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Interband Tunneling through Individual Dopants in Nanoscale pn Junctions

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1. Introduction

Study about nanoscale pn junctions has an important role in clarifying the operation of nano-devices, like tunnel field-effect transistors (TFETs) or downscaled metal-oxide-semiconductor FETs. Recently, nanoscale pn junctions have been studied from various approaches, such as tunneling functionality [1-3], or impact of low-dimension on electrical characteristics [4].

We focus on clarifying the effect of individual dopants on transport characteristics. Previously, we reported that individual dopant atoms work as electrons traps, inducing RTS in current at temperature under 30K in pn junctions with low doping concentration of ~1.0×10^{18} cm^{-3} [5]. In this report, we show I-V characteristics of nanoscale interband tunneling pn junctions with relatively high doping concentration of ~5.0×10^{19} cm^{-3}. We find that interband tunneling mechanism is strongly influenced by individual dopant states in depletion layer region.

2. Device structure

We fabricated nanoscale pn diodes in silicon-on-insulator (SOI) substrates, with a constriction structure, as shown in inset of Fig. 1.

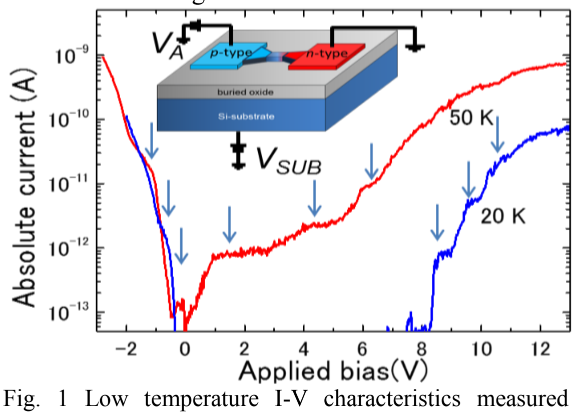

Fig. 1 Low temperature I-V characteristics measured in forward and reverse bias. Arrows mark observed current steps. Inset shows schematic structure of nanoscale lateral *pn* junctions and *I-V* measurement setup.

We utilized thermal diffusion technique for selective-doping process to define region of n-type (doped with Phosphorus) and p-type (doped with Boron). Doping concentration in both p-type and n-type regions are ~5.0×10^{19} cm^{-3}. The top-Si thickness is ~10 nm, and width of constriction region of pn diode is ~100 nm. For electrical measurements, we applied two types of bias, i.e., bias between p and the n-type (V_A), and bias from the substrate (V_{sub}). Electrical measurements have been done using low-temperature measurement system, under high vacuum condition.

3. Effect of individual dopants on interband tunneling

I-V characteristics of high doped pn junctions at low temperatures, in both forward and reverse bias, are shown in Fig. 1. As can be seen, we observed interband tunneling current with multi steps, indicated by blue arrows, in both forward and reverse bias regions. The absence of negative differential conductance (NDC) under forward bias condition, as a common feature of Esaki tunneling diode [6], indicates the existence of energy states in band gap region, inducing large excess current [7]. We also measured V_{sub} dependence characteristics at 5.5K (as shown in Fig. 2), and found that the current steps are effectively modified by changing V_{sub}. This indicates the origin of these current steps feature is most likely effect of discrete energy states in depletion layer. We consider that these energy states are caused by individual dopants existing in depletion layer.

In conclusion, we found strong dependence of interband tunneling current on individual dopant states in depletion layer, generating multi steps behavior in I-V characteristics under forward and reverse bias conditions.

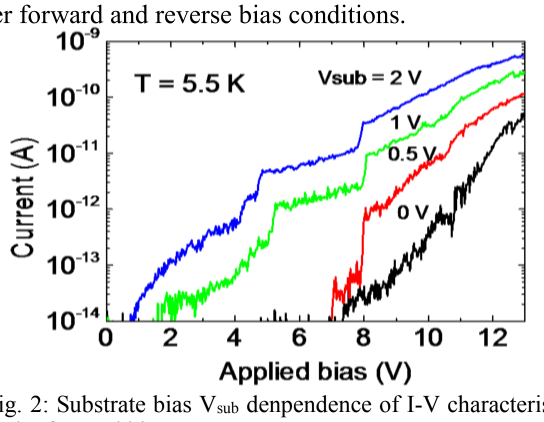

Fig. 2: Substrate bias V_{sub} denpendence of I-V characteristics under forward bias at T= 5.5K.

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