Spatiotemporal Carrier Dynamics in Inhomogeneous Electron-Hole Systems under the Rashba Effect

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Electron spin has important effects in various physical phenomena, and research fields such as spintronics have been developed in recent years. In particular, in low-dimensional electron systems with inversion asymmetry, a spin-orbit interaction (SOI) called the Rashba effect occurs despite the absence of a magnetic field [1]. As shown in Fig. 1(a), the Rashba effect breaks the spin degeneracy, resulting in a spin-dependent splitting of the energy bands, that modulates the transport properties of electrons. On the other hand, the electron transport in real space has been studied by local excitation and measurement using a scanning near-field optical microscope (SNOM), as shown in Fig. 1(b) [2]. The Rashba effect is expected to have a significant effect on the spatial properties of electron transport. In this study, we discuss the Rashba effect on the spatial transport of carriers and the spatiotemporally-resolved photoluminescence through the spin-dependent splitting energy bands in low-dimensional electron-hole systems.

First, we construct a full-quantum-mechanical kinetic theory based on the semiconductor luminescence equations and the quantum Boltzmann equations [3] with the Wigner functions [4] in order to describe real-space information. Next, we investigate numerically two cases of the homogeneous and inhomogeneous photoexcitation. In the case of the homogeneous excitation, we reveal the time evolution of the carrier density distribution and photoluminescence (PL) spectra, which depend on the spin state. The carriers are thermalized to the edge of the split energy bands, and the PL spectra are determined from the carrier relaxation process. Furthermore, we consider the inhomogeneous case with local excitation and local measurement by SNOM, and discuss the effect of the split energy bands originating from the Rashba effect on the carrier propagation in real space. This study leads to stimulate the development of the hybrid technologies using the electric charge and electron spin under the optical near field.

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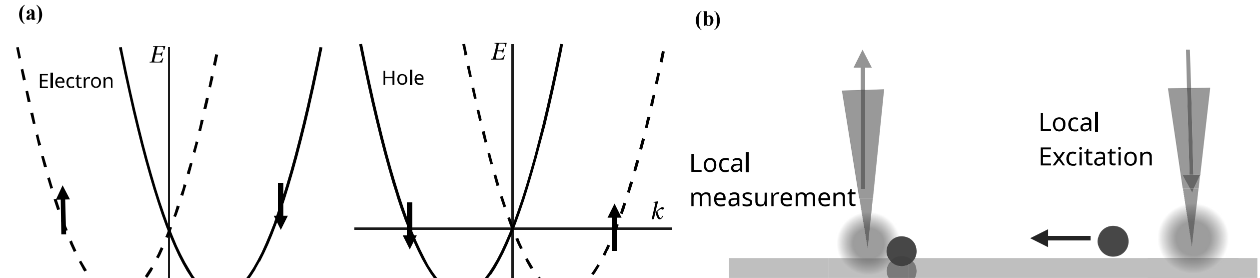

Fig. 1. (a) Split energy bands of electrons and holes depending on spin. Solid and dashed lines represent down spin and up spin, respectively. (b) Schematic drawing of local excitation and measurement of carrier propagation by SNOM.

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