Direct observation of Lévy flight of holes in bulk InP

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The spatial spread of minority carriers produced by optical excitation in semiconductors is usually well described by a diffusion equation, and can be characterized by a diffusion length $L = (D\tau)^{1/2}$, where D is the diffusion coefficient and τ is the carrier lifetime. The classical diffusion process can be viewed as a result of a random walk of particles, in which every step of the random walk x_i has the same probability distribution function $P(x_i)$ with a finite second moment $\langle x_i^2 \rangle$. This allows applying the central limit theorem to the calculation of the particle distribution after many steps.

However, in moderately doped direct-gap semiconductors the photon recycling process can radically modify the spatial spread. For this process, the steps in the random walk are defined by the re-absorption length of photons produced by radiative recombination. The step distribution $P(x)$ has an asymptotic power-law decline $P(x) \sim 1/x^{\gamma+1}$, with $0 < \gamma < 1$. Moments of this distribution diverge and the average square displacement is governed by rare but large steps. Such a class of random walk is called the Lévy flight. It corresponds to an anomalously large spread of the particle in space and a modified ("super-diffusive") temporal evolution.

Here we present results of the first direct observation of the minority carrier profile in *n*-doped InP samples. We have used a rather unusual geometry (homogeneous excitation of the wafer edge and observation of the luminescence spectra from the wafer front surface) to study the luminescence spectra and intensity as a function of distance from the wafer edge. The intensity is proportional to the minority-carrier concentration and exhibits a slow power-law drop-off up to the distances of the order of centimeters with no changes in the spectral shape. This power law, observed over more than two orders of magnitude, provides direct evidence of Lévy-flight transport of minority carriers. It has enabled us to evaluate the index of the distribution, the characteristic distance of the minority-carrier spread and the photon recycling factor.

The results are in good agreement with theoretical analysis, as well as Monte Carlo modeling.