Electrical control of interlayer excitons distribution in a bilayer TMD heterostructure

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Bilayer heterostructure which consists of monoatomic layers of transition metal dichalcogenides (TMDs) enables the formation of interlayer excitons (IX), where the electrons and holes reside in distinct layers. The electrical dipole associated with the IX allows them to interact with electrical field gradients, such that a force $\vec{F}_{IX} = ed\frac{\partial E_z}{\partial x}\hat{x}$ acts on the exciton and may move it along the x direction (here d is the dipole length). In such a field gradient, there is also a force acting on electrons and holes (or equivalently, on charged excitons), such that free electrons and holes may drift towards the sides of the sample.

In this work we study the impact of these forces on an optically excited bilayer system of hBN encapsulated $MoSe_2/WSe_2$ bilayer, and show that they give rise to dramatic changes in the PL intensity distribution in the plane, as well as accumulation of high IX density that is observed at one side of the sample. We introduce a novel technique that allows creation of very large field gradients, $10^9 - 10^{10}$ V cm^{-2}, without having to form selective ohmic contacts to each layer. This is achieved by a grounded, semi-transparent top gate and a bottom gate which consists of two thin gold electrodes with a highly resistive layer in-between them. By applying a voltage ΔV between the two sides of the bottom gate we obtain a field gradient across the bilayer.
To determine the local field in each point in space we performed spatially resolve PL measurement across the sample. Since the IX energy, ε_{IX}, redshifts by applying an electric field, E_z, as $\varepsilon_{IX}(E_z) = \varepsilon_{IX}(0) - edE_z$, this measurement allows us to determine the local electric field in the bilayer plane. The uniform field gradient, $\frac{\partial E_z}{\partial x}$, is manifested by the linear slope of $\delta\varepsilon_{IX} = \varepsilon_{IX}(E_z) - \varepsilon_{IX}(0)$ across the sample, as shown in Fig. 1a.

We next studied the PL emission distribution as a voltage difference ΔV is applied. Fig. 1b shows a normalized 1D PL image in the presence and in the absence of an in-plane field. It is seen that the application of ΔV leads to a formation of emission peak at the right side of the sample. We confirmed that by reversing ΔV the new emission peak moves to the left side. Finally, we studied the PL spectrum at the location of the new emission peak (Fig. 1c). We found that its peak energy exhibits a voltage dependent blueshift, which can be as high as 30-40 meV, representing a buildup of IX density of more than 10^{12} cm^{-2}.

We shall discuss the mechanism giving rise to this effect, and the interplay between e-h and exciton transport in this system.

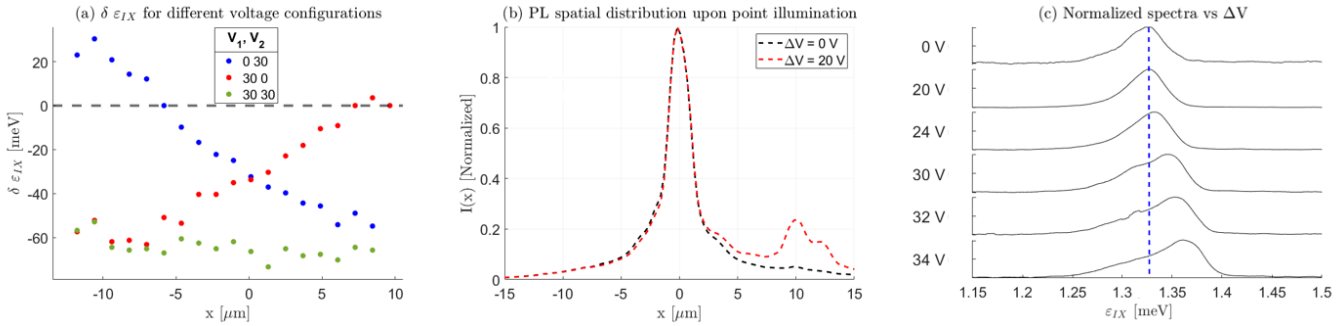

Figure 1: (a) The IX peak energy across the sample for various setting of the bottom gate electrodes voltage, V_1 and V_2. note the blueshift on the left side for $V_1, V_2 = 0{,}30$ V. (b) 1D spatial distribution of the PL intensity, $I(x)$, at $\Delta V = 0$ and 20 V. (c) Spectra measured at the side of the sample where the voltage is kept at $V_1 = 0$ while changing the voltage on V_2 where $\Delta V = V_2 - V_1$. The blueshift of the IX line is clearly visible, manifesting the exciton accumulation.

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