Enhancement of phononless optical transitions by large valley splitting in silicon MOSFETs

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One of the distinct attributes of Si compared to other semiconductors is a multi-valley band structure, which causes various interesting physics and makes applications such as valley qubits [1] and valley valves [2] possible. Here we demonstrate the enhancement of phononless optical transitions with specially prepared Si/SiO₂ interfaces, where the valley splitting is tuned by a gate electric field and its value is almost 20 times larger than that at an ordinary MOS interface [3]. For conventional Si MOS interfaces, the valley splitting is well explained by the extended zone effective mass theory [4], where real space confinement causes valley interaction. By extending this theory, it is expected that the valley splitting will lead to phononless optical transitions in Si. We therefore anticipate that phononless optical transitions can be controlled by the gate field.

Devices are Si MOSFETs with 3- or 6-nm-thick Si on insulator channel, where both heavily doped p- and n-type contacts are formed in order to inject holes and electrons into it (Fig. 1). The front and back gate control the distribution of both carriers in the thin Si channel. Figure 2 shows typical electroluminescence (EL) spectra at various back-gate voltages (V̄BG). For V̄BG < 0, an indirect TO phonon mediated optical transition dominates the EL spectra, where the valley splitting is at most several mili-electron volts. In contrast, for V̄BG > 0, the EL intensities of phononless optical transition (NP) become dominant with increasing V̄BG. The valley splitting is at least one order of the magnitude lager for V̄BG > 0. It is estimated to be 30 meV at V̄BG = 80 V, where the intensity ratio NP/TO reaches 800. Our findings indicate that direct/indirect optical transitions in Si can be tuned just by changing gate, which opens up the possibility of direct access to valley coupled states by photons.

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Fig. 1. Device structure. Fig. 2. EL spectrum at a given V̄BG (T=4K).