Integration of attractive molecular functions into a single-carrier transistor

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Molecular devices hold promise for attaining new nano-electronic devices which would not be realized by current Si technology. For this purpose, we have proposed a new single-carrier transistor, where organic molecules behave as quantum dots. [1-5] A striking point of our devices is that attractive molecules are embedded in an insulating layer of a metal-oxide-semiconductor (MOS) structure and the structure works as a double tunnel junction. Furthermore, the embedded molecules are fully isolated from each other. The feature thus enables to examine quantum transport via single molecules in the Si device with the same analogy of scanning tunnelling spectroscopy, although many molecules (10^{12}-10^{13} cm^{-2}) are present in the insulating layer underneath electrodes.

In this talk, I introduce our efforts on the single-carrier transistor with many functional molecules. First, I present the fundamental carrier transport with C_{60} molecules in our devices. [1] We observed stepwise currents at 20 K, which was ascribed to single-carrier tunnelling reflecting the discrete energy levels of the embedded molecules. Surprisingly, the quantum transport was visible even at room temperature. Second, I exhibit some unique molecular functions. Here, binary molecules, which are phthalocyanine and the fluorinated one, produced multilevel control of the tunnelling current.[2] Moreover, the adoption of diarylethene photochromic molecules allowed optical manipulation of the tunnelling.[3] Consequently, we achieved a vertical single-carrier transistor with molecular dots. [4,5] The molecular orbitals enabled the multilevel control of the drain currents, which is expected to realize multivalued transistors. Our proposed device therefore has potential to integrate molecular functions into future CMOS devices, and to deliver unique device operations unobtainable with inorganic quantum dots.

REFERENCES

[1] R. Hayakawa *et al.*, *Adv. Funct. Mater.* 21 (2011) 2933-2937.
[2] R. Hayakawa *et al.*, *ACS Appl. Matter. Interfaces* 5 (2013) 11371-11376.
[3] H.-S. Seo, R. Hayakawa *et al.*, *J. Phys. Chem. C* 118 (2014) 6467-6472.
[4] R. Hayakawa *et al.*, *Nanoscale* 9 (2017) 1129-11302.
[5] T. Basu, R. Hayakawa *et al.*, *ACS Appl. Electron. Matter.* 3 (2021) 973-978.

FIGURES

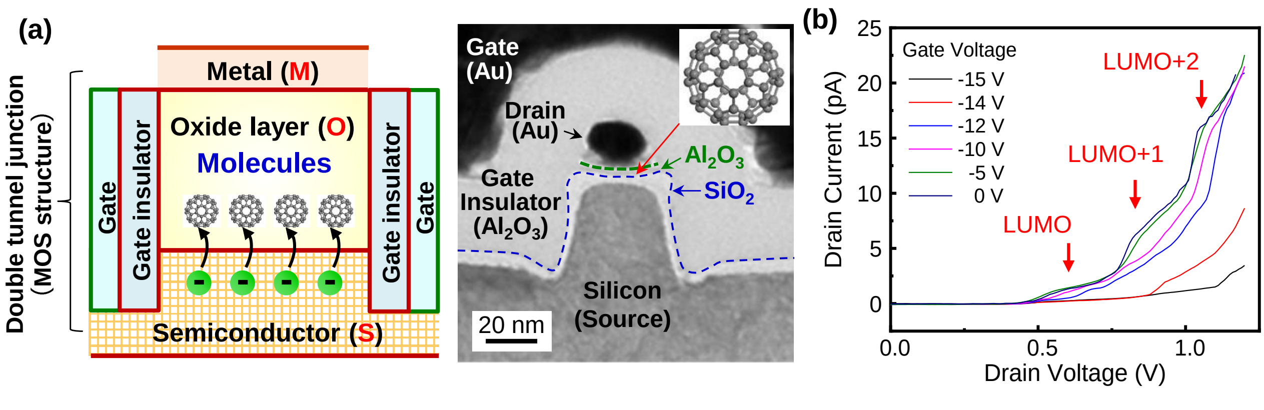

Figure: A schematic illustration and a transmission electron microscopy image of a vertical single-carrier transistor with C_{60} molecules as quantum dots. (b) A typical drain current-drain voltage characteristic of the transistor.