Scientific Report

Activity of Dr. Masahiro Hori (23/05/2011-03/06/2011)

With the gate length of MOSFETs approaching 10 nm, the channel region contains only one or a few dopant atoms. The random dopant distribution will cause fatal fluctuation of the device performances, such as threshold voltage or transconductance. On the other hand, one positive outcome of ultimately scaled-down doped devices has been demonstrated. We have fabricated transistors with deterministically implanted a few phosphorus (P) and arsenic (As) atoms and have revealed the quantum transport properties at low temperature for the first time. I report the measurement activity of the single dopant devices with controlled the position and number of arsenic atoms with the single-ion implantation (SII) method, and investigation of the electron transport around the “critical density” which causes the transition from the localized electron states to the Hubbard bands formation. The results of electrical measurement highlight the value of deterministic doping towards the doped-channel device limits.

During the stay transistors fabricated at Waseda have been exstensively measured. Figure 1 left shows the electron transport property of a transistor with the single dot (2 arsenic ions). The figure shows four current peaks originating from the Coulomb blockade and single-electron tunneling. Two pairs of Coulomb blockade peaks are associated to the D0 and D− states of the two implanted donors. Thus, the number of the peaks coincides with double of number of dopants. No other peaks above the fourth one have been observed, in agreement with the experimental evidence that no electrostatic unintentional dots are formed in the channel by the gate bias. This indicates the high reliability of the single-ion doping method that enables us to control the ion number precisely.

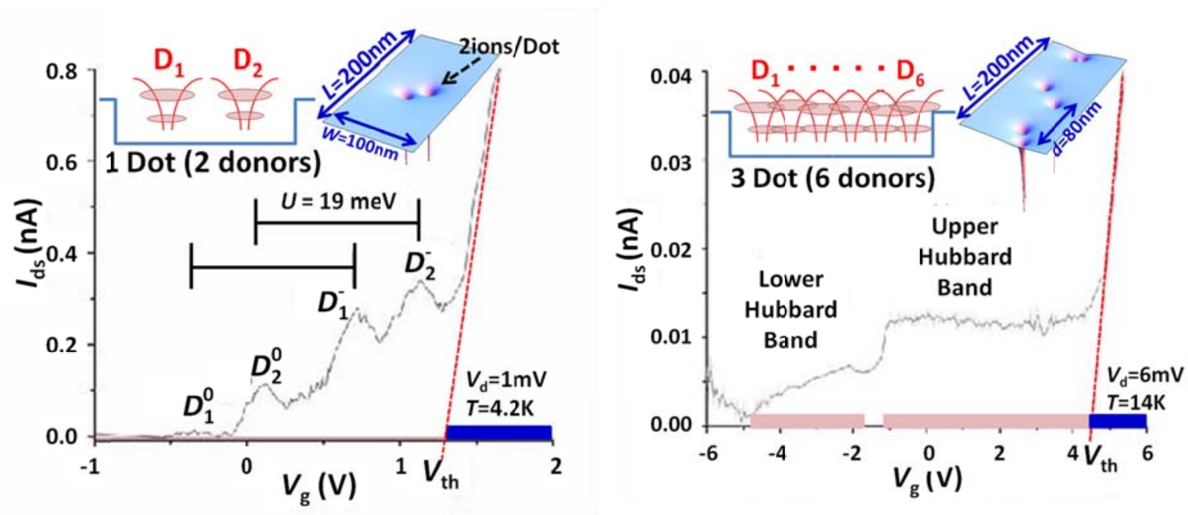

Figure 1. Left: I-V* characteristic for transistor with single dot (2 donor ions).** The four current peaks of the two donors are visible for the sample with the isolated donors. Number of the peaks coincides with double of number of dopants. ***Right: ***I-V* characteristic for transistor with three dot (6 donor ions).** The broad characteristic in which Coulomb blockade peaks merged was observed. This was attributed to the high overlap of the donor wavefunction between two contiguous sites.

Figure 1 right shows the electron transport property of a transistor with three dots (6 arsenic ions). The three-dot device has a higher donor concentration than the single dot device. The upper and lower Hubbard bands are formed out of impurity-state wave functions when the concentration of impurities in the material is sufficient to produce a critical overlap of the wave functions from adjacent impurity atoms[11]. This result indicates that the electron transport in single-dopant device is sensitive to the variation of the number and position of arsenic ions.

In the sample with two dots (4 atoms) we observed a spectacular phase transition from a Wigner like phase to a Fermi glass.

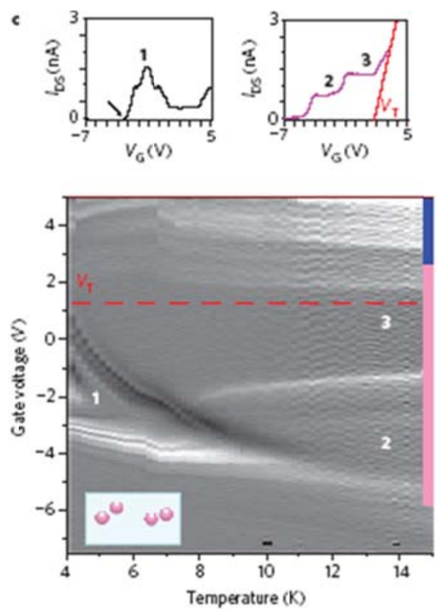

Figure 2. Transition from a Wigner-like phase to a Fermi glass.

The results obtained during the stay have been published on Nature Nanotechnology [1].

[1] E. Prati, M. Hori, F. Guagliardo, G. Ferrari, and T. Shinada, *Anderson–Mott transition in arrays of a few dopant atoms in a silicon transistor*, **Nature Nanotechnology 7**, 443–447 (2012) [IF **30.307**]