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Schottky/2DHG Silicon Barrier Diodes with Single and Coupled Delta-Doped Wells

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A Schottky/two-dimensional electron gas (2DHG) barrier diode based on boron δ-doped silicon grown by molecular beam epitaxy has been fabricated. Preliminary measurements on the single and coupled δ-doped well devices included the *I-V* and *C-V* characteristics are reported. Reverse breakdown voltages over 50 V and 35 V were obtained for the single and coupled δ-doped devices, respectively. The coupled δ-doped layer diode exhibits a larger *C-V* nonlinearity as compared to that of the single δ-doped device, which compares favorably for higher *RC* cutoff frequency Schottky/2DHG barrier diode fabrication.

1. INTRODUCTION

For the past decade, the Si/Ge heterosystem has attracted particular attention because it offers many potential device applications in Si based technology. With the current advancements in silicon molecular beam epitaxy (Si MBE) technology, device quality films of δ-doped layer on Si become possible. The δ-doping technique allows us to localize the impurity atoms within a few atomic monolayers, thereby creating a V-shaped potential well and producing a 2DEG or 2DHG in the conduction or valence bands[1]. Recently, Peatman et al[2] reported for the first time the investigation and device application of a Schottky/2DEG barrier diode with a pseudomorphic $Al_{0.25}Ga_{0.75}As$ /$In_{0.15}Ga_{0.85}As$/GaAs structure. The physics of the Schottky/2DEG junction has been investigated in 3) and 4). The Schottky/2DEG barrier diode combines a very low series resistance due to the excellent transport property of the 2DEG with a high breakdown voltage caused by the two-dimensional electric field spreading in the depletion region.

In the present work, we utilized boron δ-doping layer(s) in undoped silicon to serve as the conducting channel for the Schottky/2DHG diode fabrication. Since the use of a single δ-doping layer to enhance 2D carrier density for a high conductivity is at the expense of reduced mobility[5], double delta coupled layers which are located in close proximity to each other have also considered in the experiment. Coupled δ-doped layers have been found can have a much higher Hall mobility as compared to the single well case[6]. Hall mobility enhancement is due to wave function coupling between closely spaced wells, which leads to transport carriers spatially separated from ionized impurity scattering.

2. EXPERIMENT

Figure 1 shows schematically the cross section of the Schottky/2DHG diode. The layers were grown by Silicon Molecular Beam Epitaxy (Si-MBE) at a growth temperature of about 600°C. Delta doping was achieved by the simultaneous deposition of Si from an electron gun source and B from a high temperature Knudsen cell. Au and Ag were used for the ohmic and Schottky contacts, respectively. The width of the δ-doping layer is approximately 50 Å from SIMS analysis and the thickness of the spacer layer between the two δ-doped layers is designed to be 100 Å. Conventional Si MESFET process is used for the device fabrication. Au and Ag were used for ohmic and Schottky contacts, respectively. The source and drain contacts were subject to a thermal annealing at 330 °C for 5 minutes in N_2 ambient for better ohmic contacts. In order to form the Schottky contacts, wet chemical etching is carried out to etch out the δ-doped channel region.

3. RESULTS AND DISCUSSION

It is shown by Hall measurements that a hole mobility of 2400 $cm^2V^{-1}s^{-1}$ at 77 K for the coupled δ-doped layer has been obtained compared to a mobility of 200 $cm^2V^{-1}s^{-1}$ for the single δ-doped layer. The hole sheet carrier density of the proposed structure at 300 K is approximately 1×10^{13} cm^{-2} per delta layer. Figures 2(a) and 2(b) show the measured typical room temperature *I-V* characteristics of the single and coupled δ-doped devices, respectively. As shown in the graph, the breakdown voltage for the single and couple δ-doped devices are over 50 V and 35 V, respectively. Note the δ-doped device has a relatively smaller current under forward bias.

The series resistance R_s as a function of the under forward bias for the two type diodes are shown in Fig. 3. It is seen that the coupled delta layers device has a lower cut-in voltage as compared to that of the single δ-doped device. The relatively large series resistance might be in part due to the low mobility of holes in the δ-doped layer at room temperature, and in part attributed to insufficient Ag plating on the side wall of the V-groove and high ohmic contact resistance.

The comparison between the *C-V* curves of the single and coupled δ-doped devices are shown in Fig. 4. The channel length and width are 10 and 250 μm, respectively. The measured signal frequency is 1 MHz. The coupled δ-doped diode exhibits a larger *C-V* nonlinearity (a larger value of $(1/C_{min}-1/C_{max})$. A higher *RC* cutoff frequency f_c (= $(1/C_{min}-1/C_{max})/2\pi R_s$)[2]) is expected for the coupled δ-doped devices. It is noted that the zero-bias capacitance of the coupled δ-doped diode is about twice that of the single δ-doped diode.

4. CONCLUSION

In conclusion, a Schottky/2DHG barrier diode based on boron δ-doped silicon grown by MBE has been fabricated successfully. Reverse breakdown voltages over 50 V and 35 V were obtained for the single and coupled δ-doped devices, respectively. The coupled δ-doped diode exhibits a larger *C-V* nonlinearity as compared to that of the single δ-doped device and a higher *RC* cutoff frequency is expected for the coupled δ-doped devices. Based on the preliminary results obtained so far, the device has potential applications on high frequency circuit and is monolithic integratable with the conventional silicon VLSI technology. Further optimization for the device performance especially at low temperature and for n-type coupled wells diodes is necessary.

5. ACKNOWLEDGMENTS

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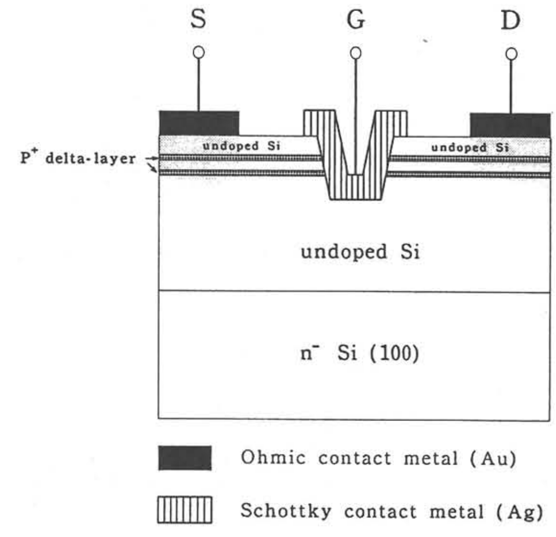
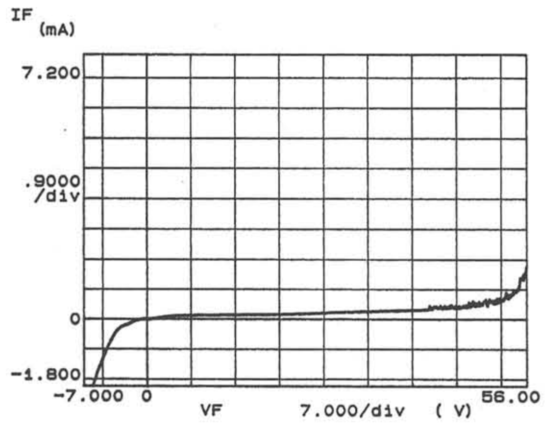
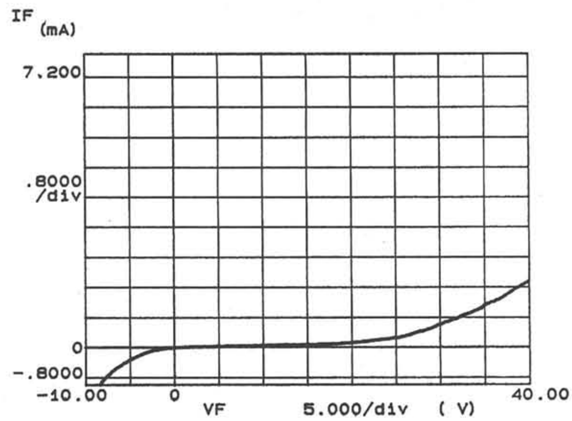


Fig. 1. Schematic cross section of the Schottky/2DHG Si barrier diode.



(a)



(b)

Fig. 2. Typical room temperature *I-V* characteristics of (a) single and (b) coupled δ-doped well barrier diode.

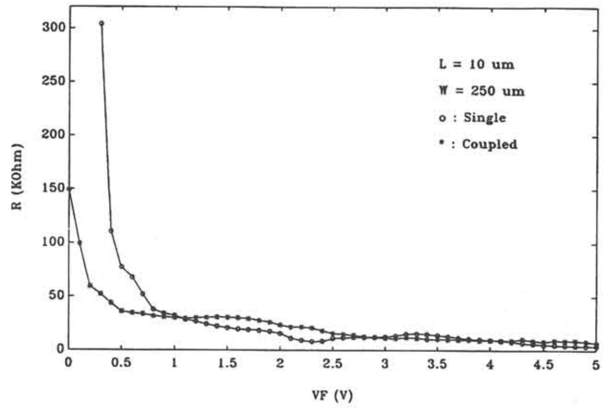


Fig. 3. The series resistance of the single and couple δ-doped well barrier diodes under forward bias.

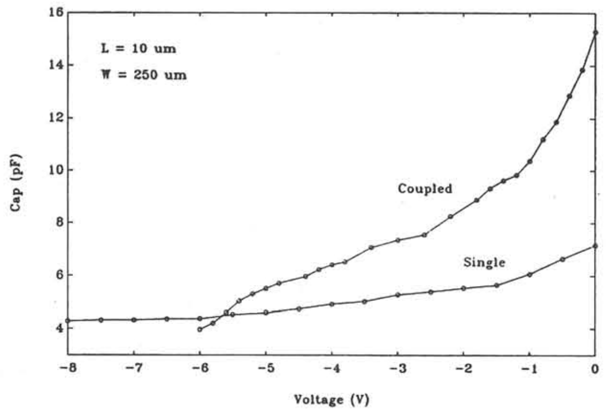


Fig. 4. Typical *C-V* characteristics of the single and couple δ-doped well barrier diodes.