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# Strong coupling and catenary field enhancement in the hybrid plasmonic metamaterial cavity and TMDC Monolayers

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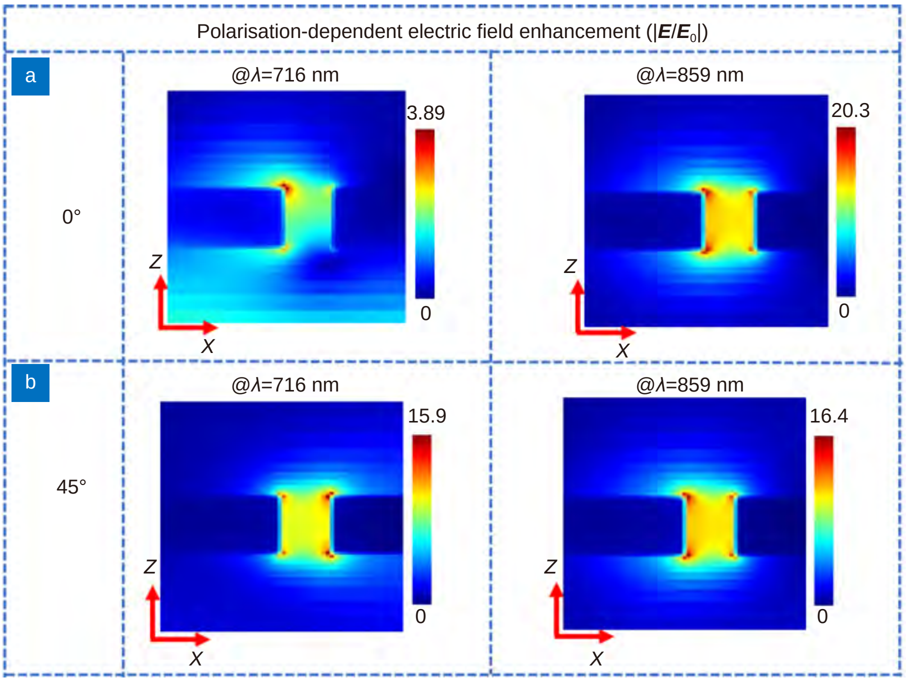


**Fig. S1 | Polarization-dependent near-field enhancement.** Electric field enhancement of the uncoupled Au cavity at a polarisation angle of (**a**) 0° and (**b**) 45° . The geometry of the Au cavity was the same as shown in Fig S1. (a).

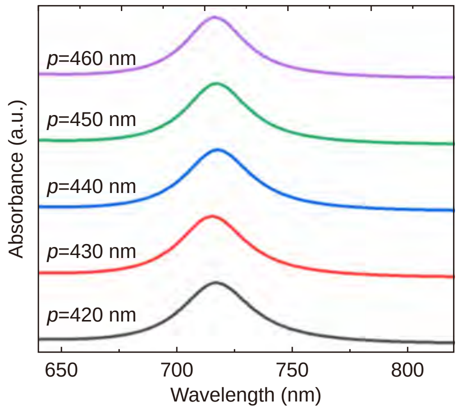


**Fig. S2 | Effect of period on tuning plasmon resonance of uncoupled Au cavity.** The plasmon resonance is not tunable with varying periods. The design parameters of the nanostructure are set as constants with $W_1$ = 39 nm, $W_2$ = 33 nm, $h$ =157 nm, $g$ = 108 nm, $\alpha$ = 307 nm, and $t$ = 60 nm (see Fig. 1(a)).

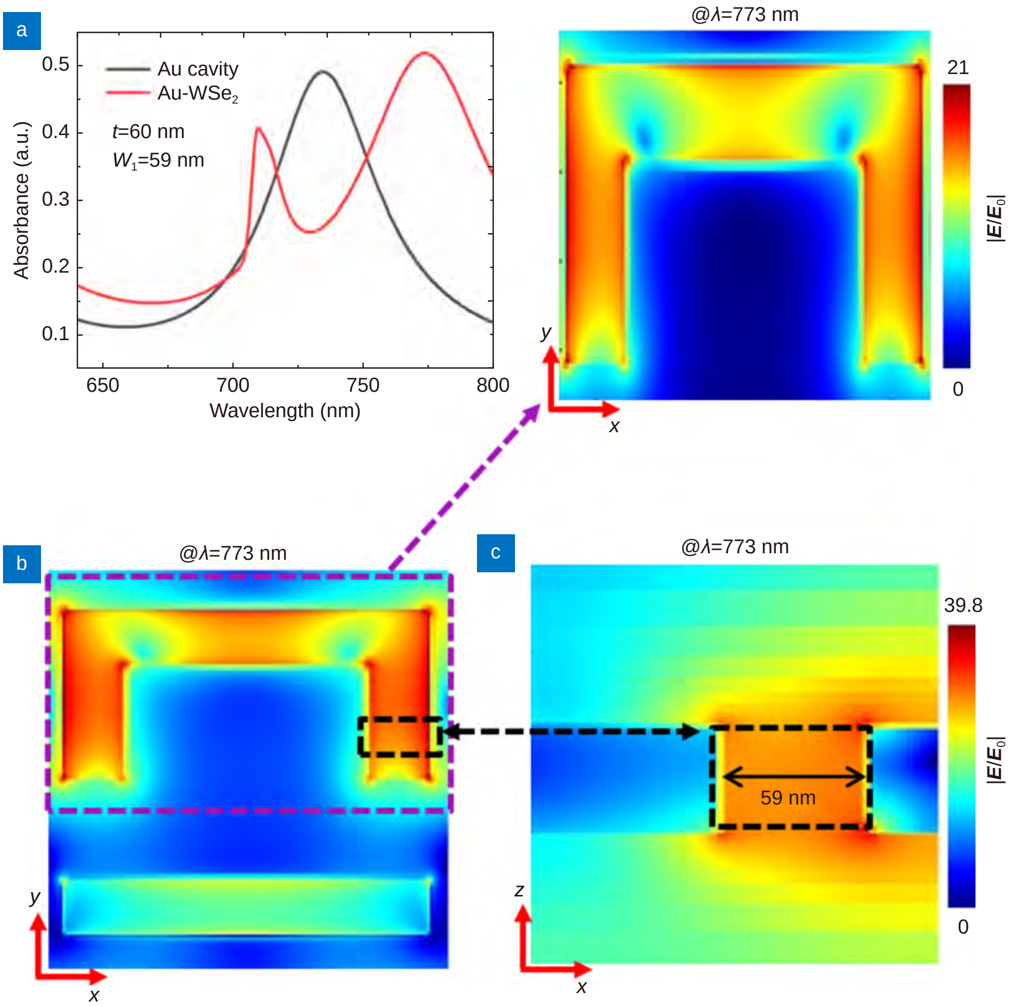


**Fig. S3 | Effect of cavity gap on absorbance and near-field enhancement of Au-WSe$_2$.** (**a**) Absorbance of Au-WSe$_2$, and the corresponding electric field generated at a unit cell of the Au cavity, for at the planes (**b**) $z$ = 13 nm, and (**c**) $y$ = 70 nm. In the Au-WSe$_2$ nanostructure, the design parameters of the Au structure are set follows: $W_1$ = 59 nm, $W_2$ = 53 nm, $h$ =166.5 nm, $g$ = 98 nm, $\alpha$ = 327 nm, and $t$ = 60 nm.

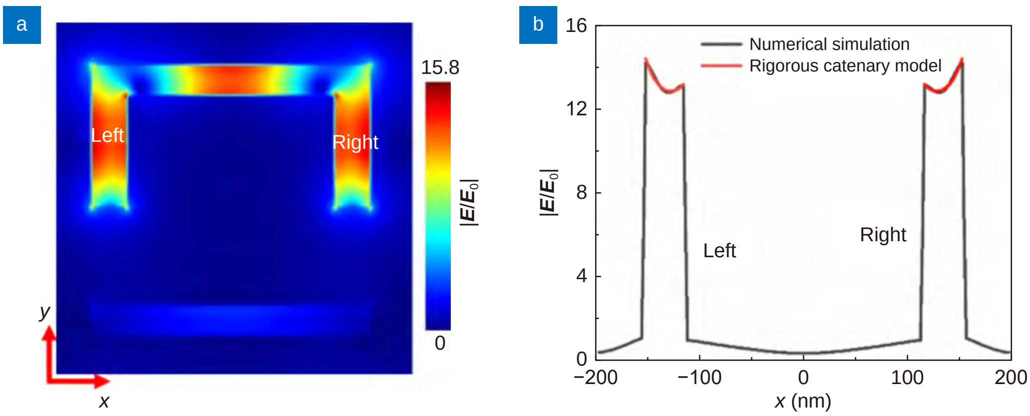


**Fig. S4 | The modelled catenary−shaped near-field enhancement.** (**a**) The electric field profile of Au cavity, at the $z$ planes with a polarization along the $y$-axis. (**b**) The retrieved catenary-shaped near-field enhancement of uncoupled Au cavity. The extracted field distribution of the left− and right−sides are symmetric and are matched with the catenary model.

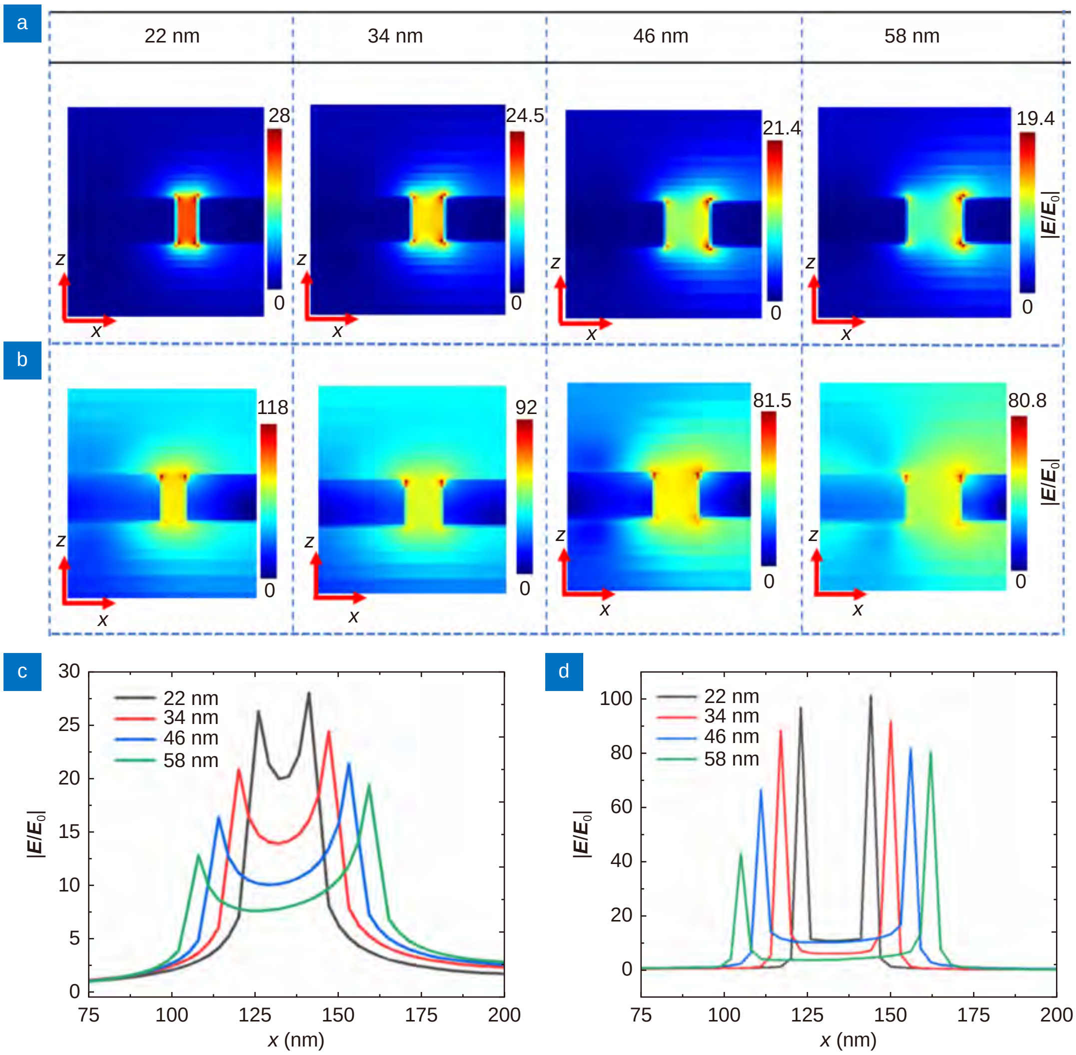


**Fig. S5 | Electric field profile and their corresponding catenary-shaped near-field enhancement.** Here, for the comparison of electric field profiles, the thickness of the Au cavity is set at 50 nm, while changing other parameters ($W_1$ = 22−58 nm, $W_2$ = 16−52 nm, $g$ = 98.5−116.5 nm, $\alpha$ = 290−326 nm, and $h$ = 148.5−166.5 nm). Calculated near-field intensity distribution of (**a**) uncoupled Au cavity, and their corresponding (**b**) Au-$WSe_2$ heterostructure. The electric field profile revealed that the electric field confinement is enhanced in Au-$WSe_2$ heterostructure compared to uncoupled Au cavity has great implications to induce plasmon-excitons coupling. The electric field profile was captured at the resonance point. The extracted electric field distribution in (**c**) Au cavity, and (**d**) Au-$WSe_2$ heterostructure with varying cavity gaps. The catenary-shaped near-field enhancement revealed the plasmon coupling is strongly dependent on the cavity gap distance.

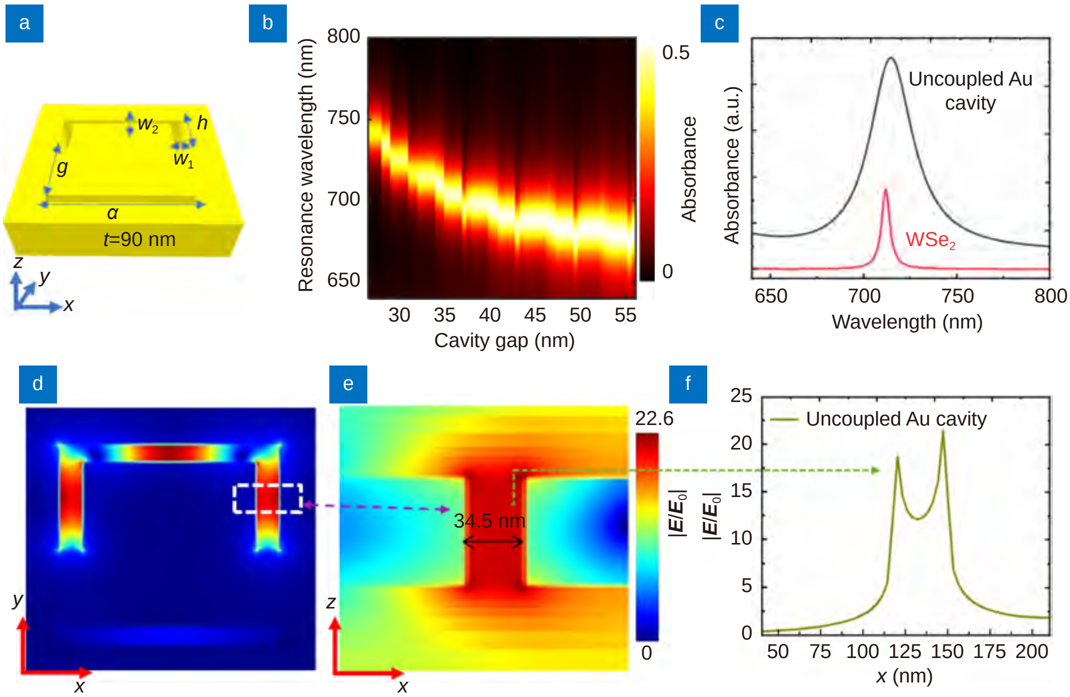


**Fig. S6 | Effect of cavity gap on tuning Au plasmon resonances.** (**a**) Schematic drawing of Au nanostructure with a thickness *t* = 90 nm and varying cavity gaps of $W_1$ from 22 to 58 nm and $W_2$ from 16 to 52 nm, while other parameters are kept the same as in Fig. 2(a). (**b**) Absorption mapping of Au cavity at a period of *p* = 420 nm. (**c**) The absorption spectra of Au cavity (black line) and the uncoupled $WSe_2$ monolayers (red line). The electric field generated at a unit cell of the Au cavity, at the planes (**d**) *z* = 13 nm, and (**e**) *y* = 70 nm with a polarization along the *y*-axis. (**f**) The retrieved catenary-shaped near-field enhancement at air−gold interfaces.

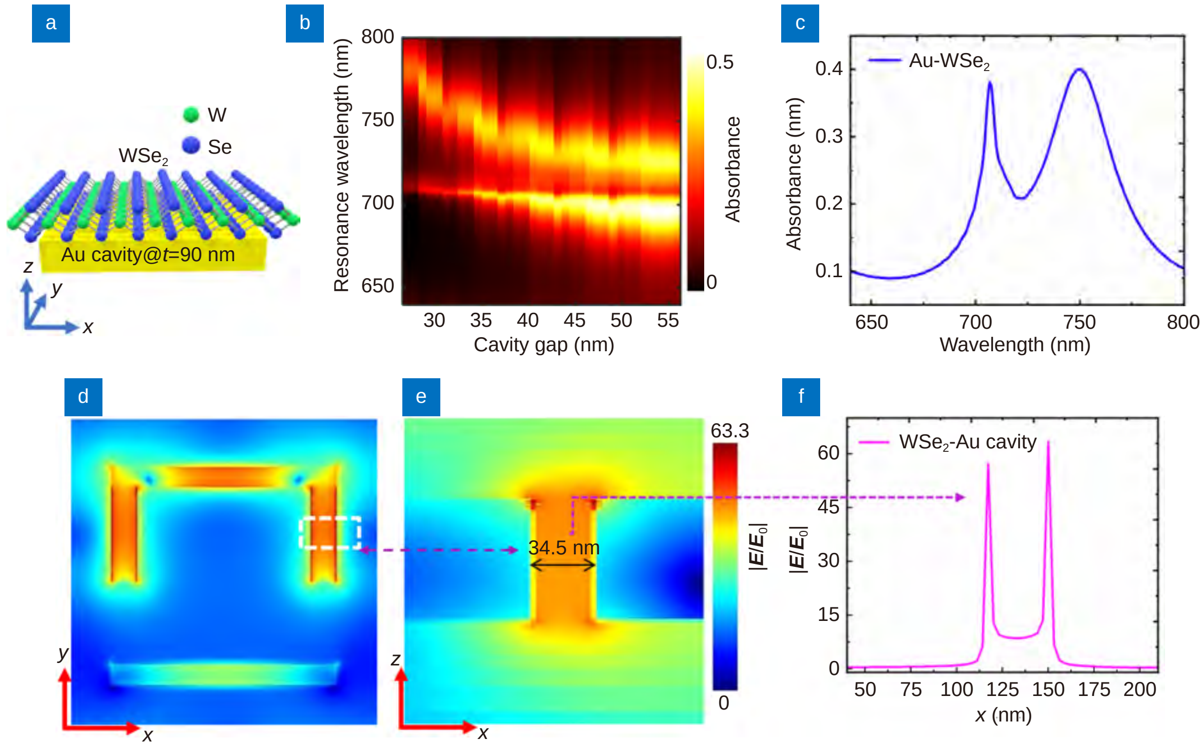


**Fig. S7 | Effect of cavity gap on strong coupling of Au-$WSe_2$ heterostructure.** (**a**) Schematic illustration of monolayer $WSe_2$ on top of Au cavity at normal incidence. (**b**) Absorption spectrum mapping of Au-$WSe_2$ as a function of cavity gap distance ($W_1$). (**c**) Absorption spectrum of Au-$WSe_2$ corresponding to figure (b) with a cavity gap of $W_1$ = 34.5 nm by $W_2$ = 28.5 nm. Electric field distribution at a unit cell of Au-$WSe_2$ nanostructure in the planes (**d**) *y*-plane and (**e**) *z*-plane taken at their resonance point. (**f**) The retrieved catenary-shaped symmetric electric field profile of Au-$WSe_2$.

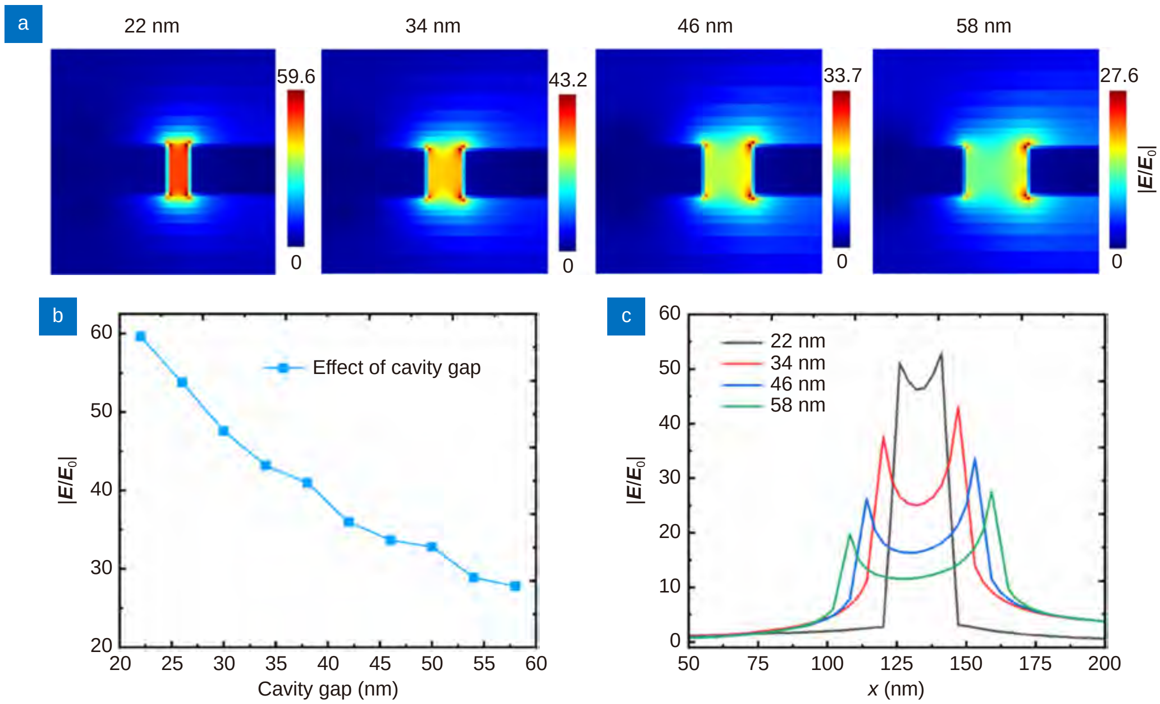


**Fig. S8 | Catenary-shaped optical fields in a thin Ag cavity. The thickness of the Ag cavity is 50 nm and varying other parameters ($W_1$ = 22−58 nm, $W_2$ = 16−52 nm, *g* = 98.5−116.5 nm, *α* = 290−326 nm, and *h* = 148.5−166.5 nm).** (**a**) The electric field distributions of Ag cavities at their corresponding resonance frequency. (**b**) The magnitude of electric field induced in the cavity, which is corresponding to the results in (a). (**c**) Retrieved catenary-shaped near-field profile of (a).

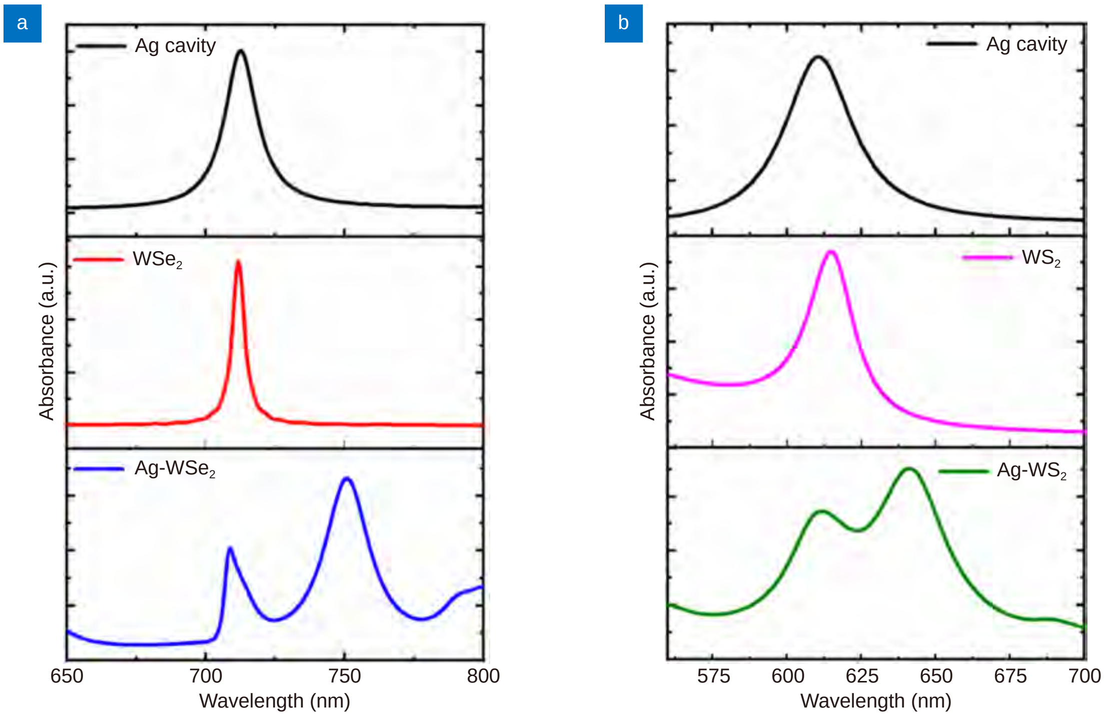


**Fig. S9 | Strong coupling in the Ag-WSe$_2$ and Ag-WS$_2$ heterostructures.** (**a**) Absorption spectra of the uncoupled Ag cavity (top), uncoupled WSe$_2$ monolayers (middle), and their Ag-WSe$_2$ hybrid nanostructure. The design parameters of Ag cavity were set as follows: $W_1$ = 39 nm, $W_2$ = 33 nm, $h$ =157 nm, $g$ = 108 nm, $\alpha$ = 307 nm, and $t$ = 50 nm (see Fig. 2(a) for the position of the parameters). To align the plasmon resonance of Ag cavity with excitons of WSe$_2$, period was set at 560 nm. (**b**) Absorption spectra of uncoupled Ag cavity (top), uncoupled WS$_2$ monolayers (middle), and their Ag-WS$_2$ hybrid nanostructure. The design parameters of Ag cavity were set as follows: $W_1$ = 70 nm, $W_2$ = 60 nm, $h$ =157 nm, $g$ = 108 nm, $\alpha$ = 307 nm, and $t$ = 50 nm (see Fig. 2(a)for the position of the parameters). To align the plasmon resonance of Au cavity with excitons of WSe$_2$, period was set at 430 nm. To note that the quality factor of ($Q$) of the Ag cavity can be enhanced by increasing the period (see Fig. 5(c)). In Ag-WSe$_2$ and Ag-WS$_2$ heterostructures, two absorption peaks are observed corresponding to the UPB and LPB.