Photogalvanic Effect in Different 2D Materials

Jiaxuan Liu
Shanghai Institute of Technology, Shanghai 201418, China.

Abstract: Spintronics is based on the control of electron spin properties. Spin-polarized currents and pure spin currents are vital to spintronics. As a method to generate current only by illumination without imposing the bias voltage, the Photogalvanic effect now is used to realize spin-polarized current or pure spin current. In order to continuously reduce the size, it is particularly important to build spintronic devices at low-dimensional scales. Because of their outstanding optical and electronic properties, 2 dimensional materials have received extensive concern and research these years. In this review, we review the photoresponse of different materials under different illuminations and the use of Photogalvanic effect to generate spin-polarized currents and even pure spin currents. The materials studied in this article include two-dimensional transition metal dichalcogenides, Zigzag silicon-carbide nanoribbons and graphene nanoribbons at the edges of armchairs. This review article provides possible directions for material selection for new spintronic devices.

Keywords: photogalvanic Effect; Pure Spin Current; Spin-Polarized Current; 2-Dimensional Materials

Introduction

Spintronics is based on the regulation of electron spin or magnetic moment to realize information transfer, computation and storage. Compared with traditional electronic devices based on charge properties, spin-based electronic devices have the characteristics of lower power consumption. In the field of spintronics, the precise control and manipulation of spins is an important goal and task, and one of the research directions is how to stably output high spin-polarized currents and spin currents in spintronic materials[1].

The variety of 2D materials is very rich, including single-element layers, such as graphene and phosphorus, as well as layered structures with mixed elemental compositions, including transition metal dichalcogenides, black phosphorus, silicon carbide, etc. These materials have a series of excellent properties such as high carrier mobility, superconductivity, high optical adsorption capacity[2]. With the spring up of two-dimensional materials and their practical prospects in nanospintronics, how to generate spin-polarized currents or pure spin currents in two-dimensional materials and devices is attracting extensive attention.

1. Literature review

1.1 Photogalvanic effect in 2D transition metal dichalcogenides from first principles

1.1.1 Photogalvanic effect in N-doped single-layer MoS2

Nitrogen atom is doped into the sulfur atom so that the spatial inversion symmetry is broken. The photoresponse of N-doped monolayer MoS2 under different light illumination is investigated by Luo et al[3]. In which the photon energy ranges from 0 to 2.3eV. Figure 1 shows the photoresponse under circularly polarized light and linearly polarized light. The photoresponse of linearly polarized light is weak in the whole photon energy range. And the optical response of circularly polarized light is about 100 times stronger than that of linearly polarized light. After 0.6eV, the circular photoelectric effect starts to appear. In addition, the optical response of circularly polarized light becomes more significant at photon energies greater than 1.6eV.

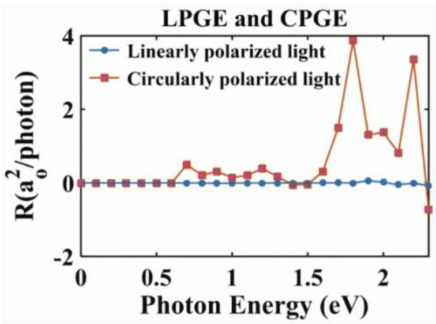
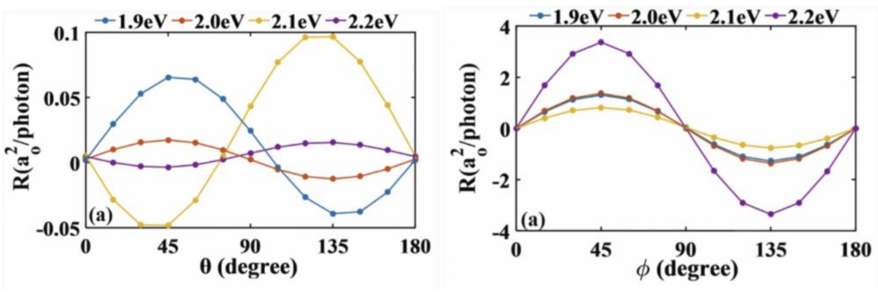


Figure 1. Photoresponse under circularly polarized light and linearly polarized light[3].

Next, Figure 2 (a) and (b) show the photoresponse of linearly polarized light under different polarization angle and the photoresponse of circularly polarized light under different phase angle, respectively. Not only can we obtain our desired photocurrent by varying the photon energy, but choosing different types of polarized light and polarization angles is also an effective method.



(a) (b)

Figure 2. (a) and (b) Photoresponse of linearly polarized light under different polarization angle[3].

1.1.2 Photoelectric effect of doped monolayer WS2 with VA group elements

Yuan et al. do research on single-layer WS2 doped with N, P, As, or Sb, respectively[4]. The type of polarized light focused on linearly polarized light. Photon energy ranges from 2.5 to 4.0eV is selected. First, the photoresponse of intrinsic monolayer WS2 is extremely small throughout the range, as shown in Figure 3. Also, all 4 dopings enhance the photoresponse of monolayer WS2 to different degrees. Among them, N doping has the best effect, obtaining the maximum photocurrent (1.75eV) upon linearly polarized light irradiation at 3.1eV. This is two orders of magnitude higher than the maximum photocurrent generated at 3.1eV (about 0.0177eV) in the intrinsic WS2.

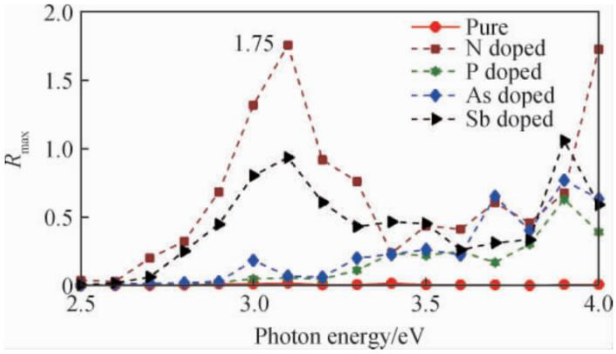


Figure 3. Photoresponse of intrinsic and doped monolayer WS2[4].

2. Photoinduced spin current

2.1 Zigzag silicon-carbide nanoribbons

The structure of the spintronic device is designed by Chen et al[5]. It consists of six zigzag chains, and hydrogenation saturation is used to maintain the structural stability of the nanoribbon edges.

Figure 4 demonstrates the variation of optical response with photon energy under vertical irradiation of polarized light. In the photon energy range of 0.01-0.12eV, both spin-up and spin-down photoresponse rise with energy in ferromagnetic coupled state. In contrast, in the antiferromagnetic coupled state, only the spin-up photocurrent exists in the entire energy range. This is related to the unique energy band structure of the zigzag silicon carbide nanoribbons[5]. Accordingly, the spin polarization always remains 100% in the antiferromagnetic coupled state, regardless of the polarized light. And as in Fig. 4(c), the right circularly polarized light in the ferromagnetic coupling state can also achieve full spin polarization when the photon energy is 0.069eV. Besides, at the right circularly polarized light with energy 0.03eV and at the left circularly polarized light with energy 0.057eV, the spin polarization is 0 and the directions of the spin-up/down photocurrents are opposite. This implies the realization of pure spin current.

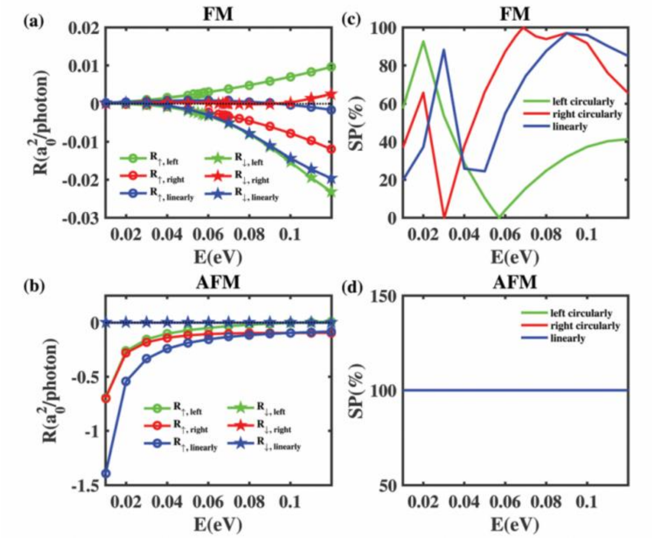
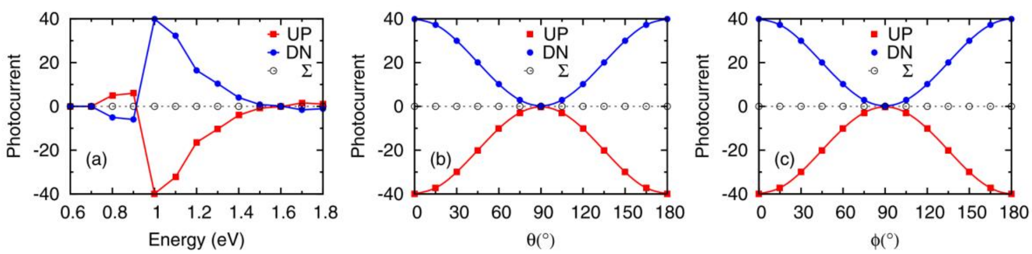


Figure 4. (a-d) Photoresponse of SiC nanoribbons[5].

2.2 Armchair graphene nanoribbons

Tao et al. transformed armchair graphene nanoribbons into spin semiconductors by the introduction of zigzag-edged triangular anti-quantum dots in opposite directions in the left and right halves, respectively[6].

When the polarization angle is 0, the variation of photocurrent with photon energy under linearly polarized light is shown in Figure 5(a). When the photon energy exceeds the spin energy gap, spin current of equal size and opposite direction start to be generated. The total photocurrent is always 0. This is because the spatial inversion symmetry with the inversion antisymmetry of the spin density. Combining with Fig. 5(b) and (c), this scheme can achieve pure spin current independent of the type of polarized light, the polarization angle and so forth. Moreover, it was found that such a system is not an exception. This method can be extended to other systems with spatial inversion symmetry consisting of 2D antiferromagnetic coupling materials.



(a) (b) (c)

Figure 5. (a-c) Photoresponse of armchair graphene nanoribbons[6].

3. Conclusion

In summary, we first review the photovoltaic galvanic effect in MoS2 and WS2 . It is shown that the photoresponse can be significantly enhanced by doping. Among them, the maximum photoresponse of nitrogen-doped monolayer MoS2 can reach about 4eV, while the maximum photoresponse of nitrogen-doped monolayer WS2 is 1.75eV. Therefore, they have promising applications in photovoltaic devices. Next, we consider the photovoltaic galvanic effect of zigzag silicon carbide nanoribbons. The antiferromagnetically coupled Sic nanoribbons can always output fully spin-polarized current. For ferromagnetically coupled silicon carbide nanoribbons, pure spin currents can be obtained at specific photon energies and polarized light. Finally, we present the photoinduced pure spin current phenomenon in armchair graphene nanoribbons. This scheme can generate robust pure spin currents independent of the magnetic configuration as well as the type of polarization, among other factors. After studying the above representative materials, we can see the great potential of 2D materials in the field of spintronics. It is hoped that this review will stimulate further theoretical and experimental studies of candidate materials for spintronic devices.

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