Van der Waals heterostructure mid-infrared emitters with electrically controllable polarization states and spectral characteristics

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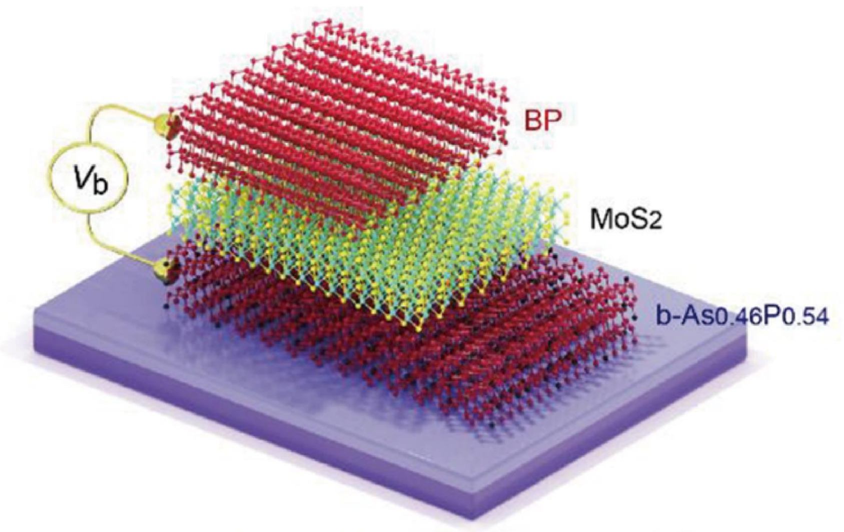
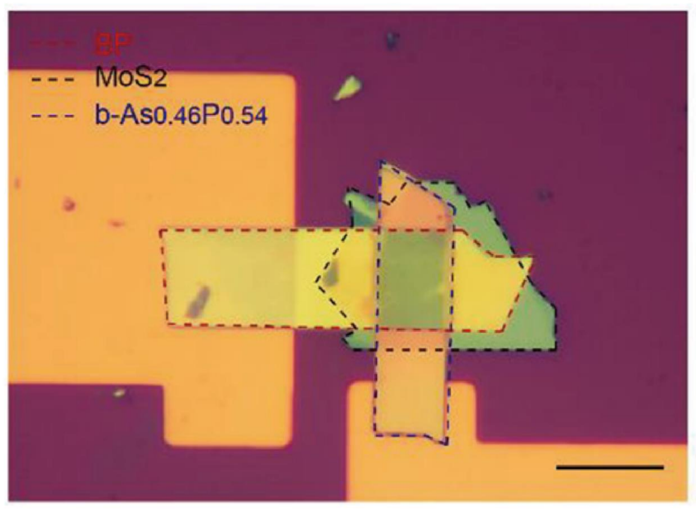
Introduction

This study introduces innovative two-terminal mid-IR emitters that enable the fine-tuning of emission wavelengths and linear polarization states by altering the polarity of the bias voltage. These emitters are constructed with two p–n junctions created by stacking anisotropic light-emitting materials, including black phosphorus, black arsenic–phosphorus, and MoS2. Through precise control of crystallographic orientations and band profiles, distinct spectral ranges and polarization orientations are achieved for each electroluminescence (EL) unit, independently activated by bias polarity. Under the polarity-switched pulse mode, the emitter exhibits time-averaged EL characteristics spanning the entire first mid-IR atmospheric window (λ: 3–5 μm) and providing electrically adjustable spectral shapes.

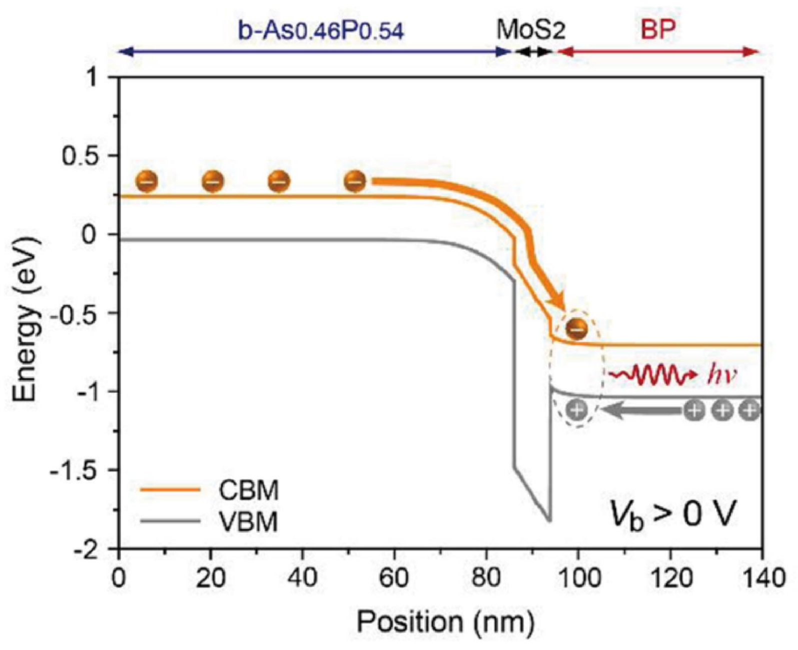
Device Structure

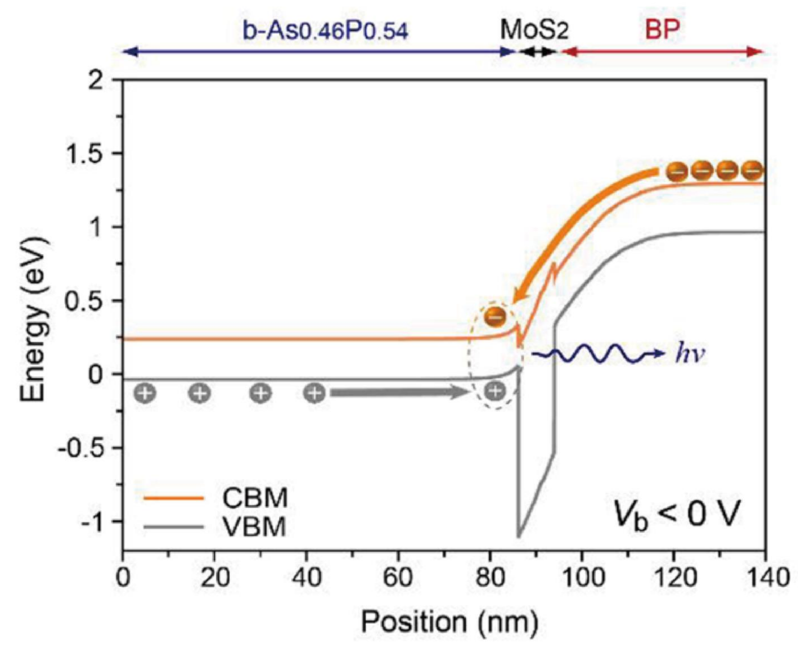




- The devices are composed of two back-to-back p–n junctions, enabling bias-selectable light emitting diode.
- Stacking anisotropic light-emitting materials, black phosphorus and black arsenic–phosphorus with MoS2.
- The armchair directions of black phosphorus and black arsenic phosphorus are orthogonal with each other.

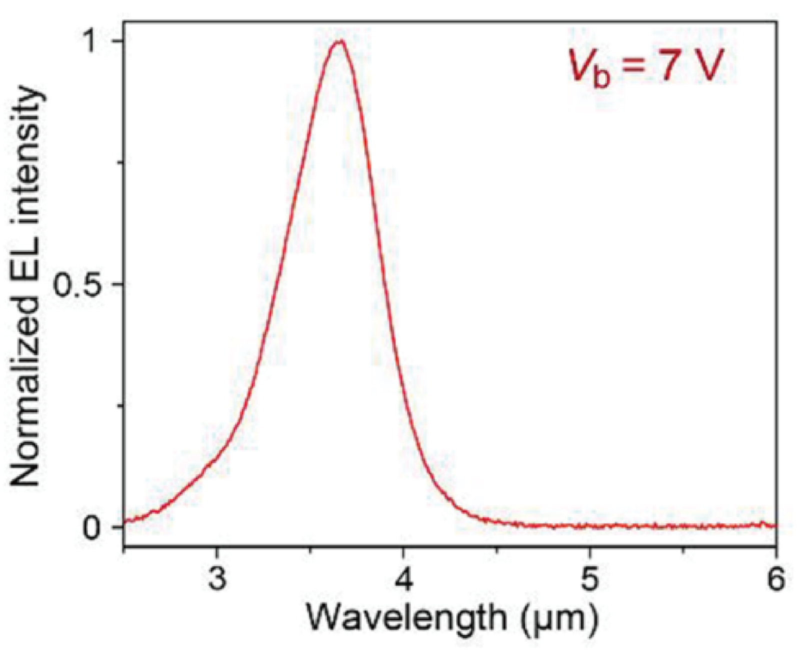
Device working Principle

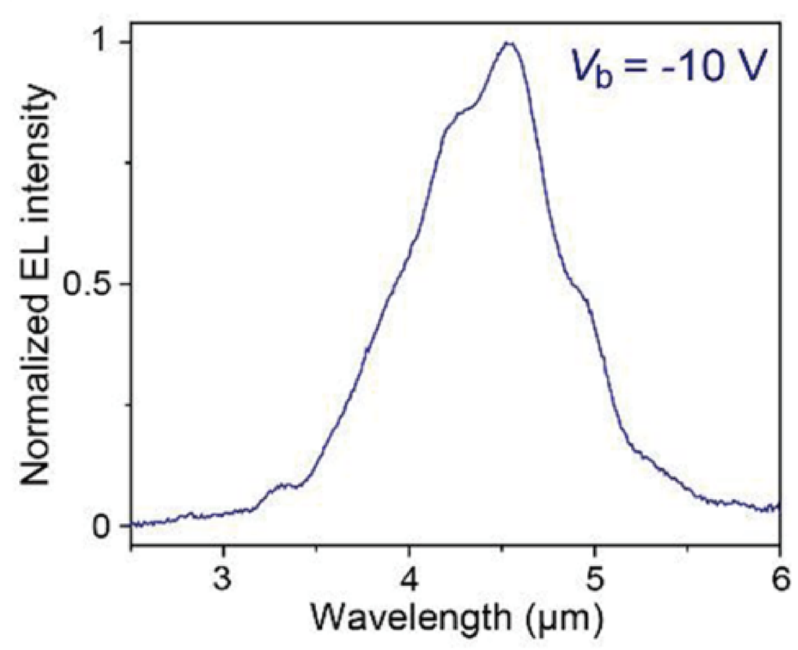




- The simulated energy band diagrams depict the impact of applying positive and negative voltages to the device.
- Electron-hole pairs recombine at either black phosphorus or black arsenic phosphorus, depending on the polarity of the applied voltage.
- MoS2 serves as an effective hole-blocking layer in this context.

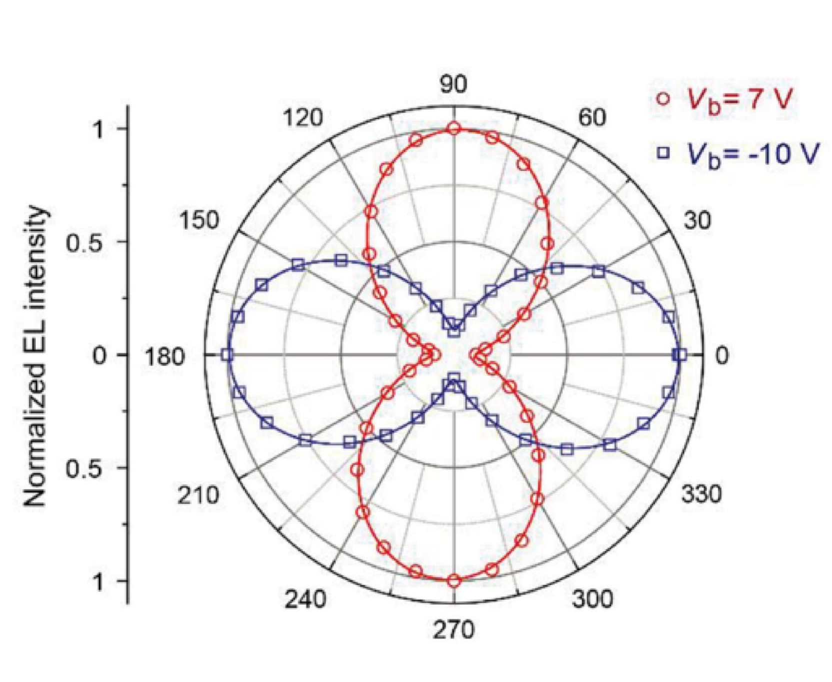
Electroluminescence spectrum

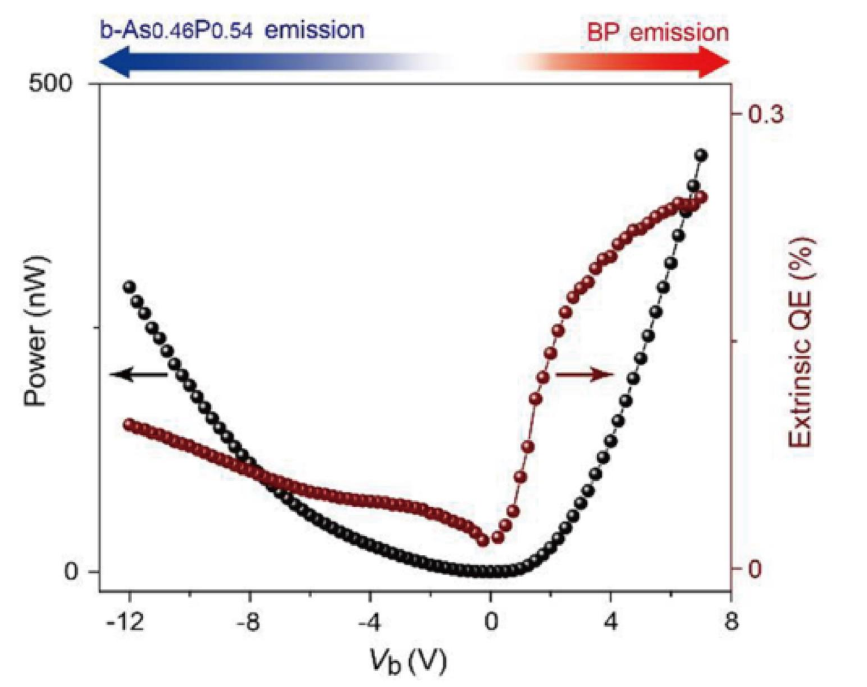




- The EL spectrum reveals that the emission spectrum can be switched by varying the voltage polarity.
- The spectrum falls within the technologically important mid-IR atmospheric window.

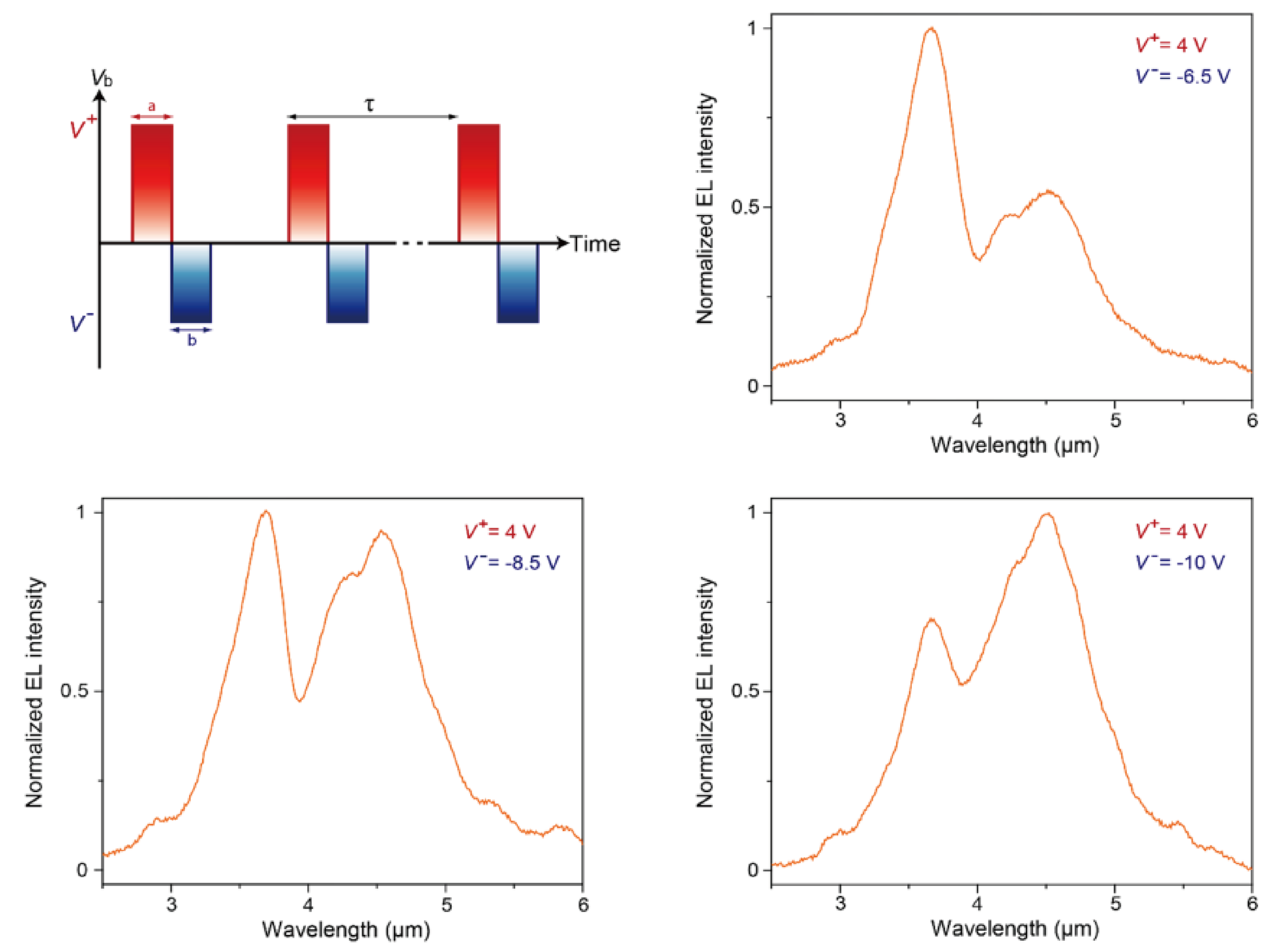
Electroluminescence characteristic and efficiency





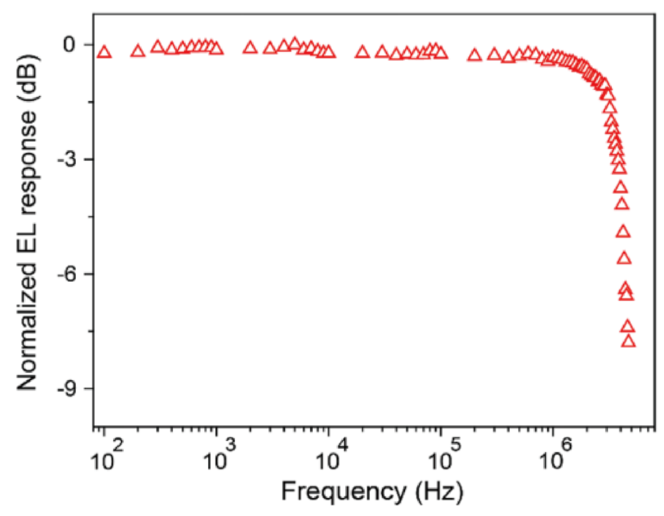
- The result shows that the linear polarization of mid-IR emission can be switched by tuning the polarity of bias voltage.
- The peak EQE can approach to 0.3 % and does not show the feature of efficiency droop.

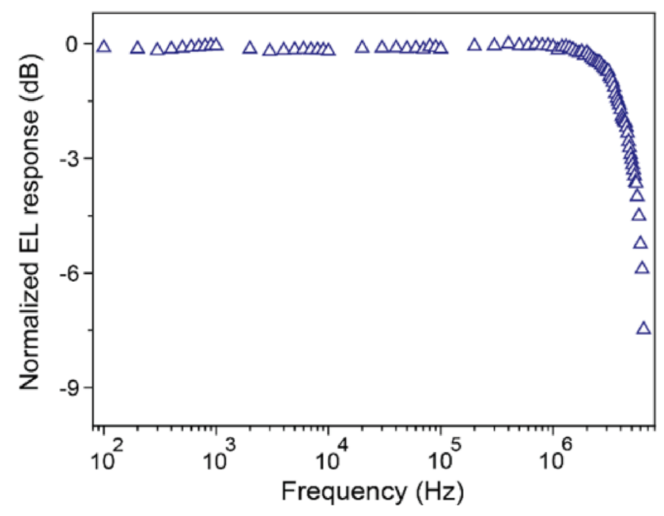
Broadband and tunable mid-IR emission



- Normalized EL spectra when applying voltage pulse trains onto the BP/MoS2/b-As0.46P0.54 heterostructure emitter.
- The figure demonstrates that the application of voltage pulse trains effectively allows for the modulation of the emission spectrum, resulting in a broader bandwidth coverage.

Frequency Response





- The device can be operated at MHz speed, suggesting its usefulness to free space communication applications without requirement of external modulators.

Conclusions

In summary, our study introduces mid-IR emitters with flexible polarization and spectral properties, achieved through precise control of crystal orientations and band profiles in van der Waals heterostructures. This results in high EQE and rapid modulation. These versatile emitters, functioning under a polarity-switched pulse mode, offer a broad spectral range and customizable characteristics, promising advancements in mid-IR sensing, data processing, and imaging. Furthermore, the potential extension of this technology to create bias-switchable emitters in the near-IR or visible range is plausible, given the recent discovery of various wide bandgap, anisotropic van der Waals light-emitting materials, such as ReS2 and TiS3.

Acknowledgements

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