Figure 3 gives the capacitance experimentally obtained versus $\ln(1/V_{bi}-V)$ with V_{bi} of 0.7eV. The capacitance depends linearly on $\ln(1/V_{bi}-V)$ in accordance with the theoretical prediction with the shunt capacitance due to the contact pads.

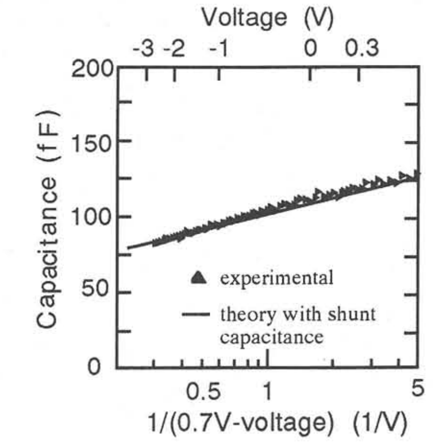

Fig.3. Capacitance versus ln{1/(Vbi-V)} of the Schottky/QW barrier with Vbi of 0.7V.

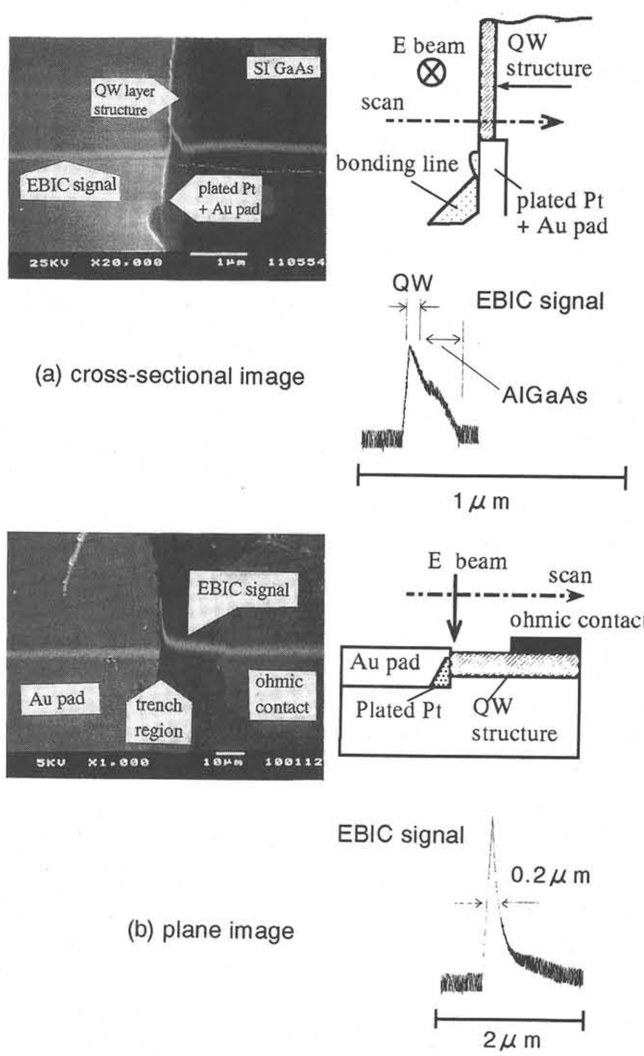

Fig.4. SEM/EBIC images of the Schottky/QW contact with corresponding schematic representations of beam scan geometry.

In order to further investigate the depletion characteristics of the Schottky/QW barriers, the SEM/EBIC measurements were employed. Figure 4 shows the cross-sectional and plane SEM/EBIC images with corresponding schematic representations of beam scan geometry. In the cross-sectional EBIC image, the peak positioned at the depth of 500-800Å from the surface, supporting that the largest electric field is provided by the Schottky barrier located at the GaAs QW region. The signal shows a fairly good correspondence to the structure given in Fig.2, although charged carriers, which are generated in the undoped AlGaAs layer and travel to the QW barrier, may be responsible for the broadening of the EBIC signal. The EBIC in-plane signal clearly indicates that the potential peak exists at the edge of the QW with the estimated depletion width of 0.2μm. Since the depth range of the electron beam is calculated to be 1200Å from the beam voltage of 5kV, the charge collection region includes the GaAs QW layer.

The depletion width as a function of the reverse bias voltage, obtained from the EBIC in-plane image, is shown in Fig.5. In the 3-dimensional/2-dimensional contact systems, the depletion width, d_{dep}, is expected to be proportional to the applied voltage as follows:[3]

$$d_{dep} = \frac{2\epsilon}{qn_s} (V_{bi} - V) \qquad (2).$$

Theoretical calculation of the dependence of the depletion width on the applied voltage is also given in Fig.5. As can be seen, the width obtained from the EBIC image is close to the calculation with $n_s = 1\times10^{12}\text{cm}^{-2}$ which was confirmed by the Hall measurement.

These results demonstrate that direct and selective Schottky contacts to QW with well-behaved depletion characteristics can be realized by the present *in-situ* electrochemical process. Thus, the technique was applied to formation of the wire structure shown in Fig.1(b). Figure 6 shows the plane SEM/EBIC image of the 18-μm wide wire with double side gates which consist of direct Schottky/QW contacts. Potential barriers are clearly seen at both edges of the wire. A decrease of the EBIC peak compared with that in Fig.4 seems to be due to the leakage current. In fact, the current between the ohmic electrodes was found to be modulated by the side gate voltage, as shown in Fig.7, indicating that the reduction of width size of the wire in the range of 1-2μm can realize the quantum well wire.

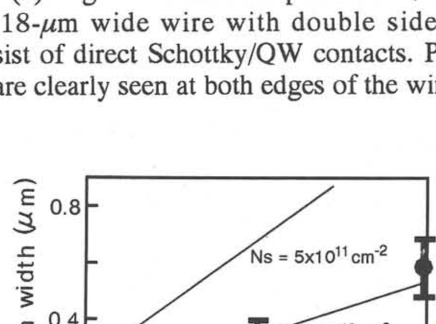

Fig.5. Depletion width of the Schottky/QW junction obtained by the EBIC image and theoretical calculation of the width with Vbi=0.7V.

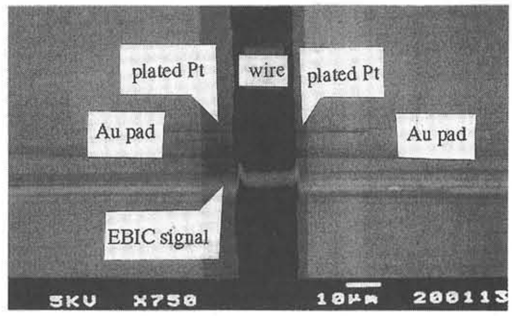

Fig.6. SEM/EBIC in-plane image of the 18-μm wide wire with the Schottky/QW side gates.

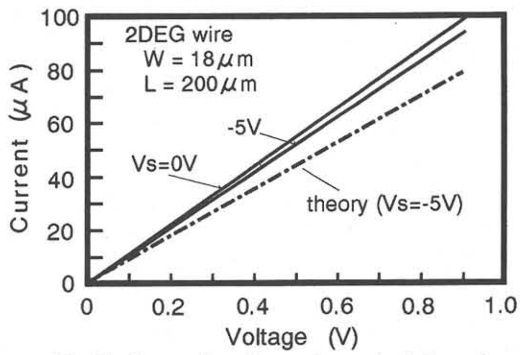

Fig.7. Current-voltage characteristics of the wire with the Schottky/QW side gates.

4. CONCLUSION

Depletion properties of direct Schottky/QW contacts formed by the *in-situ* selective electrochemical process were systematically characterized by the C-V and EBIC techniques. The EBIC images clearly showed that the barrier exists at the edge of the QW layer. It was found that the capacitance of the Schottky/QW contact depends linearly on $\ln(1/V_{bi}-V)$, where the V_{bi} is built-in voltage, and that the depletion width obtained from the EBIC measurements is proportional to the applied voltage. These results demonstrate that well-behaved depletion characteristics of the Schottky/QW systems can be realized. Preliminary results of the wire with the Schottky/QW barriers showed that the in-situ selective technique can be applicable to formation of the quantum well wire.

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