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Observation of Individual Dopants in the Electrical Characteristics of Nanoscale pn Junctions

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Introduction

In nanometer scale, discrete dopants play a key role in device transport properties. So far, the behavior of nanoscale pn junction has been reported[1,2], but not from the point of view of individual dopants. Previously, we studied individual dopant behavior in nanoscale pn junctions by Kelvin probe force microscope (KFM),[3] and by *I-V* characteristic measurement under light illumination.[4] In this work, we investigate the dopant individuality in SOI lateral nanoscale pn and pin junctions by *I-V* characteristics measured in the dark. Random telegraph signal (RTS), typically observed in pn junctions, is ascribed to charge trapping and detrapping by individual dopant in the depletion region.

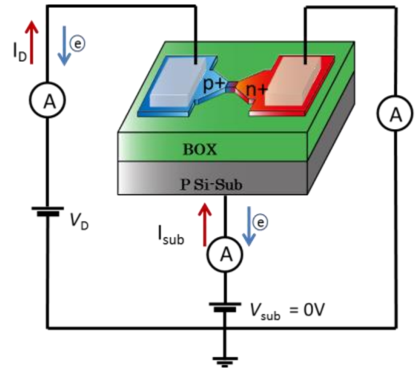

Fig. 1. Schematic structure of nanoscale lateral pn junctions and *I-V* measurement setup.

Device structure and measurement setup

We fabricated nanoscale lateral pn junction diodes in thin silicon-on-insulator (SOI) layer ($t_{Si} \cong 10$ nm). Figure 1 shows schematically the device structure and *I-V* measurement setup. The nanowire length is 1000 nm, while the width is set as a parameter, varying from 75 - 700 nm. The n-type region was doped with phosphorus ($N_D \approx 1.0 \times 10^{18}$ cm^{-3}), while the p-type region was doped with boron ($N_A \approx 1.5 \times 10^{18}$ cm^{-3}). The pn junctions contain a co-doped region, doped with both phosphorus and boron atoms, while for pin devices, i-region was kept effectively un-doped.

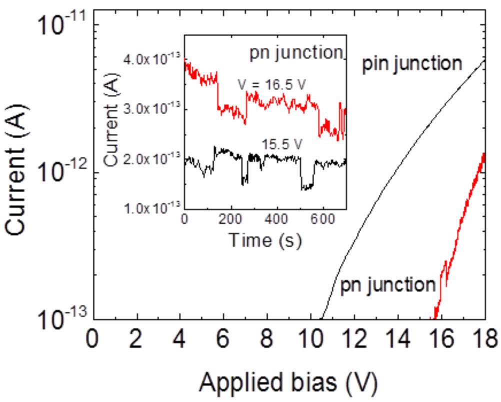

Fig. 2. *I-V* characteristics in forward bias for pn and pin junctions at T = 30 K. For pn junctions, current fluctuations can be observed. Inset: I-time characteristic of pn junction, exhibiting two levels of RTS.

Experimental results and discussion

In this study, we measured *I-V* characteristics of pn and pin junctions in dark conditions. Measurement results for pn and pin junction devices at T = 30 K are shown in Fig. 2. For pn junctions, *I-V* characteristics exhibit current fluctuations, and can be ascribed to charge trapping and detrapping by individual dopant. The time dependence of the current was measured as a function of applied bias, as shown in the inset in Fig. 2. Random telegraph signals (RTS) with two levels were observed, suggesting that the trap is most likely a single dopant, i.e. ionized dopant in the depletion region. On the other hand, for pin junctions, *I-V* characteristics exhibit no noise features, confirming that mostly in the pn junctions there is a high probability to find trapping centers. Then, the investigation is focused on pn junction devices with different channel widths. It was found that RTS mainly found for devices with channel width below 200 nm (Fig. 3). This result suggests that the presence of too many dopants in the depletion region is likely to conceal trapping events by individual dopants. Moreover, RTS was also observed in a restricted range of applied bias (not shown here).

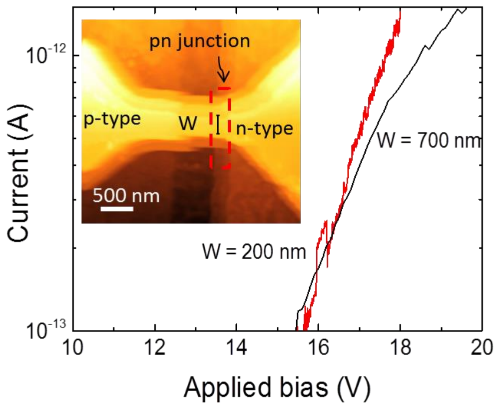

Fig. 3. *I-V* characteristics for pn junctions with different channel width. Current fluctuations can be observed in narrower device. Inset: AFM image of a typical pn junction of width ~250 nm.

References [1]S. Petrosyan *et al.*, Appl. Phys. Lett., **84,** 3313 (2004). [2]D. Reuter *et al.*, Appl. Phys. Lett., **86**, 162110 (2005). [3] R. Nowak *et al.*, Appl. Phys. Lett **102**, 083109 (2013). [4]A. Udhiarto, *et al.*, Appl. Phys. Express **5**, 112201 (2012).