Effect of Individual Dopants in Esaki Tunneling Diodes

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1. Introduction

Nanoscale pn junction is one of the fundamental building blocks not only in VLSI technology, but also in photonic devices. Recently, nanoscale pn junctions have been studied from different approaches, such as tunneling functionality [1] or photonic devices applications [2].

We are now focusing on the effect of individual dopant atoms on transport characteristics of nano pn diodes. In our previous work, nano pn diodes (device A in Fig. 2(a)) with doping concentrations of ~5.0×10^{19} cm^{-3} were studied. Several fine current steps can be observed in both forward and reverse biases at low temperatures, as marked in Fig. 2(a). We proposed a hypothetical model of electron interband tunneling via dopant-induced states localized in band gap region of the depletion layer. Tunneling mediated by different dopants could give rise to the current steps. However, probably because of large parasitic resistance, negative differential conductance (NDC) was not observed. Therefore, our hypothetical model was not sufficiently supported by this experiment. In the present work, in order to optimize the I-V characteristics, doping concentration is further enhanced to ~1.0×10^{20} cm^{-3} (device B in Fig. 2(b)). For these devices, we found NDC and a number of features, such as marked current humps, at 5.5 K. These results further confirm that such features can be ascribed to inter-band tunneling effects and further support our original hypothesis.

2. Lateral nanoscale pn junction diode structure

We fabricated nanoscale Esaki tunneling diode in silicon-on-insulator (SOI) wafer. The junction is formed in a constriction region, as shown in Fig. 1.

We utilized thermal-diffusion technique for selective-doping process to define a region of n-type (doped with phosphorus) and p-type (doped with boron), respectively. Doping concentration, measured on same thickness SOI monitor samples, is ~2.0×10^{20} cm^{-3} and 9.0×10^{19} cm^{-3} for n-type and p-type, respectively. The top-Si thickness is ~10 nm and the width of the constriction region of pn diode is ~100 nm.

3. Effect of individual dopants on interband tunneling

I-V characteristics of device B at low temperature, in both forward and reverse bias, are shown in Fig. 2(b). For comparison, results for the previous device A are also shown in Fig. 2(a). As it can be seen in Fig. 2(b), we confirm that current is due to interband tunneling by the observation of NDC behavior in forward-bias regime [3]. The current also quickly increases without an offset region, differently from our previous result shown in Fig. 2(a). In particular, we found several current humps, indicated by red arrows in Fig. 2(b), appearing in a wider range of forward bias. These humps can be ascribed to tunneling via dopant-induced states located in bandgap region of the depletion layer.

In conclusion, this result provides further evidence of atomic effects due to individual dopant atoms on interband tunneling in nanoscale pn junctions.

References

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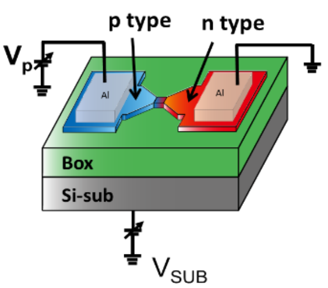

Fig. 1. Schematic structure of nanoscale lateral *pn* junctions and *I-V* measurement circuit.

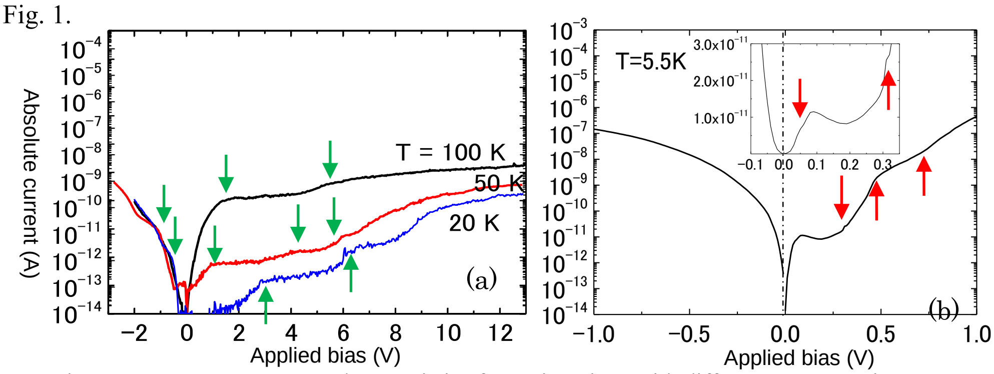

Fig. 2. Low-temperature I-V characteristics for pn junctions with different concentrations. Inset of (b) shows current in linear scale to emphasize the NDC region and fine features.