

# Strong Anisotropic Visible Resonances In Bulk Black Phosphorus

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After reports of high mobility and a tunable bandgap covering a wide spectral range from visible to mid-infrared, layered black phosphorus (BP) has emerged as a promising 2D material for high performance electronic and optoelectronic devices [1,2,3]. Owing to its orthorhombic crystallographic structure, black phosphorus expresses strong anisotropic properties [4,5]. Using photoluminescence and Raman spectroscopy, we have extensively explored the optical properties of pristine bulk BP crystals as a function of polarization, temperature and excitation wavelength. By controlling both the sample orientation and the incident beam polarization, we investigated the anisotropy of the optical response of bulk BP along the three main crystallographic axes (zigzag, armchair and orthogonal to layers). Here, we report an unexpected highly polarized room-temperature luminescence detected in the visible range of the spectrum, far above the band gap energy. By probing optical transitions in the same energy range, Raman spectroscopy further reveals the presence of strong resonances and their polarization selection rules are instrumental in elucidating the influence of the anisotropy on the optical and electronic properties of black phosphorus.

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## References

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- [1] Liu, H., Neal, A. T., Zhu, Z., Luo, Z., Xu, X., Tomanek, D., & Ye, P. D., *ACS Nano*, 8(4) (2014) 4033–4041.
- [2] Zhang, S., Yang, J., Xu, R., Wang, F., Li, W., & Ghufuran, M., *ACS Nano*, 8(9) (2014) 9590.
- [3] Li, L., Yu, Y., Ye, G. J., Ge, Q., Ou, X., Wu, H., & Feng, D., *Nature Nanotechnology*, 9 (2014) 372–377.
- [4] Ribeiro, H. B., Pimenta, M. A., De Matos, C. J. S., Moreira, R. L., Rodin, A. S., Zapata, J. D., de Souza, E. A. T., Castro Neto, A. H., *ACS Nano*, 9(4) (2015) 4270–4276.
- [5] Wang, X., Jones, A. M., Seyler, K. L., Tran, V., Jia, Y., Zhao, H., Wang, H., Yang, L., Xu, X., Xia, F., *Nature Nanotechnology*, 10(6) (2015) 517–521.