Title: Shift Current as a New Solar Power Generation System

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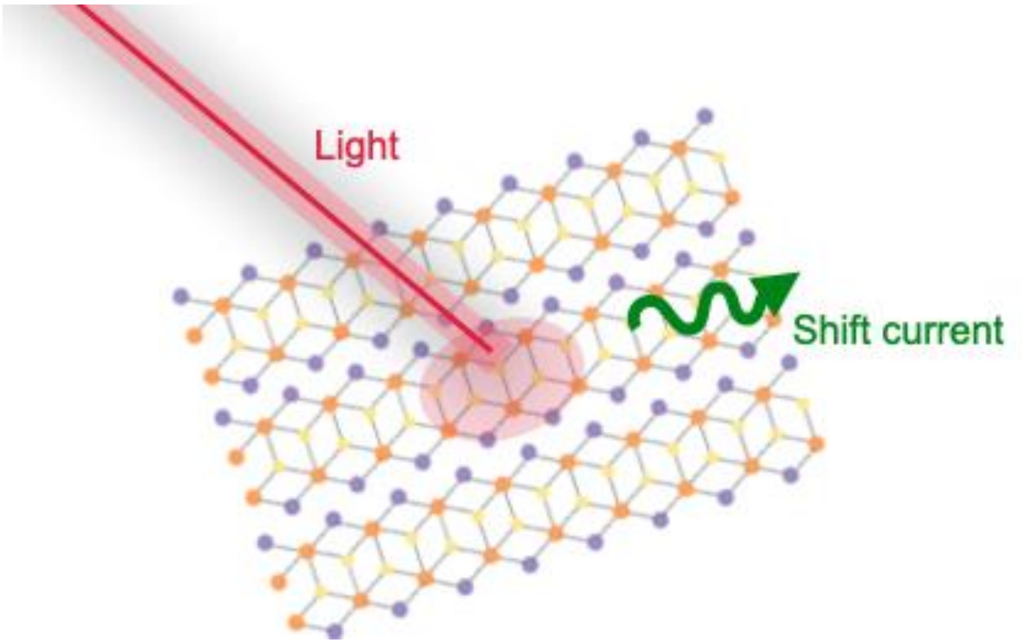

Energy issues have been a growing concern in recent years, but where does energy on Earth come from? The most basic answer is the sun. While converting sunlight energy into chemical energy, plants convert water and carbon dioxide into oxygen and sugar. We humans and animals live off plants. Plants are also raw materials for fossil fuels. As described above, we use the sun's energy indirectly. Then, can we directly extract energy from the sun? One answer is photovoltaic power generation. Photovoltaic power generation is a ecological system that can directly convert sunlight into electricity and it is attracting a lot of attention.

Existing photovoltaic systems apply photoinduced voltage at a p-n junction, simply an interface between a semiconductor with an excess of electrons and a semiconductor with a shortage of electrons. However, the efficiency of photovoltaic generation using p-n junctions is limited theoretically.

However, it was discovered around 1960 that materials with a crystal structure that breaks the property of spatial inversion symmetry can generate electric current in response to light absorption by a mechanism completely different from that of p-n junctions. This phenomenon was called the anomalous photovoltaic effect when it was first discovered. Recently, theoretical understanding of the anomalous photovoltaic effect has progressed, and it has become clear that a mechanism called the shift current is essential. The shift current could theoretically overcome the limitation of the efficiency of existing photovoltaics. Furthermore, the shift current is closely related to the concept of topology, which has been the focus of much attention in recent years. Compared to these potentials, the shift current is a "hidden gem" that is not well known to the general public. We will briefly explain the shift current and discuss its importance, scientific significance, and applications in the following.

Shift current is a phenomenon that occurs in materials with broken inversion symmetry. Inversion symmetry is the symmetry that exists when a point is symmetrical with respect to a certain point. For example, the sequence “・・・●◯●◯・・・” is inversion symmetric. Because the folding around “●” or “◯” does not change the sequence. On the other hand, the sequence “・・・●□◯■●□◯■・・・” is breaking the inversion symmetry. Because the sequence is changed by the folding. For example, if we fold the sequence around “●”, the sequence becomes “・・・●□◯■●□◯■・・・”.

When inversion symmetry is broken, the electronic polarization appears. The electric polarization is a sequence of dipoles with positive and negative charges separated by a minute distance. The polarization is closely related to the shift current. When a material is irradiated with light, electrons are excited. Furthermore, in the inversion symmetry broken system, electrons shift in a particular direction and polarization occurs. Thus, electricity is biased and electric current flows in a specific direction. This shift of electrons is a quantum mechanical effect. Thus, the shift current can be understood only by treating the substance with quantum mechanics.

Furthermore, the shift current is a quantum mechanical effect is related to the geometrical features of materials, and shift current belongs to the field of topological condensed matter. Topological condensed matter is a central field in modern condensed matter physics. Its fundamental achievements are the subject of a Nobel Prize in 2016. In the shift current, shift of the electrons and the polarization are related to the topology. Also, while the actual flow of electrons transfers ordinary currents, shift currents only involve the shift of electrons. Therefore, the response of shift currents is much faster than that of ordinary currents. Recent developments in experimental techniques have made it possible to observe the dynamics of the fast response. The theory of shift currents reproduces the characteristics of the experimental results well.

The shift currents are interesting in terms of basic science because they are an observable quantity related to topology and a quantum mechanical effect. However, it is also essential for applications. The properties mentioned above of shift currents, i.e., their potential for high efficiency, can significantly impact society.

The shift current has the potential to exceed the efficiency of existing photovoltaics. Developing highly efficient photovoltaic cells requires materials with a large shift current generation potential. In particular, there are limits to the efficiency of living p-n junction photovoltaic cells, but there is theoretically no such limit for shift current. Since the shift current is closely related to the electronic polarization associated with the topology, shift current is expected to increase for materials with large electronic polarization. Huge shift currents have been observed in unique complexes with large polarization. If such research advances, highly efficient photovoltaics using shift currents will be developed in the future.

Although the current photoelectric conversion efficiency of shift current is still insufficient, an exhaustive search for candidate materials using the materials database is beginning to be conducted to improve it. Therefore, although shift current is not yet widely used in applications, it is a "hidden gem" that has the potential to become commonly used in the future.

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