Dopant-atom-based Tunnel SOI-MOSFETs


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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, FET characteristics influenced by a single-dopant atom were reported from several groups [2-5], where carrier transport mechanism is tunneling through individual dopant atoms. In this background, we have proposed and demonstrated dopant-atom devices from a different viewpoint to the CMOS technology trend, i.e., single-dopant (SD) transistors [5], SD memories [6], SD turnstiles [7-9] and SD photonic devices [10-12]. In these devices, only one or a few dopants are intentionally used in the channel and one dopant works as a quantum well for electron (or hole) tunneling transport.

P-donor atom in nanoscale channels of SOI-MOSFETs

When we focus on a phosphorous (P) donor atom, it can be treated as a hydrogen-like atom in Si matrix. Based on the effective mass approximation, the ionization energy, or the binding energy, of the donor atom with respect to the Si conduction band minimum is as small as 45 meV. Therefore, P-atom tunneling devices can operate only at low temperatures below ~20 K, since at high temperatures electrons are thermally excited and tunneling transport mechanism does not work. However, when a dopant is embedded in Si nanostructures, its electronic states are significantly different from those in bulk Si, and its ionization energy is predicted to be enhanced due to effects of dielectric and quantum size confinement [13].

Most recently, we have demonstrated high-temperature operation of dopant-atom MOSFETs at around 100 K because of donor state deepening in specifically-designed nano-stub-channels, as shown in Figs. 1 and 2 [14]. Such progress toward room temperature operation is critical for practical application of “atom devices”. These results are qualitatively evidenced by ab initio atomistic simulations of individual dopants in Si nanostructures. More details, including observation of single dopants by low-temperature Kelvin probe force microscopy (LT-KFM) [15-18], will also be presented.

References