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Tunneling Mode Dependence of Current-Voltage Characteristics in Si/SiO_2 Resonant Tunneling Diodes

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1. Introduction

Although a resonant tunneling diode (RTD) has been expected as high-speed novel devices, there are only a few reports on RTDs based on a Si/SiO_2 system. Moreover, in the reported RTDs, non-linear current-voltage (I-V) curves were observed, but negative differential conductance (NDC) was absent [1,2]. Recently, we have fabricated RTDs by a new and simple method based on ultrathin silicon-on-insulator (SOI) structures and found that a RTD with a Si-well width of 2 nm shows NDC in its current-voltage (I-V) curve [3].

In this work, we studied RTD characteristics with various thicknesses of the buried SiO_2 (BOX) layer and clarified the effect of the tunneling mode change from direct tunneling to Fowler-Nordheim (F-N) tunneling. In the direct tunneling mode, normal NDC characteristics due to resonant tunneling were observed, whereas, in the F-N mode, a charge storage effect appeared obviously.

2. Fabrication of Si/SiO_2 Double Barrier Diodes

An SOI wafer used here has an ultrathin (3-5 nm) thermally grown BOX layer, which finally works as a lower tunneling barrier. Since such an SOI wafer with the ultrathin BOX is not commercially available, the wafer was fabricated in our laboratory by a wafer bonding technique. Then, the SiO_2/Si double barrier structure was fabricated by three successive steps; thinning of the top Si layer to 2 nm in thickness by oxidation, the oxide removal and oxidation for the formation of an upper tunnel barrier (2-nm-thick SiO_2). For the I-V characterization, each RTD was isolated with neighboring ones by local oxidation. The resultant structure is schematically shown in Fig. 1. As the top electrodes, Al, whose work function is close to that of an n^+-Si substrate, was deposited by the conventional vacuum evaporation.

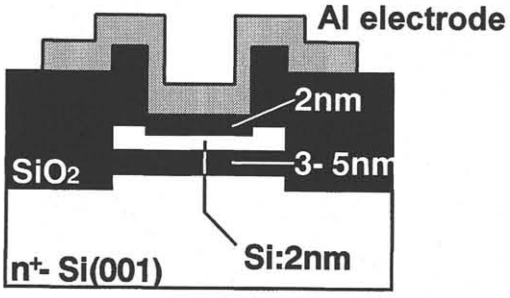

Fig. 1 Cross-sectional diagram of a RTD structure.

3. Results and Discussion

Figure 2 shows I-V characteristics of RTDs with a BOX thickness of (a) 3, (b) 4 and (c) 5 nm, measured at 15K. The diode area is about 150 μm^2. In all samples, NDCs are clearly observed. The NDCs in Figs. 2(a) and 2(b) can be ascribed to resonant tunneling in a direct-tunneling regime. However, the NDC in Fig. 2(c) is caused by a different origin because the tunneling mode is in or close to an F-N tunneling regime [4]. As shown in Fig. 2(c), the NDC has also large hysteresis and an opposite-direction current below 4.6 V even when the Al gate electrode of the RTD is positively biased. These findings indicate that negative charges are accumulated in or near the Si well during increasing the gate bias, as schematically shown in Fig. 3. As a result, the Si-well potential rises energetically due to the negative-charge storage.

As described above, in the RTD with 5-nm-thick BOX, the F-N tunneling process dominates [4]. In the cases of 3- and 4-nm-thick BOX layers where a direct tunneling process is observable, on the other hand, neither hysteresis nor opposite current is observed. Hence, it can be deduced from these facts that the F-N tunneling process works as a trigger of the negative-charge storage around the Si well. Inelastic scattering of electrons in the BOX layer under the F-N tunneling condition may be primarily responsible for electron trapping.

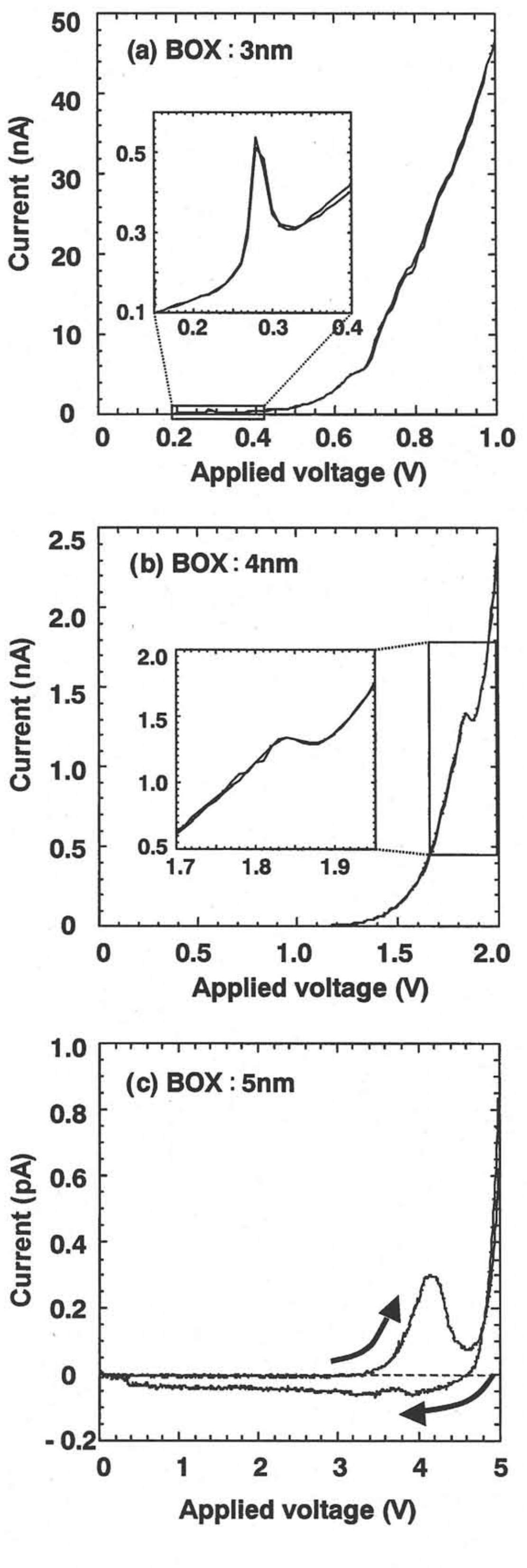

Fig. 2 Current-voltage characteristics of RTDs with a BOX thickness of (a) 3, (b) 4 and (c) 5nm, measured at 15K. The diode area is about 150 μm^2.

Another important fact obtained from Fig. 2 is that the background current level decreases by a factor of orders with an increase in the BOX thickness. This obviously indicates that the background current is mainly governed by the electron tunneling from the Si substrate to the Si well, which is due to reduction in the tunneling probability with tunneling distance.

4. Conclusions

We have investigated the relationship between the RTD characteristics and the electron injection processes (direct tunneling and F-N tunneling process). It is found that resonant-tunneling-induced NDC characteristics appear in the direct tunneling mode, while, in the F-N tunneling mode above 5 nm in BOX thickness, hysteresis in the I-V characteristics and opposite-direction current are observed due to the negative-charge storage around the Si well.

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References

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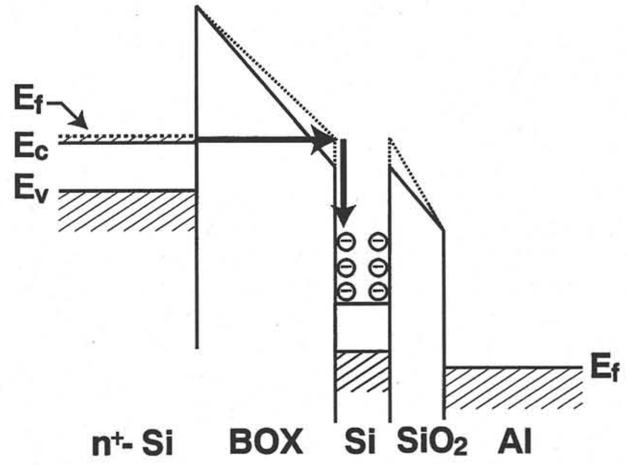

Fig. 3 Band diagram of a RTD with a 5-nm-thick BOX layer.