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# Ultrafast Decay of Photodiffractive Gratings in Hetero n-i-p-i's by Enhanced In-Plane Transport

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Charge separation is shown to cause an order-of-magnitude enhancement of the in-plane diffusive decay of photorefractive and photoabsorptive gratings in a semiconducting hetero n-i-p-i.

Hetero n-i-p-i's are one of several semiconductor quantum-well devices that use second-order electro-optic effects and that continue to attract interest for possible applications to low-power two-dimensional switching arrays and all-optical spatial light modulators. The turn-on time for a hetero n-i-p-i device is usually determined by transport perpendicular to the quantum wells. More specifically, it is determined by the time required for carriers generated in the quantum wells to escape the wells and to move to screen the built-in electric field, thus shifting the exciton. Consequently, typical turn-on times are of the order of a few ps. By contrast, when used in the conventional single-beam geometry, the recovery (or turn-off) time of hetero n-i-p-i's is determined by the slow recombination of the spatially-separated charges in the doped regions and is typically in the range of $\mu$s-ms. If instead, however, we use a two-beam mixing geometry for the device (where gratings are written in the material by the interference of the two beams), then the decay or turn off of the signal is determined by the decay of the gratings by in-plane transport over micron dimensions. Here, we use transient grating techniques to measure the recovery of such photorefractive and photoabsorptive gratings written in all-binary hetero n-i-p-i's. In this geometry, we show that the separation of photogenerated charge actually speeds the recovery by enhancing the effective in-plane ambipolar diffusion coefficient by roughly an order of magnitude (in contrast to the single beam geometry where charge separation prolongs the recombination and recovery time).

The structure we will focus on here is a hetero n-i-p-i containing quantum wells in the intrinsic regions which are composed of all-binary InAs/GaAs short-period strained-layer superlattices. The n and p regions are 20 nm thick layers of GaAs doped to a concentration of $2\times10^{17}$ and $1.2\times10^{18}$ cm$^{-3}$, respectively. Each intrinsic region is a 120 nm wide layer of undoped GaAs, which contains three quantum wells. Each quantum well consists of 6 periods of 2 monolayers of InAs alternating with 5 monolayers of GaAs. The growth and the dynamics of single-beam excitation of this sample are described elsewhere [1].

Here, we measure the in-plane ambipolar diffusive transport at room temperature by using a conventional transient grating technique. That is, a ~1 ps optical pulse produced by a cavity-dumped, synchronously-modelocked dye laser, which can be tuned across the excitonic resonance, is split into three parts. Two parts are spatially and temporally overlapped in the sample. The absorption of these two interfering pulses creates a periodic modulation of the carrier density in the plane of the quantum wells. These carriers then escape the wells and move perpendicular to the wells to produce a periodic screening of the built-in field and, thus, a periodic modulation of the quantum-confined Stark shift in the plane of the wells. This photorefractive and photoabsorptive grating, associated with spatially-separated carriers, will decay by ambipolar diffusive transport of the carriers in the plane of the wells. The decay of this grating was monitored by measuring the diffraction efficiency of the third probe pulse as a function of time delay. These measurements were repeated as a function of wavelength and fluence.

The decays of the gratings written in the hetero n-i-p-i at several fluences are compared in Fig. 1 to the decay in an undoped sample containing identical quantum wells (i.e. under flat band conditions). Notice that the decay rate is strongly fluence dependent. Also notice that at the lowest fluence the decay rate in the hetero n-i-p-i is ~7 times faster than that in the undoped sample and ~7 times faster than that predicted using the conventional ambipolar diffusion coefficient. These points are more apparent in Fig. 2 where we summarize the effective ambipolar diffusion coefficients, $D_a$, extracted from measurements at several fluences and three wavelengths. These wavelengths correspond to

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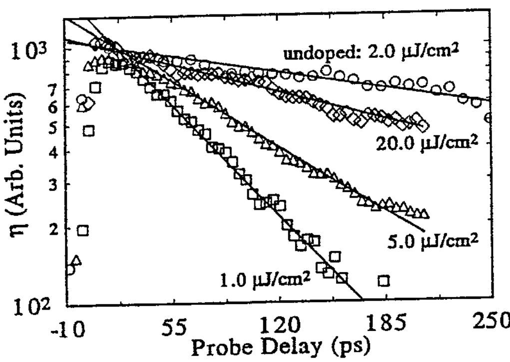


FIG. 1 Diffraction efficiency, $\eta$, vs probe delay for the hetero n-i-p-i for total peak pump fluences 1.0 $\mu J/cm^2$ (squares), 5.0 $\mu J/cm^2$ (triangles) and 20 $\mu J/cm^2$ (diamonds), and for the undoped sample at total peak pump fluence 2.0 $\mu J/cm^2$ (circles).

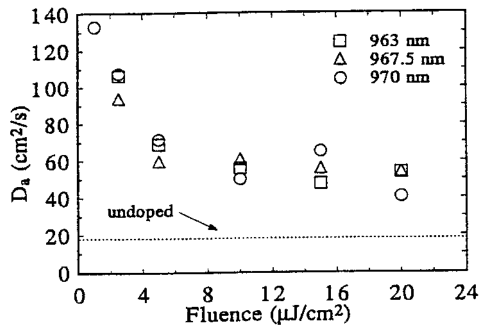


FIG. 2 Effective ambipolar diffusion coefficient, $D_a$, of the hetero n-i-p-i for total peak pump fluences in the range 1.0 $\mu J/cm^2$ to 20 $\mu J/cm^2$, at the excitonic peak (triangles), 2.5 nm to the red (circles) and 4.5 nm to the blue (squares). $D_a$ for the undoped sample is indicated by the broken line.

exciting on the excitonic peak, 2.5 nm to the red and 4.5 nm to the blue. The effective $D_a$ decreases smoothly from a maximum of 133 $cm^2/s$ observed at a total peak pump fluence of 1.0 $\mu J/cm^2$ monotonically toward the conventional ambipolar value of 18 $cm^2/s$ measured in the undoped sample and shown as the dotted line.

This enhanced in-plane transport in a semiconducting hetero n-i-p-i is a direct consequence of the charge separation dictated by the built-in field. That is, the photogenerated electrons and holes escape the wells in the intrinsic region and move perpendicular to the wells to screen the built-in field. Since the photogenerated charge is periodically modulated in the plane of the sample, the screening will be similarly modulated. The gradient of the potential (i.e., the field) associated with this periodic screening is the source of an additional force driving the grating decay. Since this in-plane drift field (associated with the screening) is proportional to the carrier density, the transport appears diffusive in nature. The importance of charge separation in this process is confirmed and illustrated by examining the dependence of $D_a$ on fluence. That is, as the fluence is increased, the screening becomes more complete and charge separation (and hence $D_a$) is reduced. At the highest fluences, we approach complete flat band conditions, there is little charge separation, and $D_a$ approaches the conventional value. Consequently, we see that the same space charge separation that slows the recombination can significantly enhance the diffusive decay. Although it differs in detail, this process is similar to the high-speed diffusive conduction recently reported in p-i-n structures [2] and to the giant ambipolar diffusion reported in semi-metallic p-n junctions [3].

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