Executive Summary

Title: Single dopant devices: Single-electron transport through single-dopants

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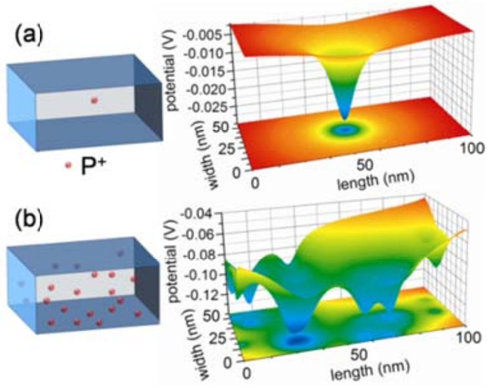
Introduction

Recently, *dopant-induced fluctuation* of device characteristics has been recognized as one of the most serious problems for further progress of CMOS technology [1]. On the other hand, as an extreme limit of MOSFETs, single-dopant single-electron transistors were reported from Delft University [2], NTT [3], and our group (Shizuoka University) [4, 5]. Those devices work as single-electron (-hole) tunneling transistors through the dopants as a steppingstone for electron (hole) tunneling between source and drain electrodes.

In this background, we aim at developing *fundamental atom devices* from a different viewpoint to the CMOS technology trend, i.e., single-dopant (SD) transistors [5], SD memories [6], SD turnstile [7-9] and SD photonic devices [10-12]. In those devices, only one or a few dopants are intentionally used in the channel and the dopants work as quantum dots having a homogeneous size of potential well. These SD devices work as single-charge tunneling devices due to Coulomb blockade mechanism and operation temperatures are limited to low temperatures below 100K at present.

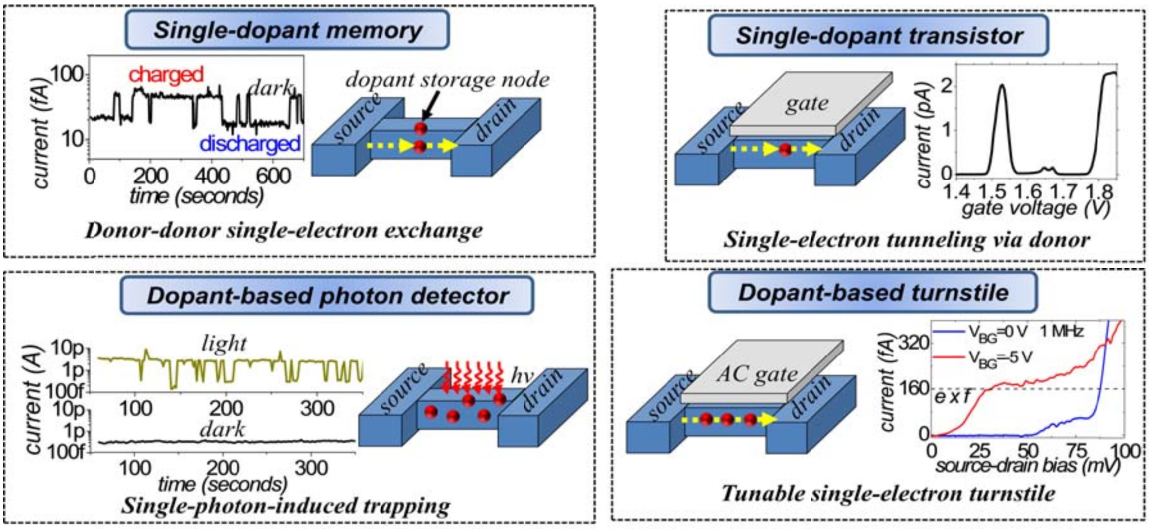
In these devices, it is desired that the dopants are individually controlled in position and in number by means of single-ion implantation (SII) technique [13, 14]. The SII process is, however, still under development and not available in most of laboratories at present. Therefore, we have studied SD devices under the environment of many dopants without using sophisticated individual doping process. We have demonstrated that even under donor-rich environments the early stage of I_d-V_g characteristics are dominated only by one or a few single-donors and such characteristics are sensitively affected by channel shape [5]. This finding allows us to do research on SD devices even with the conventional doping process.



The progress of selected topics over the past five years including your results

According to this concept of *atom* devices, in our group, we have demonstrated the following device functions:

1) Single-electron transistors using only one single-donor in the channel have been demonstrated in donor-rich environment [5]. Also, two-donor-based memory effect is observed [6].
2) Single-electron transfer (turnstile) devices using a few dopants in the channel [7-9].
3) Also, for the purpose of photonic application, photon detection has been demonstrated [10-12].
4) Furthermore, we have developed a novel technique for single dopant detection, low-temperature Kelvin probe force microscopy (LT-KFM), and succeeded in observing single-dopant potential in the channel [15, 16].



r group.

Potential application opportunities, if possible (What is the potential impact on ITRS?)

Our approach (single-dopant devices) may be merged and cross over in the future with the ITRS CMOS technology. At the same time, single-dopant devices may open up a new technology field covering nanoelectronics and nanophotonics, since the devices have potential of new functions with electrons, spins and photons beyond CMOS.

The difficult challenges and potential solutions for the next 10 – 15 years

The following points are important challenges to gain significant progress in single-dopant devices;

1) to develop *deterministic doping process*: (i) single ion implantation or equivalent doping techniques as well as atomic scale annealing and diffusion process, (ii) effect of nanometer-scale channel structures, i.e., effect of high stress field and nearby interfaces, and (iii) interaction with S/D electrodes,
2) to *increase of dopant potential for room temperature operation* by means of coupled dopants,
3) to develop *devices having immunity from unavoidable fluctuation* in position of dopants in nanometer scale,
4) to develop *single-dopant observation techniques* as well as theoretical work on dopant physics.

Experts and expertise with references (Shaded papers are from our group.)

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Experts (in the order of references): A. Asenov[1], S. Rogge[2], Y. Ono[3], T. Shinada[13, 14]