Ferroelectric and piezoelectric effects on light-emissions and their applications in energy harvesting and sensors

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Abstract: Here, I will introduce the tuning strategies of optical process based on ferroelectric and piezoelectric effects. In my group, we have made progress on modulating the light-emissions for energy harvesting light sources and sensors.
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1. Introduction

Development of energy harvesting light sources and sensors converted from multiple stimuli requires the search of new types of materials and devices. Smart materials have the ability to respond to external stimuli such as electric or magnetic fields, strain, temperature, and moisture, in in a controlled manner. Ferroelectric and piezoelectric materials occupy an important position among the family of smart materials. Ferroelectrics are a special class of piezoelectric materials, which have a spontaneous electric polarization that can be switched by an applied electric field. Piezoelectric materials can produce electrical potential under mechanical stress. Conversely, they also response to applied electric fields with mechanical displacements. Ferroelectric and piezoelectric materials have shown enormous potential use for coupling with and control of electronic and optoelectronic properties of various materials, and have led to extremely fertile areas of research in energy devices and sensors. Importantly, the coupling effect between piezoelectricity and semiconductor properties in wurtzite-structured semiconductors has given rise to the emerging fields of piezotronics and piezophototronics coined by Wang [1,2].

2. Results and discussion

As shown in Fig. 1, ferroelectric and piezoelectric have effects on the optical process of recently emerging materials for energy and sensoring applications [3].

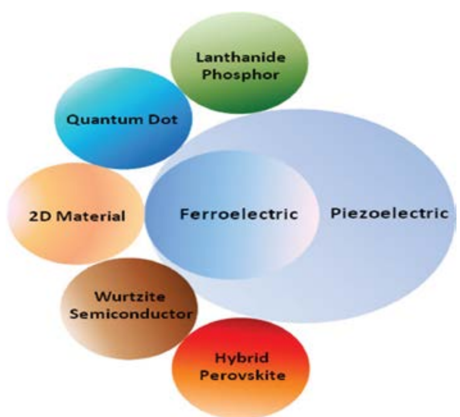

Figure 1. Ferroelectric and piezoelectric effects on advanced optical materials.

In general, there are three ways for them to impact on the optical process in various materials. They can act as external perturbations, such as ferroelectric gating and piezoelectric strain, to tune the optical properties of the materials and devices. Second, ferroelectricity and piezoelectricity as innate attributes may exist in some optoelectronic materials, which can couple with other functional features (e.g., semiconductor transport, photoexcitation, and photovoltaics) in the materials giving rise to unprecedented device characteristics. The last way is artificially introducing optical functionalities into ferroelectric and piezoelectric materials and devices, which provides an opportunity for investigating the intriguing interplay between the parameters (e.g., electric field, temperature, and strain) and the introduced optical properties.

Piezophotonics is based on a two-way coupling effect between piezoelectricity and photoexcitation properties [1,2]. The utilization of a broad range of luminescent ions, including lanthanide and transition metals can be considered for a wide variety of applications. In our works, various heterostructures and composite materials have been prepared, which can sense or harvest broad mechanical energy, including stretch, vibration pressure, handwriting and mechanical friction [4-6]. Moreover, magnetic-induced luminescence (MIL) has firstly been realized by coupling magnetic field to piezophotonics [7,8]. In real world, magnetic fields exist in many systems, and therefore the detection of magnetic field is essential for environmental surveillance, mineral exploring, and safety monitoring. For example, the large magnetic flux generated from a grid-connected power wire can be used to monitor power consumption of electric appliances in power industry. Differing from conventional magnetic sensors, the MIL-based devices enjoy competitive advantages, including environmental energy harvesting, real-time visualization, remote sensing without making electric contact, nondestructive and noninvasive detection. On the other hand, the ultimate goal of making atomically thin electronic and optoelectronic devices greatly stimulates the research two-dimensional (2D) materials [9-11], such as transition metal dichalcogenides (TMDs). Luminescent ion doped TMDs, such as MoS_2 samples are firstly achieved in my group [12,13], and their structural and optical properties are investigated. The study opens the possibility for realizing novel 2D luminescent device. Through these works, great potential application can be perceived, which may contribute to future ambient energy harvesting, sensor as well as self-powered electronics and optoelectronics. The research was supported by the grant Research Grants Council of Hong Kong (GRF No. PolyU 153033/17P).

3. References

[1] Z. L. Wang, “Piezopotential gated nanowire devices: Piezotronics and piezo-phototronics”, Nano Today, **5**, 540 (2010).

[2] W. Wu and Z. L. Wang, C. van Trigt, “Piezotronics and piezo-phototronics for adaptive electronics and optoelectronics” Nat. Rev. Mater. **1**, 16031 (2016).

[3] Y. Zhang, W. Jie, P. Chen, W. Liu, and J. Hao, "Ferroelectric and piezoelectric effects on the optical process in advanced materials and devices", Adv. Mater. (Invited Review), DOI: 10.1002/adma.201707007 (2018).

[4] J. Hao, Y. Zhang, and X. Wei, “Electric-induced enhancement and modulation of upconversion photoluminescence in epitaxial $BaTiO_3$:Yb/Er thin films”, Angew. Chem. Int. Ed., **50**, 6876 (2011).

[5] Y. Zhang, G. Y. Gao, H. L.W. Chan, J. Y. Dai, Y. Wang, and J. H. Hao “Piezo-phototronic effect induced dual-mode light and ultrasound emissions from ZnS:Mn/PMN-PT thin-film structure”, Adv. Mater. **24**, 1729 (2012).

[6] L. Chen, M.-C. Wong, G. Bai, W. Jie, and J. Hao, “White and green light emissions of flexible polymer composites under electric field and multiple strains”, Nano Energy **14**, 372 (2015).

[7] M.-C. Wong, L. Chen, M.-K. Tsang, Y. Zhang, and J. Hao, “Magnetic-induced luminescence from flexible composite laminates by coupling magnetic field to piezophotonic effect”, Adv. Mater. **27**, 4488 (2015).

[8] M.-C. Wong, L. Chen, G. Bai, L.-B. Huang, and J. Hao, "Temporal and remote tuning of piezophotonic effect induced luminescence and color gamut via modulating magnetic field", Adv. Mater. **29**, 1701945 (2017).

[9] W. J. Jie, Z. B. Yang, F. Zhang, G. X. Bai, C. W. Leung, and J. H. Hao, "Observation of room-temperature magnetoresistance in monolayer MoS_2 by ferromagnetic gating", ACS Nano **11**, 6950 (2017).

[10] Z. Yang, W. Jie, C.-Hin Mak, S. Lin, H. Lin, Xianfeng Yang, F. Yan, S. P. Lau, and J. Hao, "Wafer-scale synthesis of high-quality semiconducting two-dimensional layered InSe with broadband photoresponse", ACS Nano **11**, 4225 (2017).

[11] W. Jie, Z. Yang, G. Bai, and J. Hao, "Luminescence in 2D materials and van der Waals heterostructures", Adv. Opt. Mater. **6**, 1701296 (2018).

[12] G. Bai, Z. Yang, H. Lin, W. Jie, and J. Hao, "Lanthanide Yb/Er co-doped semiconductor layered WSe_2 nanosheets with near-infrared luminescence in telecommunication wavelengths", Nanoscale, **10**, 9261 (2018).

[13] G. Bai, S. Yuan, Y. Zhao, Z. Yang, S. Y. Choi, Y. Chai, S. F. Yu, S. P. Lau, and J. Hao, "2D layered materials of rare-earth Er-doped MoS_2 with NIR-to-NIR down- and up-conversion photoluminescence", Adv. Mater., **28**, 7472 (2016).