Molecules meet Si: bridging single-molecular function with practical device

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Our main purpose is to develop an electron tunneling devices by taking advantages of molecular functions. A key point of this study is to integrate organic molecules into Si-based device architecture. Here, we present the process to prepare a metal-oxide-semiconductor (MOS)-device with molecules, fundamental mechanism of electron tunneling [1], multi-level tunneling through multiple molecules [2], and optical control of electron tunneling via photochromic molecules for optoelectronic device [3].

For practical development, quantum dots for the electron tunneling devices should be well designed on nanometer scale. For example, the size of the quantum dots should be a few nanometers for realizing room temperature operation. Size uniformity is another important factor for fine control of threshold voltage (V_{th}). To meet these requirements, we adopted organic molecules as quantum dots. First, fullerene (C_{60}) molecules were embedded in a MOS structure (Fig. 1(a)). Staircases in current-voltage curves were observed in a double-tunneling junction consisting of $Au/Al_2O_3/C_{60}/SiO_2$ multi-layers on Si(100) substrates. Here, C_{60} and Al_2O_3, SiO_2 layers served as intermediate electrodes and tunneling barriers, respectively. We elucidated that the observed staircases can be attributed to resonant tunneling through the empty and occupied energy levels of the C_{60} molecules. The energy diagram is drawn in Fig. 1(b). These results clearly indicate that the V_{th} for electron tunneling can be tuned precisely as requested by designing molecular structure.

We applied this mechanism to various functional tunneling manipulation those are multi-level tunneling and optical switching of electron tunneling. In the multi-level tunneling, heterogeneous phthalocyanine molecules with different energy levels were embedded together in MOS structure. For optical switching, reversible photochromic reaction (open-ring/closed-ring isomerization) of diarylethene was applied to optical control of electron tunneling.

Importantly, our device configuration is compatible with the conventional MOS-FET device and, therefore, these results demonstrate the potential of practical use of molecules for the tunneling devices in the Si-based devices, such as single-electron memory and tunneling transistor.

References

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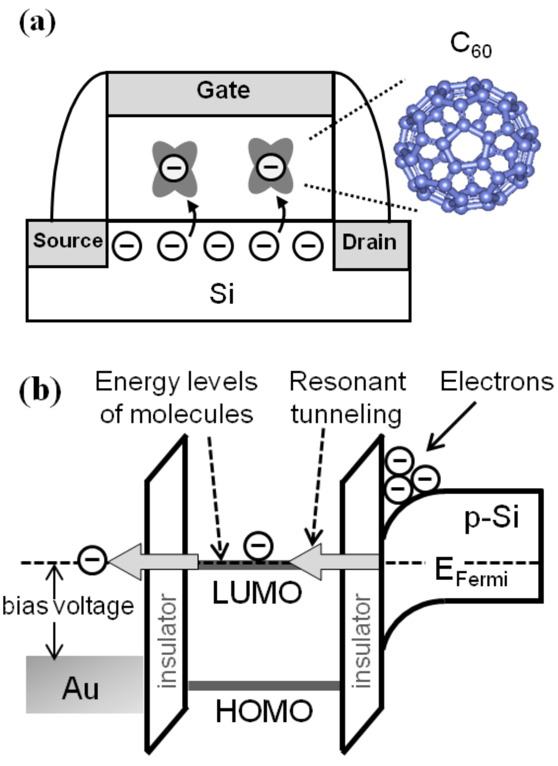

Figure 1. (a) Device and molecular structures, (b) Energy diagram of resonant tunneling