Nanotechnologies, Smart devices

Investigation of novel physical properties of atomic layer crystals: fundamental research for creating next-generation quantum devices

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Researchmap https://researchmap.jp/read0184558?lang=en

Abstract

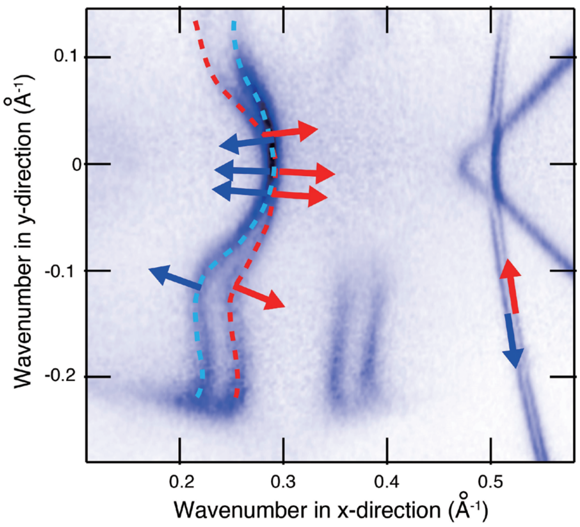
Two-dimensional atomic layer materials with a thickness of one to a few atoms, which are the thinnest materials possible, exhibit physical phenomena not seen in three-dimensional solids, and these phenomena can be used to create completely new devices. In order to further develop the basic scientific knowledge and applications of these materials, we have created "atomic layer crystals," i.e., materials that do not exist in nature, on solid surfaces, and have investigated the origin of their novel physical phenomena. We are also developing methods to control the novel physical properties of atomic layer crystals by adsorbing different atoms and molecules onto them and also by photoirradiation.

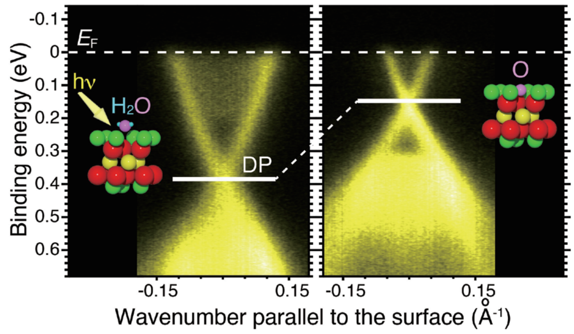
Background & Results

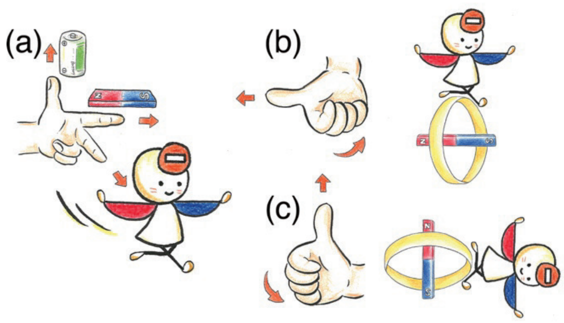
Electron spins appearing in nonmagnetic atomic layer crystals were thought to originate from the asymmetric density of electrons around the nucleus, and their orientation was thought to be perpendicular to the atomic layer plane and the direction of motion. This can be thought of as being similar to Fleming's left-hand rule. Although electron spins in different directions have also been observed, they have been explained by different reasons and no universal understanding has been obtained so far. Since electron spins in atomic layer crystals play a fundamental role in the operation of quantum devices, elucidation of their origin and control methods is indispensable for the construction of next-generation highly functional quantum devices. Our recent experimental results show that the orientation of all electron spins is due to the orbital motion of electrons. This means that the direction of electron spins can be thought of not as Fleming's left-hand rule, but as a right-handed screw rule. This kind of spin motion originating from the orbital motion of electrons is a completely new mechanism that has not been considered before, and it means that if the orbital motion of electrons can be freely designed, the spin direction can be arbitrarily changed. We have also succeeded in controlling the physical properties of such atomic layer crystals by the adsorption of organic molecules or, by photo-irradiation, in the case of topological insulators where electron spins similar to those of atomic layer crystals appear.

Significance of the research and Future perspective

In order to cope with the explosive increase in the amount of information and its processing, which is an urgent issue in the modern society, it is essential to create quantum devices with high processing speed, long lifetime, and drastically reduced power consumption. Redesigning devices based on atomic layer crystals can greatly improve the device performance, but to do so, it is essential to first understand the fundamental quantum properties of these materials. This research will not only open up a new field of basic science on the physical properties of atomic layer crystals, but also create quantum materials with highly efficient spin currents which is essential for next-generation devices.







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URL http://snp.ap.eng.osaka-u.ac.jp

Keyword atomic layer crystals, electronic states, electron spin, rashba-edelstein effect, photoelectron spectroscopy