Energy Transfer from an Electron-Hole Plasma Layer to a Quantum Well

by ***S.K. Lyo***

Motivation—Energy transfer (ET) of charge-neutral optical excitations such as excitons and plasmas in confined structures is not only a fundamental physics problem that lacks full understanding but also has important applications to modern opto-electronic devices such as solid state lighting (SSL) structures. In SSL devices, optical energies or excitations are created through the diffusion of an electron/hole current into conduction/valence band. These excitations emit light after going through a series of ET. The optical excitations are in the form of excitons at a low density or a plasma at a high density of electrons and holes. The goal of our research is to investigate most efficient ET mechanisms between confined structures.

Accomplishment—As an initial study of various types of ET, we have studied the rates of ET from a two-dimensional (2D) quantum well (QW) populated by excitons/electron-hole (e-h) plasma in the low/high carrier-density regime to an empty QW as a function of the carrier density, the temperature, and the distance between the two QWs. The two QWs shown in Fig. 1(a) are assumed to be unequal with a finite energy-mismatch between the initial and final ground state sublevels and are coupled through dipole-dipole (i.e., Foerster) interaction. In ET processes, an e-h pair is destroyed in the initial QW, creating a free e-h pair in the final QW. The momentum of the center-of-mass is conserved. For anti-Stokes processes, energy is supplied through activation in the initial QW for energy conservation, while the excess energy is dissipated into the kinetic energies of the e-h relative motion for Stokes processes.

We found that the exciton ET rate (which is independent of the carrier density) is much faster than the plasma ET rate per e-h pair as shown in Fig. 1 (b). The latter increases sublinearly with the increasing density and saturates in the high-density limit. It dominates the former for the total ET power because of the large number of the carriers. Note that the temperature dependence of the exciton ET rate is strikingly different from the ET rates of plasmas as shown in Fig. 1 (b), indicating that the bound and unbound nature of the excitations can be distinguished from the temperature dependence of the rate. For excitons, the rate has a peak as a function of the decreasing temperature and vanishes at 0 K, while it increases steadily, saturating at 0 K for plasmas. This distinct behavior arises from 1) the linear dependence of the rate on the kinetic energy of the center-of-mass at low energy and 2) the Boltzmann/Fermi-Dirac statistics of excitons/plasmas. We have also calculated the ET power density as a function of the carrier density, the temperature, and the distance. The power is significantly large and decreases slowly as a function of the temperature as shown in Fig. 2. The rates and power decreases roughly as $1/d^4$ as a function of the distance d.

Significance—The power density of 2D-2D ET was shown to be significantly large even at room temperature, showing that plasmas are a useful power source for SSL applications. Our next step for the investigation is ET from a 2D plasma to quantum dots which have large oscillator strengths and are expected to be important for future efficient SSL devices.

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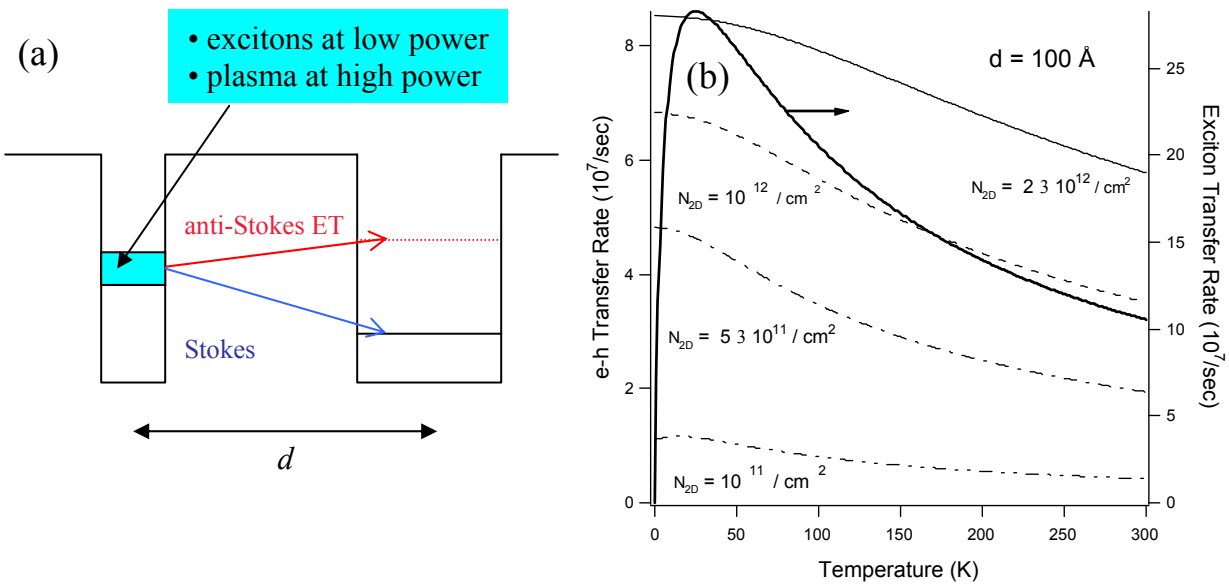

Figure 1. (a) Energy transfer from a quasi-2D exciton/plasma layer to an empty QW. (b) Energy transfer rates per e-h pair for plasmas for several pair densities (left axis: thin curves) at a distance *d* = 100 Å. The exciton transfer rate (right axis: thick solid curve) is independent of the density.

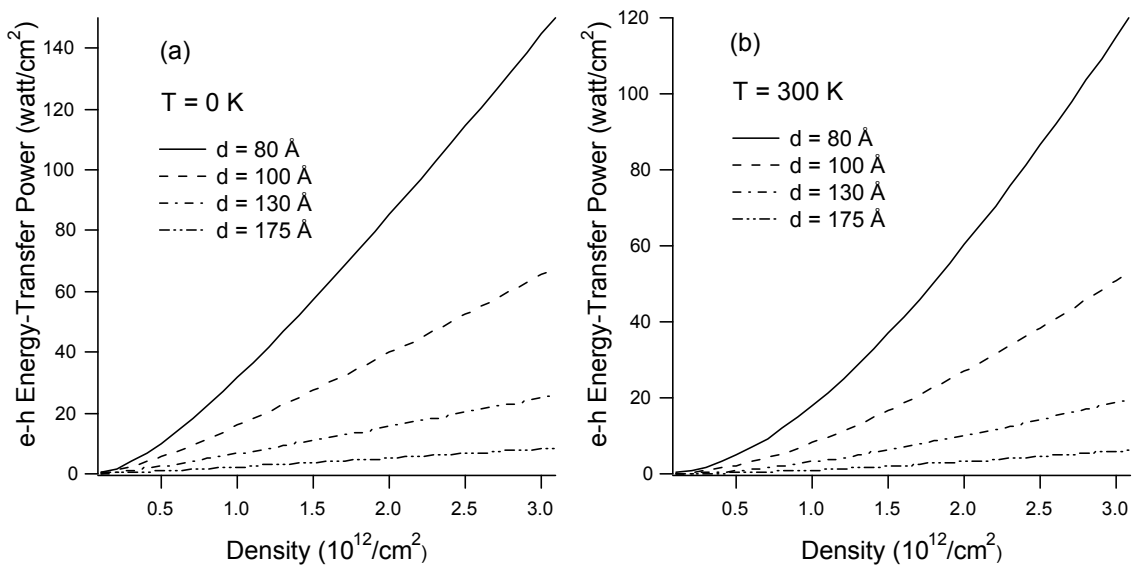

Figure 2. Energy transfer power per area as a function of the e-h pair density from a plasma layer to an empty QW at (a) 0 K and (b) 300 K for several distances *d*.