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SUPPLEMENTARY INFORMATION

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A room-temperature polariton light-emitting diode based on monolayer WS_2

Jie Gu[1,2,3], Biswanath Chakraborty[1,3], Mandeep Khatoniar[1,2] and Vinod M. Menon[1,2]*

[1]Department of Physics, City College of New York, City University of New York, New York, USA. [2]Department of Physics, The Graduate Center, City University of New York, New York, USA. [3]These authors contributed equally: Jie Gu, Biswanath Chakraborty. *e-mail: vmenon@ccny.cuny.edu

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S1. Cavity mode distribution

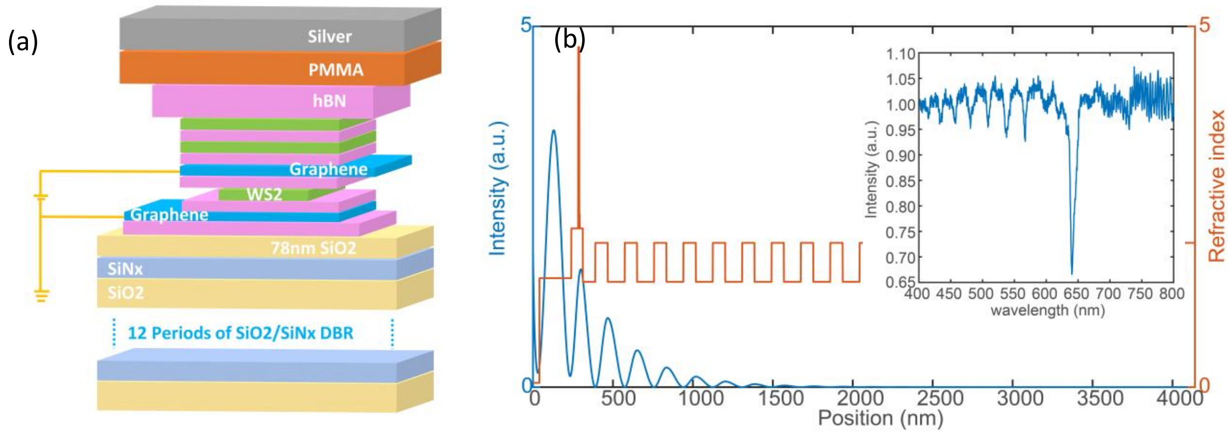


Figure S1 | Device schematic and cavity mode distribution. a, Device schematic. **b**, Mode distribution for wavelength at 620.1nm which is the WS_2 exciton energy. Position '0' relates to the top surface which is silver. Thickness of the cavity is tuned to have the mode profile's second maximum position falling on the WS_2 region. Inset shows the bare cavity mode with 8.2nm (24meV) linewidth.

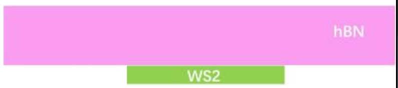
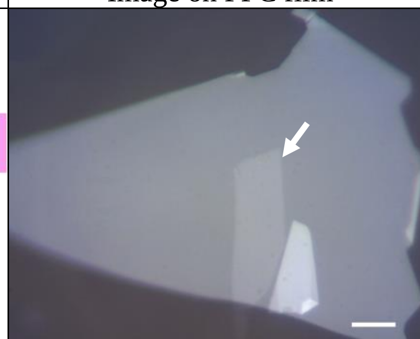
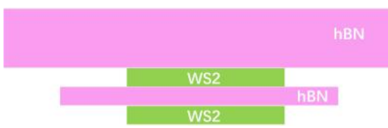
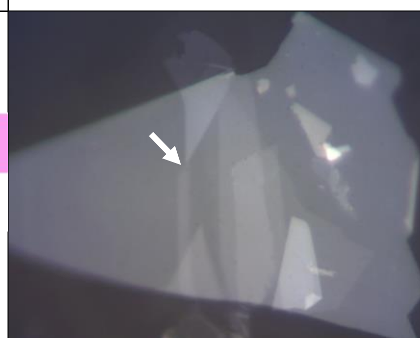
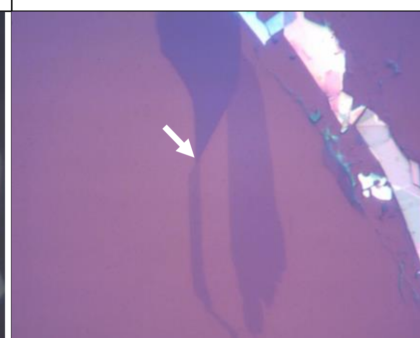
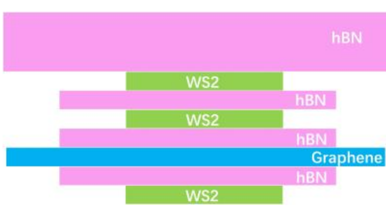
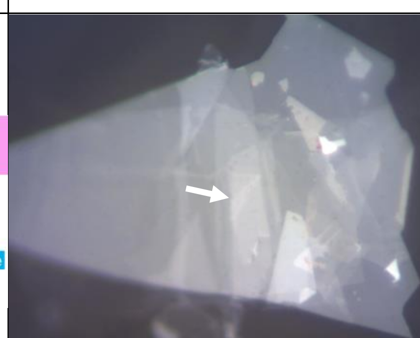
Table S1 | Thickness of each layer in Figure S1a

Material	Silver	PMMA	hBN	WS_2	hBN	WS_2	hBN	Graphene	hBN	WS_2	hBN	Graphene	hBN	SiO_2	DBR-SiNx	DBR-SiO_2
Thickness (nm)	40	200	40	0.7	2	0.7	3	0.4	2	0.7	2	0.4	20	78	77.5	106.2

S2. More Stacking images

This section shows the optical images of stacking steps after each WS_2 layer was picked up.

Table S2 | Optical images of the stacking at different steps

Stacking order	Image on PPC film	WS_2 image
1. First WS_2 		
2. Second WS_2 		
3. Third WS_2 		

Left: Schematics of the stacked layer order. **Middle:** Optical image of the PPC film at different steps. **Right:** Microscope optical image of different WS_2 layers. In each row, there are two white arrows in middle and right columns pointing at the same position for the guiding of view to ensure the WS_2 has been successfully picked up at each step. Monolayer WS_2 is easy to identify due to the color contrast, for example, in the first WS_2 image, the white arrow is pointing at the monolayer region. All the figures have the same scale. A 10 μm scale bar is shown in the first row PPC film image.

S3. EL spatial image

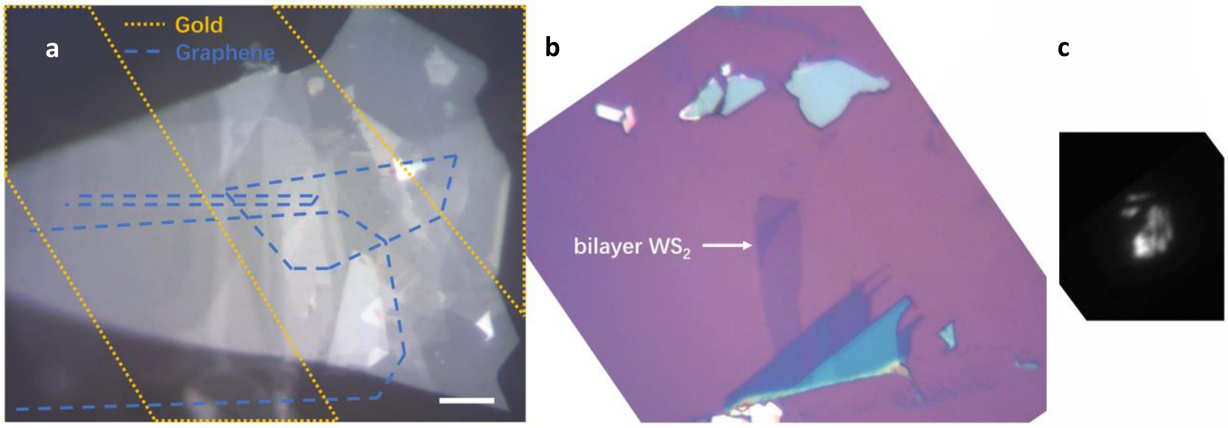


Figure S3 | EL spatial image. a, Sample optical image on the PPC film after the third WS_2 layer was picked up. The graphene (long dash) and gold contacts (short dash) outlines are labeled with different colors. The scale bar is 10μm. All the images have the same scale bar. **b**, Optical image of the third WS_2 layer on SiO_2/Si substrate before the picking up. There is a small bilayer region shown by the white arrow. **c**, EL spacial image at 0.28 $\mu A/\mu m^2$. Because only the third WS_2 layer is inside the tunneling region, as shown in **Table S2**, row 3, when a bias is applied across the graphene contacts, only the third layer WS_2 will show EL. The bilayer region in the third WS_2 shows much less EL due to its indirect band gap.

S4. Compare EL and PL

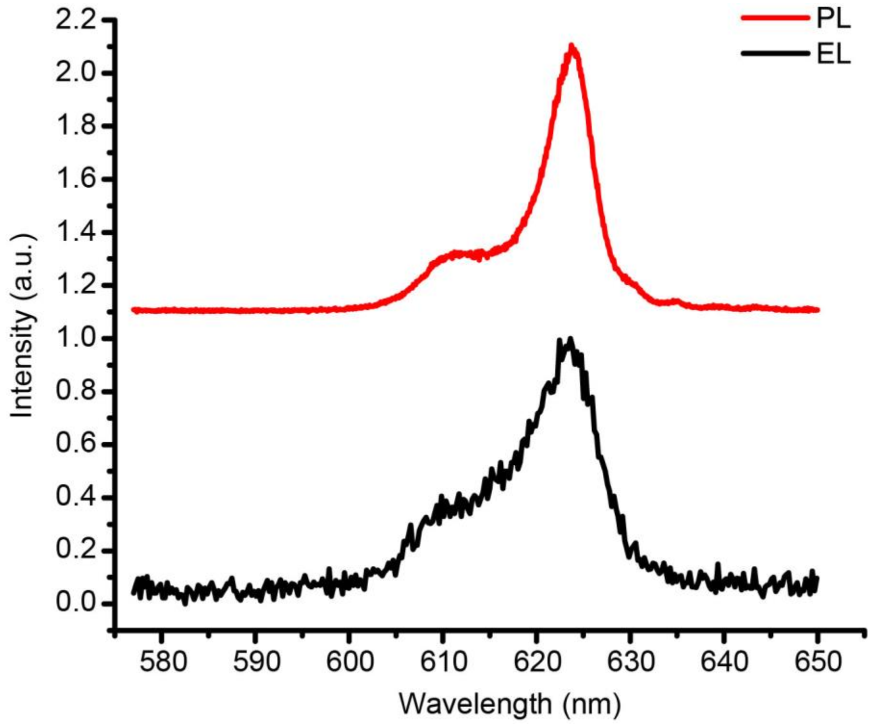
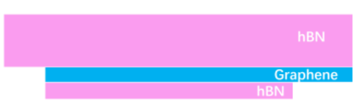
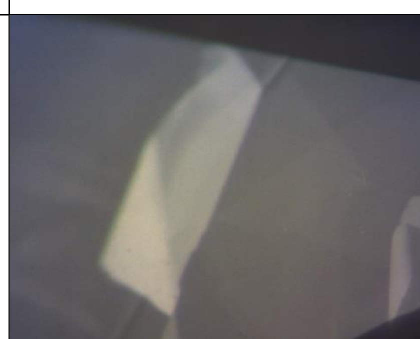
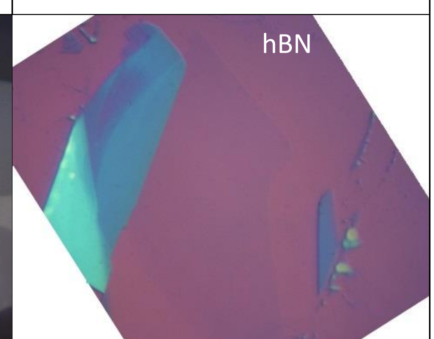


Figure S4| EL at PL at 20°. Due to the non-uniform surface created in the transfer process, the cavity is broadened if the integration is taken from a larger area. In PL, our emission area is determined by the excitation spot which is 1 μm^2, while our EL emission area is more than 20 μm^2. Thus, EL shows more broadening effect.

S5. Device 2 data

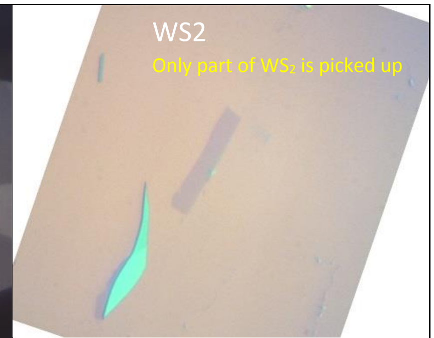
We made another device by **first** stacking and transferring the tunneling structure, which has only one WS_2 monolayer inside, followed by stacking and transferring another top two WS_2 monolayers ($hBN/WS_2/hBN/WS_2$), unlike the device 1 stacking steps, which stacked the top two WS_2 layers first and then stacked the tunneling structure. The final structure of device 2 is the same as device 1 as shown in Fig. S1a. The only difference is that the third hBN (count from top to bottom) layer thickness is 30 nm because this hBN layer acts as the first picking up layer for the tunneling structure in device 2. The rest of PMMA and SiO_2 thickness were also tuned to match to mode position. One of the advantages of trying this method is that, by separating the stacking process into two (one has 7 stacking layers, another has 4 stacking layers), the device fabrication will have a much higher success rate. The original stacking encounters continuous 11 layers with much higher chance of damaging the thin graphene contact by more stacking-picking up process. Images of the first stacking process which evolves 7 stacking layers are shown in **Table S5** (below). Device 2 also shows strong coupling with Rabi splitting 27meV.

Table S5 | Device 2 stacking images

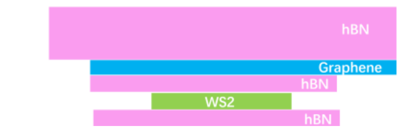
Stacking order	Stacking image	Current stacked layer image
1. 		
2. 		

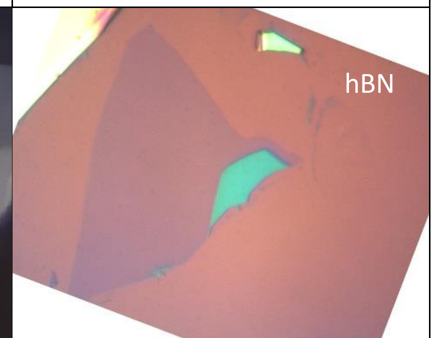
3.


hBN
Graphene
hBN
WS2

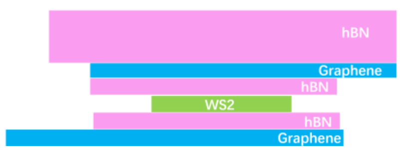

WS2
Only part of WS_2 is picked up

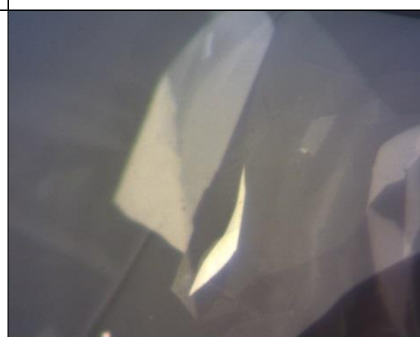
4.

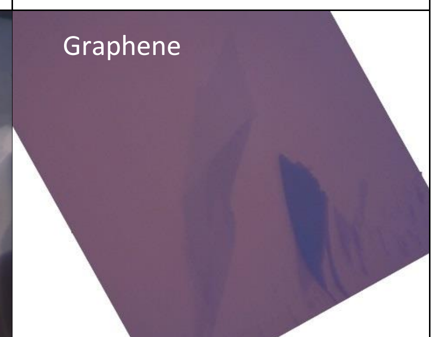

hBN
Graphene
hBN
WS2
hBN


hBN

5.

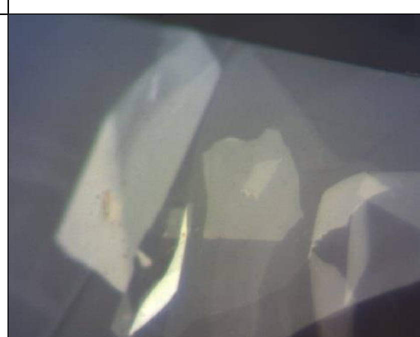

hBN
Graphene
hBN
WS2
hBN
Graphene

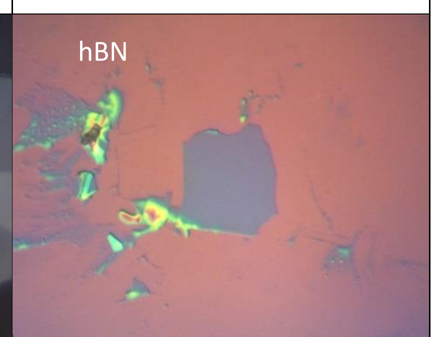



Graphene

6.


hBN
Graphene
hBN
WS2
hBN
Graphene
hBN




hBN

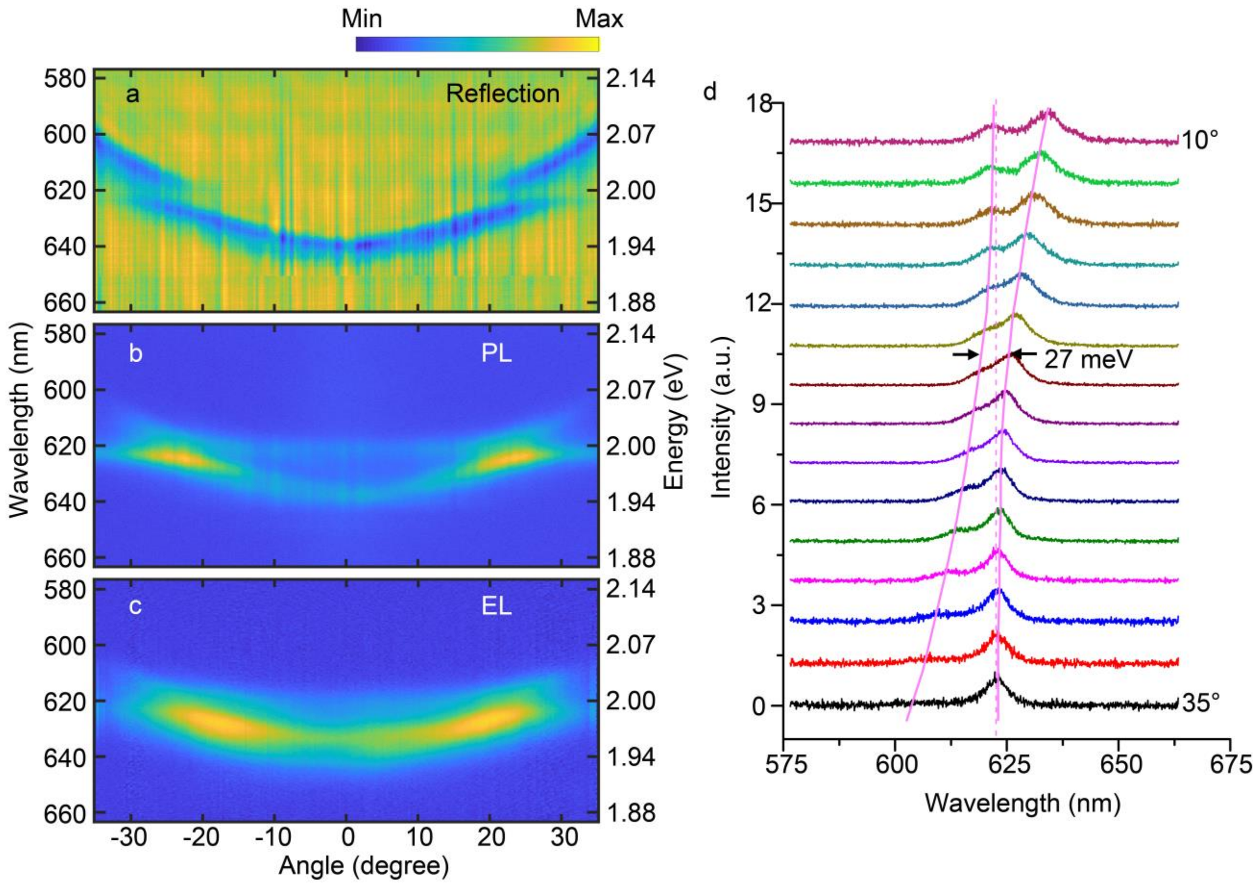


Figure S5-1| Angle resolved spectra from device 2. Angle resolved reflection (**a**) PL (**b**) EL (**c**) spectra. **d**, EL linecut from 10 degree to 35 degree showing 27 meV Rabi splitting.

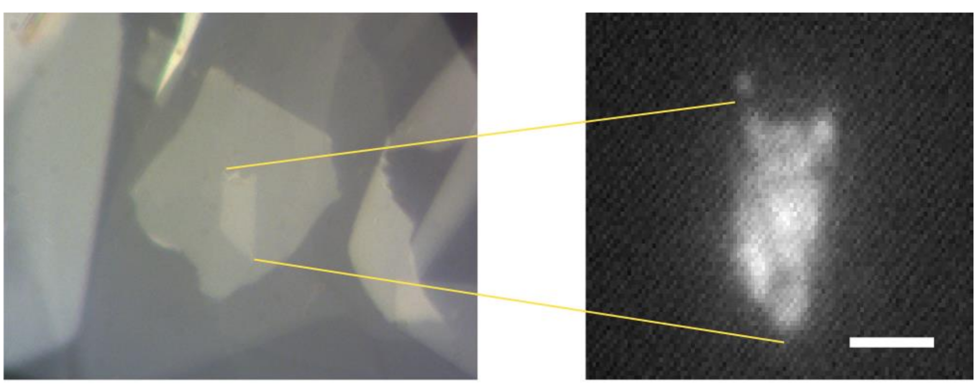


Figure S5-2| Device 2 EL image. Left is the optical image and right is the zoomed EL image under current 0.2 μA/μm^2. Scale bar is 5 μm.

S6. Compare three devices

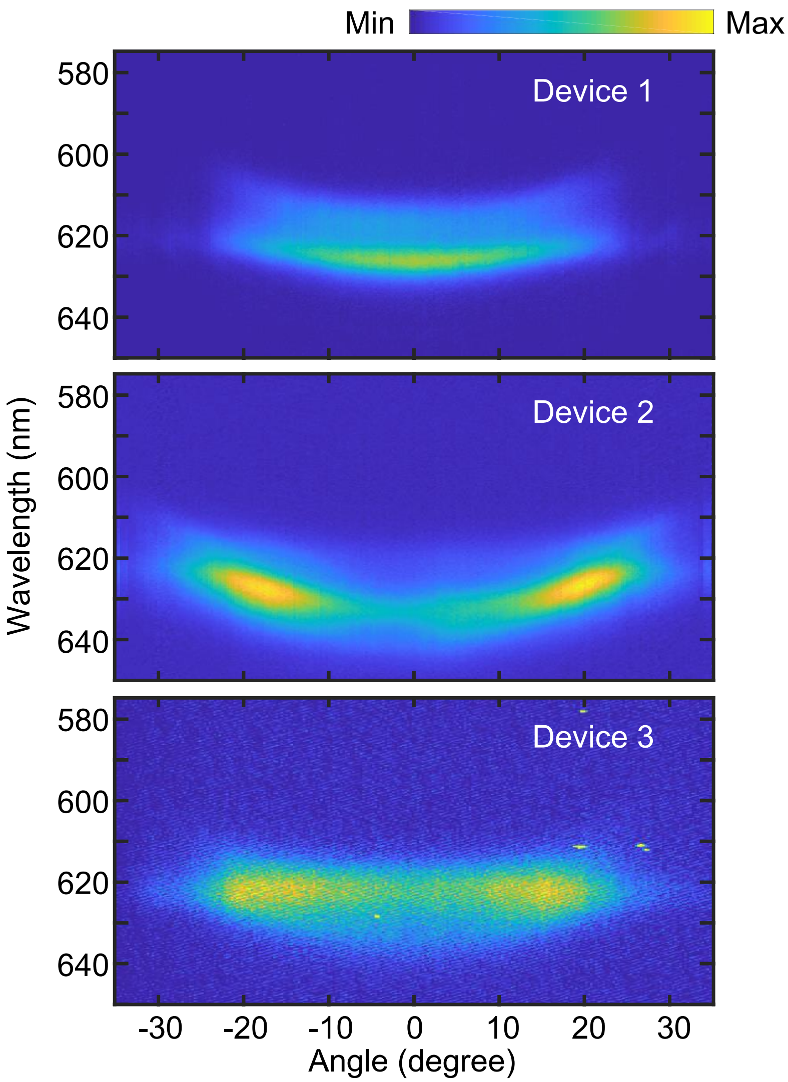


Figure S6 | Compare EL from three different devices.

EL from different devices. Device 1 and Device 2 EL has been shown in Fig. 2c and Fig. 4a. Device 3 has only one WS_2 layer inside the cavity, the structure is Silver / PMMA / hBN / Graphene / hBN / WS_2 / hBN / Graphene / hBN / DBR. Because of the reduced WS_2 layers, we could not observe any splitting in device 3. To compensate the cavity broadening due to graphene loss as well as non-uniform surface created during transfer steps, more layers of WS_2 (device 1 and device 2) are embedded inside the cavity to have an observable Rabi splitting.

S7. External Quantum efficiency

The external quantum efficiency (EQE) is defined as the number of photon emitted per tunneling carrier Ne/i (N is the photon emitted every second from the total tunneling monolayer WS_2 area, e is the electron charge, i the current passing through the total tunneling monolayer WS_2 area). N is defined as

$$N = \frac{N_{detected}}{\alpha_{total}}$$

$N_{detected}$ is the intensity detected by the detector per second from WS_2 tunneling emission. α_{total} is the total collection efficiency of the whole system. Light emitted from monolayer is collected by an objective with N.A 0.7 and guided through mirrors and lenses into the detector. The detector is set to a high gain factor. All those will affect the actual counts read by the detector. In order to know N, we need to measure α_{total} for a given set up that is exactly the same as the one we use to detect the tunneling emission. We did this by shine a laser that has the same wavelength (620.1nm) as our tunneling emission to a perfect reflector and the reflected beam will be guided in the same way as the tunneling emission into the detector. The laser power on the total reflector surface is measured to be P. The measured laser counts is N_{laser} per second. α_{total} is calculated as:

$$\alpha_{total} = \frac{N_{laser}}{P} * E$$

E is the laser energy which is 2 eV.

So N is:

$$N = \frac{N_{detected}}{N_{laser} * E} * P$$