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The Formation of Resonance Tunnel Device by γ-Al_2O_3/Si Multiple Hetrostructure

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1. Introduction

Recent advancement in device miniaturization has pushed the size of electronic devices into the region where quantum effects become dominant. In devices such as Resonant Tunneling Diodes (RTDs) and High Electron Mobility Transistors (HEMTs), for example, the traditional carrier transport mechanisms of drift and diffusion, are replaced by quantum tunneling or ballistic transport [1]. RTD is an excellent candidate for nanoelectronic devices for digital circuit applications because of its negative differential resistance (NDR), structural simplicity, relative ease of fabrication, inherent high speed, flexible design freedom and versatile circuit functionality[2]. The electron properties of ultrathin SOI hetrostructure have not been studied so much at the present stage. The quantum well structure which consists of Si as well and an insulator γ- Al_2O_3 as barrier can be expected to lock up electrons of high energy, because this insulator film has a high energy barrier. Also very thin and smooth surfaces are required to prepare RTDs because these surfaces can emit electrons of constant energy.

In this work we report the fabrication of γ-Al_2O_3/Si/γ-Al_2O_3 /n-Si(111) Double Barrier Quantum well device with very thin and flat surface. The quantum well structure formed by Si and γ-Al_2O_3 has a potential application to an emitter which can emit electrons of constant energy.

2. Experimental

To fabricate γ-Al_2O_3/Si/γ-Al_2O_3/n-Si(111) Double Barrier Quantum Well Device the following steps were performed sequentially. γ-Al_2O_3 thin films of 3nm thickness was deposited on n-type Si(111) substrate by Metalorganic Molecular Beam Epitaxy (MOMBE) method. To get good quality γ-Al_2O_3 surface a pre-layer of γ-Al_2O_3 was deposited on Si substrate[3]. The deposition of 3 nm thick γ-Al_2O_3 layers was performed at 750 °C at a pressure 2×10^{-2} Pa. An epitaxial layer of 4 nm thick Si was deposited on γ-Al_2O_3 films by mini e-beam evaporator model EGCO4 Oxford Applied Research, at a temperature of 800°C. We use Si rod of 1.9 mm diameter as Si source. The Si growth rate was kept very small about 4 nm/hour. To get smooth surface of Si, Al pre-deposition layer is very useful before Si growth[4]. Finally a 3 nm thick γ-Al_2O_3 layer was deposited on the epitaxial Si surface. RHEED and AFM images of as grown epitaxial γ-Al_2O_3 and Si surfaces were taken. Current voltage measurements of the samples were performed at room temperature by Hewlett Packard pico Ampere Meter HP4140B. A negative differential resistance was observed. Conduction band offset was obtained from Fowler-Nordhiem plotting.

3. Results and Discussion

Figures 1(a) and 1(b) show the RHEED patterns of 3 nm thick γ-Al_2O_3 and 4 nm thick Si as grown surfaces. These streak RHEED patterns indicate the epitaxial grown of γ-Al_2O_3 and Si layers. Surface morphology of the as grown epitaxial layers was studied using atomic force microscopy (AFM). Figures 2(a) and 2(b) show the AFM images of 3 nm thick γ-Al_2O_3 and 4 nm Si as grown surfaces respectively. The images were taken in air and ambient pressure. RMS values of these surfaces are 0.39 nm and 0.65 nm respectively which ensure the smoothness of the surfaces.

Figure 3(a) shows the Current density – Electric field characteristic of the sample with 6nm-thick γ-Al_2O_3 /n-Si(111). From this result, Fowler-Nordhiem plot was performed as shown in Figure 3(b) . In this F-N plot we observe a straight line portion which indicates the presence of F-N tunnel phenomenon. We calculate the conduction band offset (ΔEc) from this plot and its value is 1.7 eV.

Room temperature I-V characteristic of double barrier resonant tunnel diode γ-Al_2O_3 / Si / γ-Al_2O_3 / n-Si (111) was performed as shown in Figure 4. A Negative Differential Resistance is observed at 0.3V with Peak to Valley ratio 1.6. In the current voltage measurement we used Al gate electrode with area $100 \times 100\ \mu m^2$. We also prepare a triple barrier resonant tunnel diode and current voltage characteristic was measured as shown in Figure 5. We observe tunneling effect at 0.2V, 0.3V and 0.4V neighborhood. Peak to Valley current ratio at maximum is 4.6. When the measurement was repeated, the characteristics deteriorates and it was checked that peak stops appearing gradually.

4. Conclusion

In this study we fabricate ultra thin layers of γ-Al_2O_3 and Si with very smooth surface which is useful for emitting constant energy electrons. The Resonance tunnel device fabricated by γ-Al_2O_3/Si hetrostructure with 3 nm thick γ-Al_2O_3 as barrier and 4 nm thick epitaxial Si as quantum well, shows negative differential resistance (NDR) at room temperature with peak to valley current ratio 1.6 for double barrier and 4.5 for triple barrier. These values are relatively high and useful for device fabrication.

Acknowledgments

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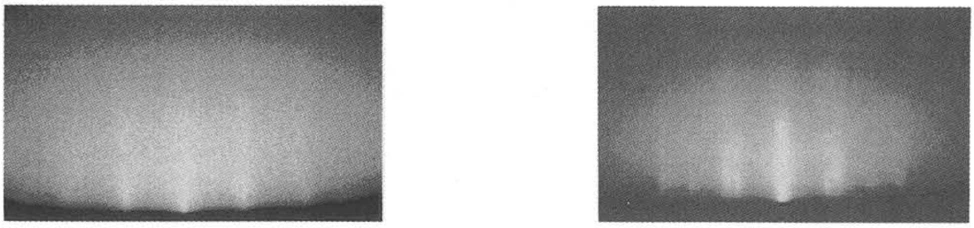
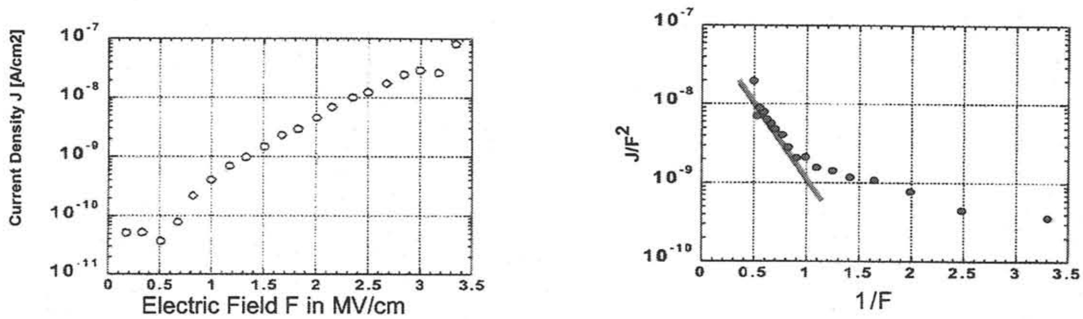


(a) (b)

Figure 1. RHEED patterns of (a) 3 nm thick γ-Al_2O_3 surface deposited on S(111) substrate and (b) 4 nm thick Si surface deposited on γ-Al_2O_3/ Si(111).

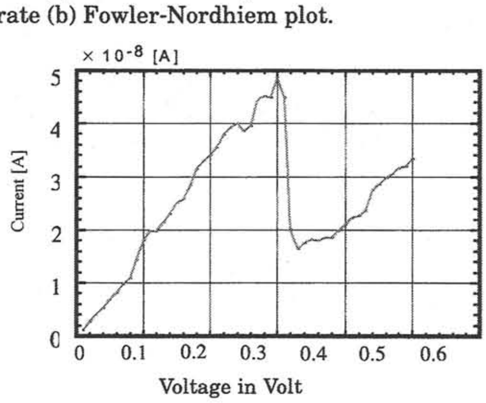
(a) (b)

Figure 2. AFM images of (a) 3 nm thick γ-Al_2O_3 surface deposited on Si(111) substrate and (b) 4 nm thick Si surface deposited on γ-Al_2O_3/ Si(111).



(a) (b)

Figure 3. (a) Current density Electric field characteristic of 6 nm thick γ-Al_2O_3 deposited on Si(111) substrate (b) Fowler-Nordhiem plot.



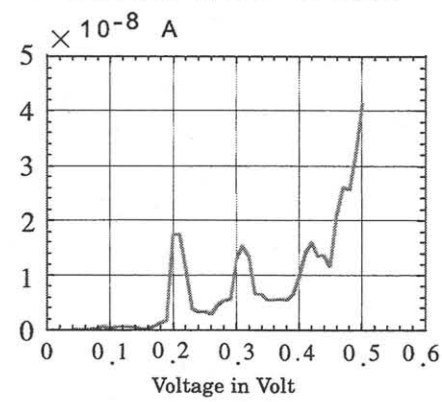


Figure 4. I-V characteristic of γ-Al_2O_3/Si double barrier quantum well device.

Figure 5. I-V characteristic of γ-Al_2O_3/Si triple barrier quantum well device.