Giant Optical Anisotropy in van der Waals Materials: Perspectives and Challenges

Volkov V.S.[1], Ermolaev G.A.[1], Grudinin D.V.[1], Vyshnevyy A.A.[1], Mazitov A.B.[1], Tselikov G.I.[1], Kruglov I.A.[1], Arsenin A.V.1, Novoselov K.S.[2]
[1] *Emerging Technologies Research Center, XPANCEO, Dubai, UAE*
[2] *Department of Materials Science and Engineering, National University of Singapore, Singapore*
vsv@xpanceo.com

Abstract

Materials with high optical anisotropy are of great importance in technology and science [1]. Recently, one of the largest birefringences in the visible and near-infrared intervals up to 0.8 was reported in quasi-one-dimensional crystal $BaTiS_3$ [2]. However, anisotropic nanophotonics requires an optical anisotropy of about 1.5 to fully exploit the advantages of anisotropic properties [3, 4]. Inspired by this challenge, we focused on two-dimensional materials and their bulk counterpart – van der Waals (vdW) materials.

Our findings showed that their fundamental difference between interlayer strong covalent bonding and interlayer weak van der Waals interaction leads to unprecedented high birefringence with values exceeding 1.5 in the infrared and 3.0 in the visible spectral intervals (for example, see optical constants of MoS_2 in Figure 1). Thus, our studies enable a new field of vdW anisotropic nanophotonics. In detail, we managed to achieve unmatched lateral dimensions for van der Waals-based waveguides with only several tens of nanometers footprint. In other words, it gives a unique opportunity to place around 10000 waveguides on an mm-scale photonic chip. These characteristics make us a step closer to electronic integrated circuits. Hence, vdW-based photonic integrated circuits can become a decisive platform for an electronic-to-photonic replacement to increase computer data processing. The idea behind the use of vdW materials has four advantages. First, vdW materials have larger optical bandgap in comparison with conventional high refractive index materials (TiO_2, GaP, Si, Ge, and many others) and, therefore, smaller operation wavelength without dissipative losses. Secondly, vdW materials have one of the largest refractive indices among known materials. Thirdly, the record-breaking optical anisotropy of vdW gives an additional degree of freedom for the design optimization of integrated photonic elements.

Finally, vdW materials have dangling bonds-free surfaces and atomically sharp edges after the lithography process, which results in minimum scattering losses in photonic waveguides and high-intensity nonlinear properties in addition to superior linear response. From a broader perspective, we would like to note that these vdW features are also beneficial for countless optical devices (resonators, dielectric mirrors, waveplates, and many others) beyond on-chip integration.

References

[1] Ermolaev G. *et al.*, Nature Communications, 12, 854, 2021.
[2] Niu S. *et al.*, Nature Photonics, 12, 392-396, 2018.
[3] Ermolaev G. *et al.*, Photonics, 9, 744, 2022.
[4] Jahani S. *et al.*, Nature Communications, 9, 1893, 2018

Figures

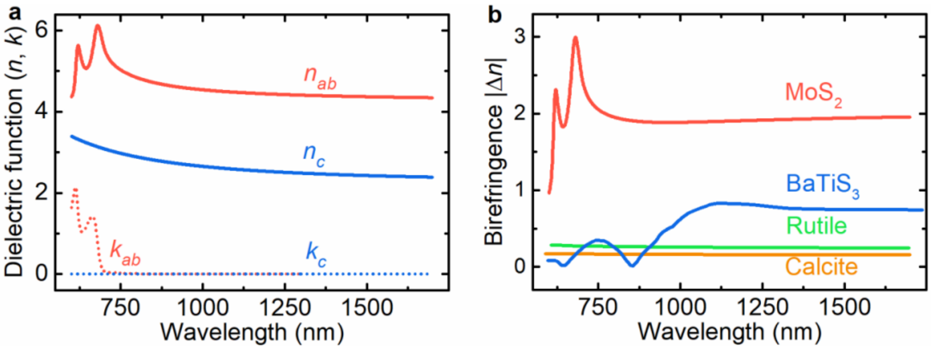

Figure 1: a. Optical constants of MoS_2. **b.** Birefringence of MoS_2 in comparison with other anisotropic materials.