Fabry-Perot Cavity-Enhanced Optical Absorption in Ultrasensitive Tunable Photodiodes Based on Hybrid 2D Materials

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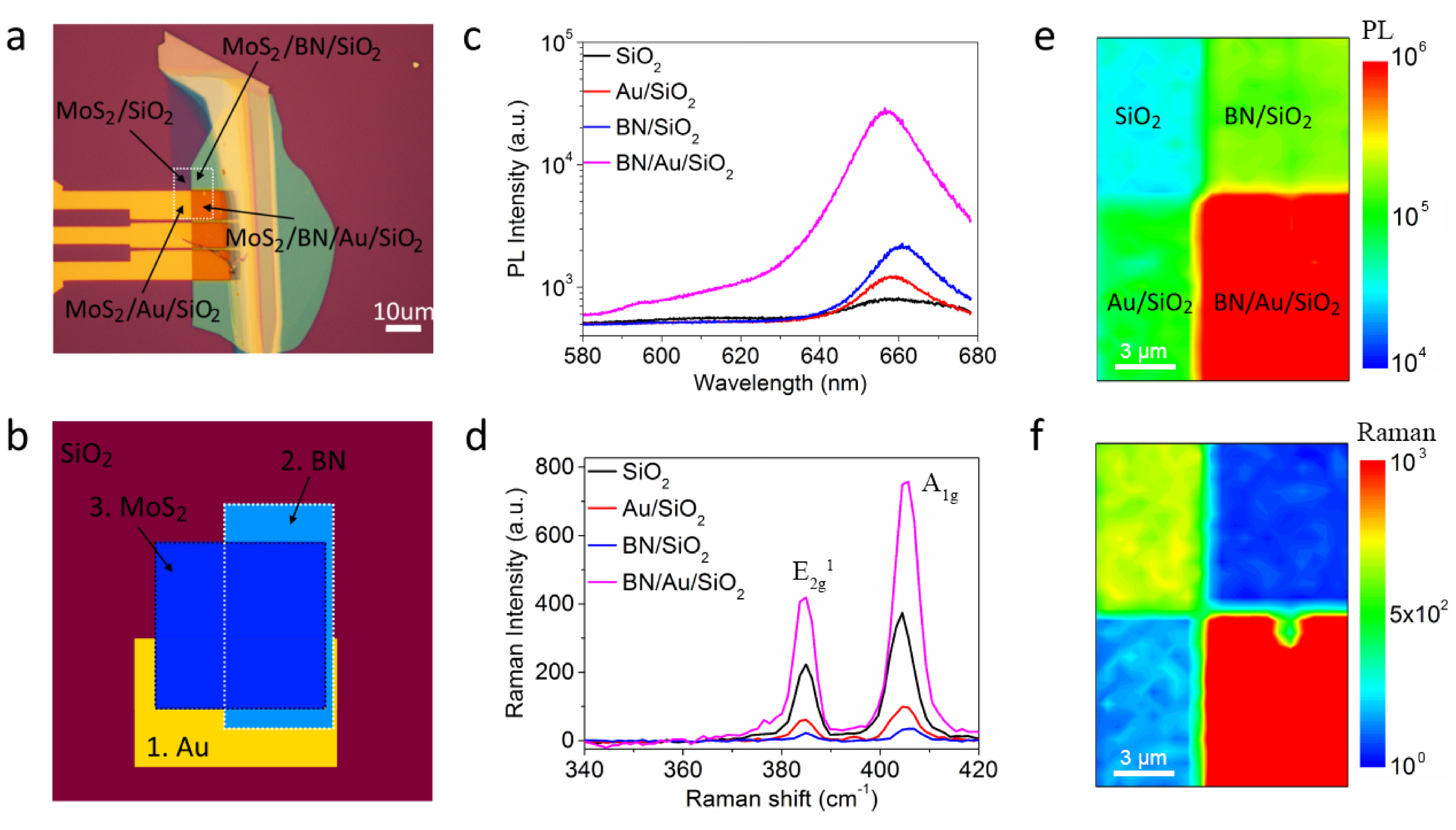
Abstract

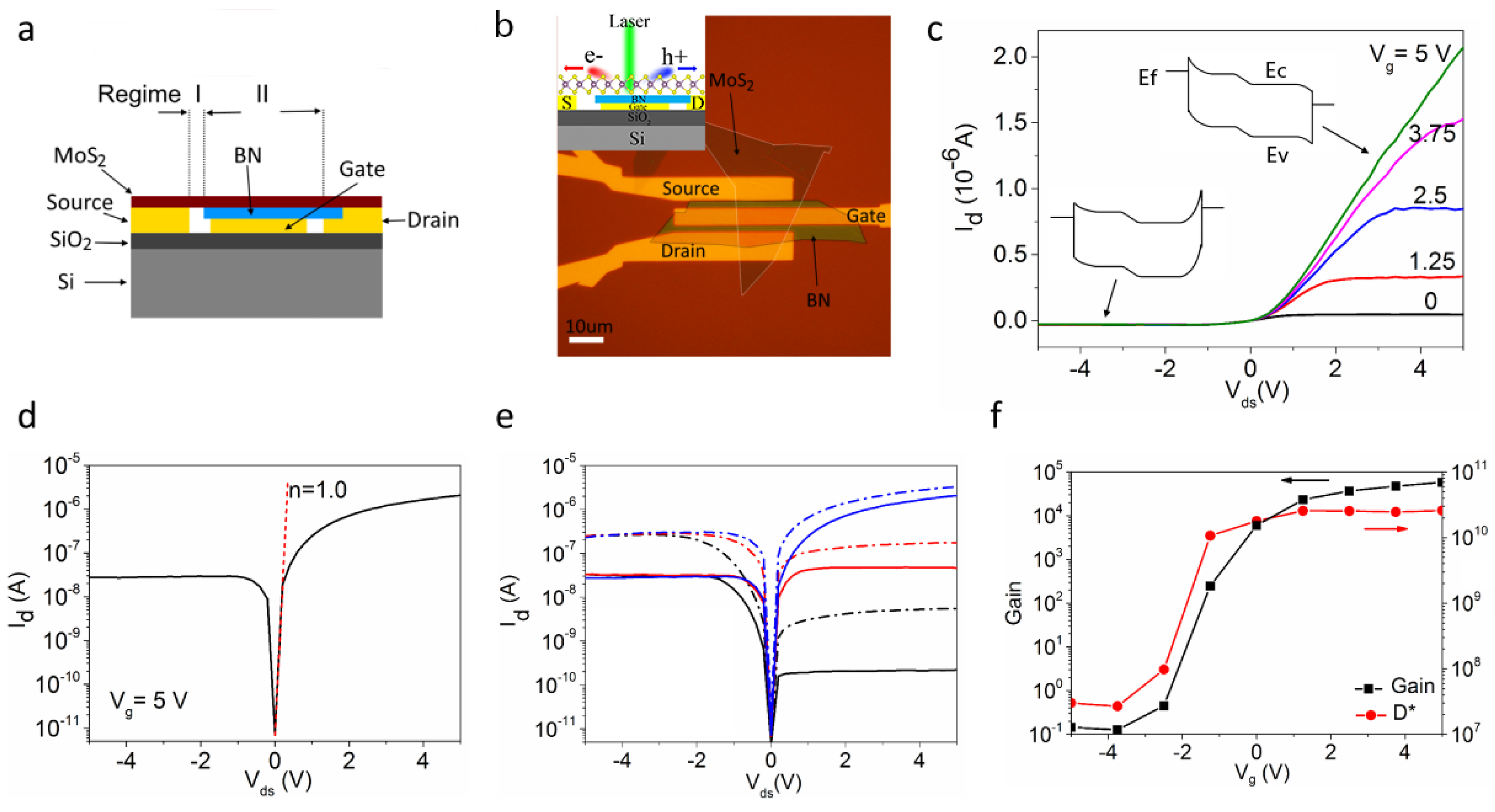
Monolayer two-dimensional (2D) transition metal dichalcogenides (TMDs) show interesting optical and electrical properties because of their direct bandgap[1,2]. However, the low absorption[3-6] of atomically thin TMDs limits their applications. Here, we reported enhanced absorption and optoelectronic properties of monolayer molybdenum disulfide (MoS_2) by using an asymmetric Fabry-Perot cavity. The cavity is based on a hybrid structure of MoS_2/ hexagonal boron nitride (BN)/Au/SiO_2 realized through layer-by-layer vertical stacking. Photoluminescence (PL) intensity of monolayer MoS_2 is enhanced over two orders of magnitude. Theoretical calculations show that the strong absorption of MoS_2 comes from photonic localization on the top of the micro cavity at optimal BN spacer thickness. The n/n$^+$ MoS_2 homojunction photodiode incorporating this asymmetric Fabry-Perot cavity exhibits excellent current rectifying behavior with an ideality factor of 1 and an ultrasensitive and gate tunable external photo gain and specific detectivity. Our work offers an effective method to achieve uniform enhanced light absorption by monolayer TMDs, which has promising applications for highly sensitive optoelectronic devices.

Fabrication, PL &Raman



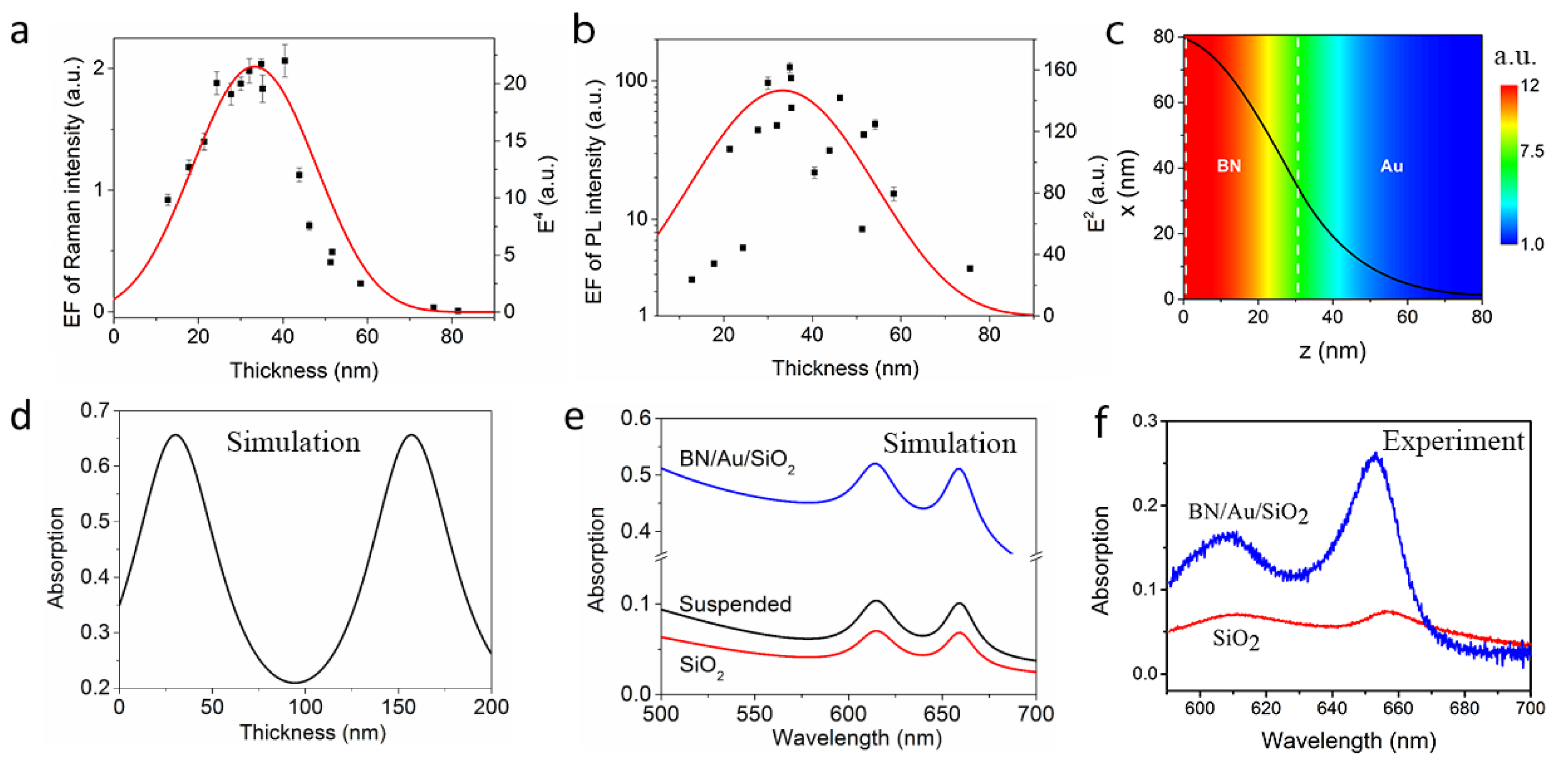
(a) Optical micrograph of monolayer MoS_2 on different substrates. (b) Schematic of sample preparation. (c) Semi-logarithmic PL spectra. (d) Raman spectra. (e), (f) PL and Raman mapping image respectively.

Ultrasensitive Tunable Photodiode



(a), (b) Schematic cross-section and optical micrograph of the device respectively. (c) I_d-V_{ds} characteristics of the diode. (d) The ideality factor n=1.0. (e) Semi-logarithmic plots of I_d as a function of V_{ds} in dark (solid lines) and illumination (dash dotted lines). (f) The external photo gain (black squares) and specific detectivity (red dots).

Experiment vs Simulation



(a) Experimental EF of Raman $E_{2g}{}^1$ peak intensity (black squares) and calculated E^4 (red line). (b) Experimental EF of PL intensity (black squares) and E^2 (red line). (c) Electric field intensity profile. (d)The calculated absorption of MoS2 at 532 nm as a function of BN thickness. (e) (f) The calculated and experimental absorption spectra.

Conclusions

1. MoS_2/BN/Au/SiO_2 Fabry-Perot cavity.
2. Light localization at the monolayer MoS_2.
3. Increasing the absorption of MoS_2.
4. Enhancing the PL and Raman intensities of MoS_2
5. Nearly perfect diode behavior for a photodiode based on this Fabry-Perot cavity structure.
6. High and tunable external photo gain and specific detectivity.

References

(1) Wang, Q. H.; Kalantar-Zadeh, K.; Kis, A.; Coleman, J. N.; Strano, M. S. *Nat. Nanotechnol.* **2012**, 7, 699-712.
(2) Koppens, F. H.; Mueller, T.; Avouris, P.; Ferrari, A. C.; Vitiello, M. S.; Polini, M. Nat. Nanotechnol. 2014, 9, 780-93.
(3) Li, Y.; Chernikov, A.; Zhang, X.; Rigosi, A.; Hill, H. M.; van der Zande, A. M.; Chenet, D. A.; Shih, E.-M.; Hone, J.; Heinz, T. F. Phys. Rev. B 2014, 90, 205422.
(4) Mak, K. F.; Lee, C.; Hone, J.; Shan, J.; Heinz, T. F. Phys. Rev. Lett. 2010, 105, 4.
(5) Huang, J. K.; Pu, J.; Hsu, C. L.; Chiu, M. H.; Juang, Z. Y.; Chang, Y. H.; Chang, W. H.; Iwasa, Y.; Takenobu, T.; Li, L. J. Acs Nano 2014, 8, 923-930.
(6) Bernardi, M.; Palummo, M.; Grossman, J. C. Nano Lett. 2013, 13, 3664-3670.