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Evidence for an electron-hole plasma in the photoluminescence spectra of insulating InSb at very low pump intensities

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We have studied the photoluminescence spectra of insulating *n*-type InSb at 2 K. Spectra are observed at pump intensities as low as 100 mW/cm^2, more than a factor of 30 lower than any previously reported study. From an analysis of the line shape and intensity dependence of the spectra, the photoexcited carrier density is determined to be significantly larger than the Mott density, indicating that the photoexcited system exists as an electron-hole plasma. Additional analysis shows that nonradiative decay is the dominant recombination process, with a lifetime of the order of 25 nsec. The photoluminescence spectra exhibit intensity-dependent shifts in the spectral features, which we interpret within the context of band-gap renormalization. Quantitative comparison with a standard model of band-gap renormalization yields a 2-K, zero-density band gap of 235.3 meV, in agreement with recent magneto-optical studies. The observation of band-gap renormalization is strong evidence supporting the thesis that even at very low pump intensity, the photoexcited system exists as an electron-hole plasma.

I. INTRODUCTION

Recent advances in the growth[1] and processing[2] of InSb have provided the impetus for a reexamination of the photoluminescence of the bulk material. Although the study of photoluminescence in InSb is more than 35 years old,[3] there exist surprisingly few detailed studies.[4,5] Recently, several groups have put forth contrasting interpretations of the low-temperature photoluminescence (PL) and magnetophotoluminescence (MPL) spectra. These interpretations are based on theories of free excitons,[6,7] donor-bound electrons,[8] and electron-hole plasmas.[9] Consequently, there is little consensus on the relevant physics in this low-temperature, photoexcited system.

We report here a study of photoluminescence of low-density, *n*-type InSb at 2 K. The photoluminescence is excited using a Nd:YAG (yttrium aluminum garnet) laser at power densities as low as 100 mW/cm^2. Because this power density is more than a factor of 30 lower than that used in any previously reported photoluminescence study of InSb, we are able to probe the system at much lower photoexcited carrier densities. The photoexcited carrier density is determined by analysis of both the PL intensity dependence and the PL spectral line shape. These results are compared with a model calculation of the spatial profile of the photoexcited carrier density from which the non-radiative-recombination lifetime is determined. Shifts observed in the spectral features as a function of pump intensity are attributed to band-gap renormalization. An analysis of these shifts give a zero-density, 2-K band gap of 235.3 meV. From these results we conclude that even at very low pump power densities, the photoexcited system exists as an electron-hole plasma.

II. EXPERIMENTAL DETAILS AND RESULTS

The PL spectra reported in this study are of *n*-type InSb [$n_0=2\times10^{13}$ cm^{-3} and $\mu(77\ K)=450\,000$ cm^2/V sec]. The sample surface was prepared by polishing with Al_2O_3 and subsequently etching with a lactic acid and nitric acid solution. The sample was mounted in a Janis Varitemp cryostat and immersed in superfluid liquid helium to maintain a temperature of 2 K during the experiment. The Nd:YAG laser ($\lambda=1.0641$ μm, continuous-wave output) used to photoexcite the sample had a maximum output power of 1 W distributed over a 0.45-cm $1/e^2$ diam spot size. Photoluminescence was collected using toroidal mirrors and dispersed with a Jarrel-Ash $\frac{1}{4}$-m grating monochromator. The monochromator provided resolution of 0.4 meV for radiation near the band gap of InSb (235 meV). Use of a computer-controlled stepping motor to drive the grating resulted in spectra reproducibility better than ±0.1 meV. The signal was detected by a liquid-nitrogen-cooled mercury cadmium telluride detector, processed using phase-sensitive electronics, digitized, and collected by computer. Atmospheric absorption in the 4–6 μm range complicates the photoluminescence spectra of InSb. We eliminated these complications by normalizing the photoluminescence spectra to the measured atmospheric absorption spectrum.

Typical spectra obtained at different pump intensities are displayed in Fig. 1. We observe two dominant peaks, one at 227 meV and the other at 235 meV. These two features, both of which have been reported in the literature, are the focus of this paper. The 227-meV peak is associated with transitions of conduction-band electrons to acceptor bound holes. The 235-meV peak is associated with transitions of conduction-band electrons to valence-

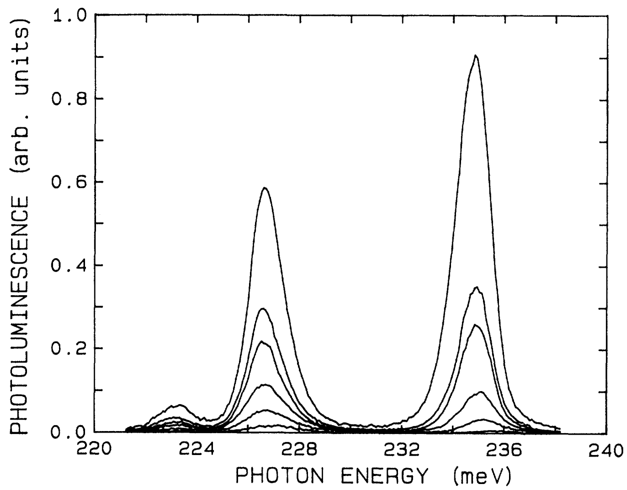

FIG. 1. Photoluminescence spectra of InSb at 2 K for various pump intensities. The peaks at 227 and 235 meV are the focus of this study. The values of the pump intensity are as follows (all values in W/cm^2): 0.26, 0.48, 0.74, 0.90, 1.19, 2.04.

band holes. We confirm the results of Mooradian and Fan[5] that the integrated intensity of the 227-meV peak increases linearly with pump intensity, while the intensity of the 235-meV peak increases as the square of the pump intensity.

The photon energy at which the 235-meV peak is observed decreases with increasing pump intensity. This shift is documented in Fig. 2(a). The 227-meV peak does not shift significantly throughout the investigated range of pump intensities, as shown in Fig. 2(b). The data points in Figs. 2(a) and 2(b) represent the position of the long-wavelength half-maximum (LWHM) of the particular peak. Although the positions of the peak and the short-wavelength half-maximum behave similarly, the LWHM was chosen to compare the data with theory, as will be discussed later in this paper. The observation of these shifts is central to our conclusions.

The PL spectra have also been studied to temperatures as high as 25 K. Temperatures above 4.2 K were maintained by blowing helium gas over the sample. These temperature-dependent spectra will be discussed later in this paper.

III. DISCUSSION AND COMPARISON WITH THEORY

A. The intensity dependence

The Mott density (n_c) in InSb is only 8×10^{13} cm^{-3} due to the system's very small electron effective mass ($m_e=0.014m_0$) and large dielectric constant ($\epsilon=16.8$). The corresponding exciton rydberg, E_{ex}, is 0.65 meV. When studying InSb with equilibrium carrier densities in the low 10^{13} cm^{-3} range, it is important to know the magnitude of the photoexcited carrier density relative to the Mott density. For carrier densities below n_c, the photoexcited system should consist of a gas of excitons and donor-bound electrons. At carrier densities significantly above n_c, donor-bound electrons and excitons will not exist due to screening effects; therefore, the photoexcited carriers should exist as an electron-hole plasma. We address this issue initially by considering the intensity dependence of the PL.

The intensity dependence of the photoluminescence spectra can be understood by analysis of a simple rate equation. The electron population in nonthermal equilibrium is described approximately by the equation

$$\frac{\delta(\Delta n)}{\delta t}=0=-\frac{\Delta n}{\tau}-R(n_0+\Delta n)(\Delta n)-R'(n_0+\Delta n)N_a+I\ , \qquad (1)$$

where n_0 is the equilibrium electron density, Δn is the photoexcited electron density (i.e., $n_{\text{total}}=n_0+\Delta n$), N_a is the density of the acceptor-bound holes, and I is the photoexcitation rate. The first term on the right models nonradiative decay, the second term models radiative decay

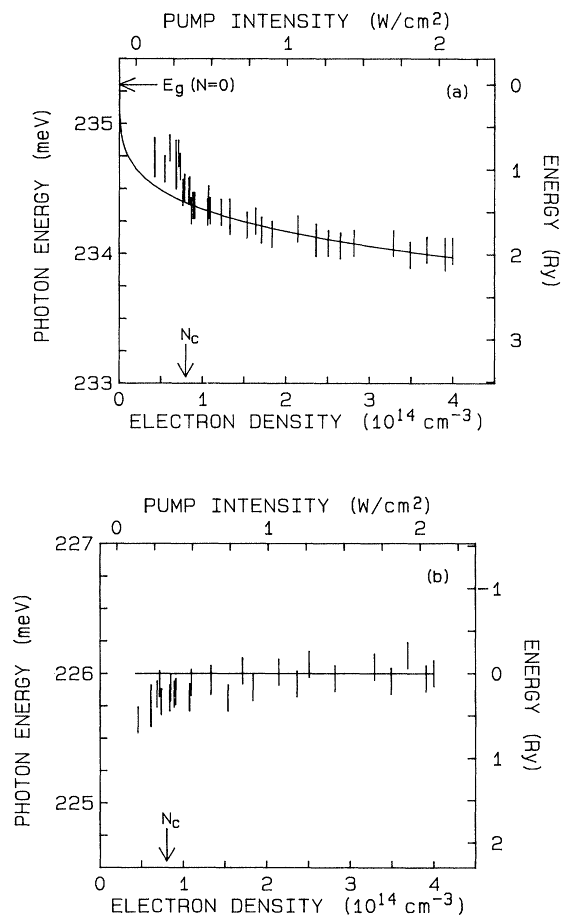

FIG. 2. Position of the LWHM as a function of pump intensity for (a) the 235-meV peak and (b) the 227-meV peak. Solid line (a) is the universal band-gap renormalization function of the Vashishta and Kalia, where a zero-density band gap of 235.3 meV is assumed. The solid line (b) is a straight line drawn for reference. The axis on the right is marked in units of exciton Ry. N_c is the Mott density and $E_g(n=0)$ is the band gap in the limit of zero carrier density.

between free electrons and holes, the third term models radiative decay between electrons and acceptor-bound holes, and the last term is the photoexcitation rate. For the intensity of the peak at 235 meV to be proportional to I^2, the conditions $\Delta n \gg n_0$ and $\Delta n \propto I$ must exist. These conditions are consistent with the observation that the 227-meV peak intensity is proportional to I, which requires $\Delta n \propto I$ and N_a=const. At low temperatures in samples of moderate compensation, one expects all of the acceptors to be occupied when $\Delta n \gg n_0$. This justifies the condition N_a=const. The $\Delta n \propto I$ condition implies that nonradiative decay is a more effective recombination mechanism than radiative decay.

In summary, the two most significant results of this rate equation analysis are (1) $\Delta n \gg n_0$ and (2) $\Delta n \propto I$. Since for our sample n_0 is only a factor of 4 smaller than the Mott density, this analysis implies $\Delta n > n_c$: The photoexcited system is on the metallic side of the Mott density.

B. Calculation of the carrier density spatial profile

A more quantitative method of estimating the photoexcited carrier density is to calculate the carrier density profile which results from the ambipolar diffusion of carriers after they are photoexcited at the semiconductor surface. We have studied numerically the following simplified model of the carrier dynamics:

$$\frac{\delta \zeta^h}{\delta x} = I_0 \kappa \exp(-\kappa x) - \frac{np}{\tau(n+p)} , \quad (2)$$

$$\frac{\delta \zeta^e}{\delta x} = I_0 \kappa \exp(-\kappa x) - \frac{np}{\tau(n+p)} , \quad (3)$$

$$D_e \frac{\delta n}{\delta x} = -\zeta^e - n\mu_e E , \quad (4)$$

$$D_h \frac{\delta p}{\delta x} = -\zeta^h + p\mu_h E , \quad (5)$$

$$\frac{\delta E}{\delta x} = \frac{4\pi e}{\epsilon}(p-n) . \quad (6)$$

Equations (2) and (3) are continuity equations and take into account carrier generation and recombination. The recombination term, which was reasoned above to be nonradiative, is a simplified form of the general term for Shockley-Read recombination.[10] Equations (4) and (5) are the current equations for carrier drift and diffusion. Equation (6) is the Poisson equation. The notation is as follows: n is the electron density, p is the hole density, ζ_e and ζ_h are the electron and hole current densities (i.e., the charge current density J normalized by the electronic charge), I_0 is the incident number of photons/cm^2, κ is the absorption length of the optical pump (0.25 μm for 1.064-μm radiation), τ is the nonradiative decay time, μ_e and μ_h are the electron and hole mobilities [μ_e=450 000 cm^2/V sec and μ_h=10 000 cm^2/V sec (Ref. 11)], D_e and D_h are the electron and hole diffusion coefficients,[12] and E is the electric field due to charge inhomogeneity.

The applicability of this numerical analysis is primarily limited by the validity of the following two initial assumptions. (1) The effect of surface recombination is negligible. We found that for a surface recombination velocity of 1×10^3 cm/sec, as suggested by Malyutenko *et al.*,[13] the calculated carrier densities decrease by only 10% from the values obtained for the case of no surface recombination. (2) The value of μ_h is assumed to be equal to 10 000 cm^2/V sec. Since the carrier diffusion length, and hence the carrier density, is determined primarily by the product of μ_h and τ, any error in the value of μ_n will result in a similar error in the value of τ. Although we cannot directly measure μ_h, the values of the hole mobility reported in the literature[11] are consistent with the assumption μ_h=10 000 cm^2/V sec to within 20–30 %.

We calculated the resulting density profiles for values of τ ranging from 15 to 400 nsec. Displayed in Fig. 3 are the calculated carrier densities near the surface as a function of pump intensity for various values of τ. We focus on the density near the surface as this is the region that contributes most strongly to the PL. The result of this calculation shows clearly that throughout most of the range of pump intensities investigated in this experiment and for all reasonable values of τ,[14] the carrier density of the photoexcited system is greater than the Mott density.

Our best estimate of the actual carrier density generated in the sample as a function of pump intensity is shown as the dashed line in Fig. 3. In this estimate we assumed that the carrier density is proportional to the pump intensity, as was reasoned above, and that the carrier density is 4×10^{14} cm^{-3} at the highest pump intensity. The last assumption was justified by fitting the spectra to a theoretical PL line shape, as will be discussed later in this paper. Comparison with the density-profile calculation suggests a value of τ of the order of 25 nsec. Although this value is faster than the radiative recombination times reported by Fossum and Ancker-Johnson[15] and McClure, Seiler, and Littler,[16] it is consistent with the fast decay observed by Dick and Ancker-Johnson.[17]

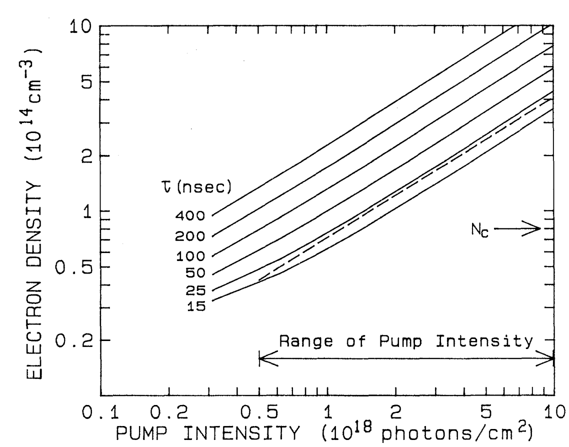

FIG. 3. The density of electrons near the sample surface as a function of pump intensity for various values of recombination time as calculated using the model described in the text. The dashed line is our best estimate of the actual carrier density of the photoexcited system. Comparison of the two calculations suggests a nonradiative recombination time of 25 nsec.

C. Band-gap renormalization

Both the intensity-dependence analysis and the density-profile calculation provide strong evidence that the photoexcited system is an electron-hole plasma. Electron-hole plasmas in semiconductors are known to exhibit band-gap renormalization due to exchange and correlation interactions.[18] Renormalization has recently been documented in both three-dimensional[19] and two-dimensional[20] GaAs-based systems. Vashishta and Kalia[21] proposed the following universal expression for band-gap renormalization:

$$\Delta E = \frac{-4.8316 - 5.0879 r_s}{0.0152 + 3.0426 r_s + r_s^2} , \qquad (7)$$

where ΔE is the renormalization energy normalized to the exciton rydberg, r_s is a dimensionless parameter defined as $(4\pi r_s^3 a_B^3)/3 = 1/n$, and a_B is the Bohr radius. In Fig. 2(a) we show a fit of Eq. (7) to the shift of the 235-meV peak. The carrier densities are determined in the manner described above. The fit neglected the few data points below the Mott density. The relevance of these points will be discussed below. The best fit is obtained using a zero-density band gap of 235.3 meV. This value agrees with the recent magneto-optical experiments of Littler *et al.*,[22] where they determine the band gap to be 235.2 meV. That we are able to reconcile the results of PL and magneto-optical experiments by considering renormalization effects is a strong argument in support of the thesis of this paper.

The observation that the acceptor peak does not shift significantly with increasing pump intensity is consistent with a renormalized system. As described by Haug and Schmitt-Rink,[18] the reduction of the binding energy of a bound system exactly cancels the renormalization of the band gap resulting in no appreciable shift of the PL peak. Although numerical analysis is required to determine this result in a degenerate electron-hole plasma, an analytical solution exists in the limit of nondegeneracy. The band-edge renormalization (ΔE_g) is simply the self-energy of an electron interacting with an electron gas. In the classical limit this self-energy is given by $\lim(r \to 0)[V_s(r) - V(r)] = -e^2 q_s = \Delta E_g$, where $V_s(r)$ is the statically screened Coulomb potential[23] and q_s is the screening wave vector. Similarly, the binding energy of the ground state of a hydrogenic atom in a weak Yukawa potential (i.e., $q_s a_b \ll 1$) is less than the rydberg, $E_{\rm Ry}$. The difference is given by the relation $E_{\rm Ry} + \Delta E_b = E_{\rm Ry}(1 - 2q_s a_b) = E_{\rm Ry} - e^2 q_s$. Consequently, the resulting shift of the PL peak is $\Delta E_g - \Delta E_b = -e^2 q_s + e^2 q_s = 0$. Although the limit of nondegeneracy is not immediately applicable, this analytical example provides physical insight.

The data for both the 227-meV peak and 235-meV peak deviate from theory at densities below the Mott density. Bound electrons (i.e., donor-bound electrons and electron-hole excitons) should exist below the Mott density. These bound electrons should alter the spectra in two significant ways. First, bound electrons are less efficient at screening than are free electrons. Any shift in the spectra due to screening by electrons should become smaller as the free electrons become bound. Second, these bound electrons should contribute to the low-energy edge of the PL spectra. Though we offer no quantitative analysis of the few data points below the Mott density, we emphasize that it is interesting that these data deviate from theory.

D. Line-shape analysis

PL line-shape analysis in this system has many complications.[24] In a nondegenerate system the spatial dependence of the carrier density does not significantly affect the line shape, as the linewidth is only sensitive to the density of states and the temperature.[25] For a degenerate system the linewidth is determined by the Fermi energy. This carrier-density-dependent linewidth significantly complicates the line shape of a degenerate system with a spatially dependent carrier density. This is especially relevant to InSb at 2 K because the electrons become degenerate at 1×10^{13} cm^{-3}. Fortunately, there are some qualitative arguments which simplify the problem. Band-to-band luminescence is proportional to the square of the carrier density. For this reason, luminescence from the region nearest the surface of the semiconductor (i.e., where the carrier density is largest) will dominate the spectra. In addition, the weaker luminescence from within the sample will have a narrower linewidth. Since both spectra have their onset at the band edge, luminescence from within the sample should be obscured under the center portion of the dominant luminescence. Fitting such spectra to theoretical line shapes which assume a homogeneous carrier density should provide reasonable estimates of (1) the band edge, which is determined by the low-energy edge of the spectra; (2) the Fermi energy of the carriers near the sample surface, which is determined by the spectral linewidth; and (3) the carrier temperature, which is determined by the high-energy edge of the spectra.

The line-shape problem becomes more complicated when one considers the effects of band-gap renormalization. In this case the spectral energy of the band-to-band luminescence decreases as the carrier density increases. Luminescence from within the sample may no longer be obscured. In fact such luminescence should distort the high-energy edge of the observed spectra. There are several generalities one can make from this qualitative description. (1) The low-energy edge of the luminescence will always be determined by the carrier density near the surface, which justifies the choice of the long-wavelength edge of the spectra as a measure of renormalization effects. (2) The linewidth of the luminescence should be determined by the larger of the renormalization energy E_r or the Fermi energy E_F of the carriers near the sample surface. (3) In the case $E_r > E_F$, the line shape will strongly depend on the carrier density profile, particularly the shape of the high-energy edge. (4) In the case $E_F > E_r$, the line shape should predominantly be determined by the carrier density near the surface, especially the low- and high-energy tails and the linewidth. (5) Theoretical PL line shapes should more accurately fit the experimental spectra as the pump intensity is increased. According to the renormalization formula of Vashishta and Kahlia, E_F exceeds E_r when $n > 3.5\times10^{14}$ cm^{-3}.

The theoretical line shape discussed by Capizzi *et al.*[19] was fit to the 235-meV peak of the PL spectra. Their theoretical PL line shape is given by the expression

$$I_{\rm PL}(\hbar\omega)=\int d^3k \int dE_e \int dE_h\, G_e G_h F_e F_h \times\delta(E_e-E_h-\hbar\omega)\ , \qquad (8)$$

where F_e and F_h are Fermi functions, and G_e and G_h are Lorentzian spectral density functions centered at energy $E_{e,h}(k)=\hbar^2k^2/2m_{e,h}$. Because the holes are nondegenerate at the carrier densities relevant to this study, it is justifiable to simplify the model slightly by treating G_h as a δ function at $E_h=\hbar^2k^2/2m_h$. This model fits the low-energy edge of the spectra very well when compared to the unbroadened PL line-shape model used by Mooradian and Fan.[5] Both models are depicted in Fig. 4. For purposes of comparing the theory with the experimental data, the theoretical models are convolved with a Gaussian which is used to model the instrument function of the monochromator.[26] While comparing the model of Capizzi *et al.* with the more traditional model of Mooradian and Fan, we concluded that the LWHM of the raw data provides a quick, reasonable estimate of the band gap. The data shown in Fig. 4 were taken with a pump intensity of 2 W/cm^2, the highest excitation intensity investigated in this study. The electron density that provides the best fit is 4.0×10^{14} cm^{-3}, which is in the regime $E_F > E_r$. The electron temperature, which is determined by the shape of the high-energy edge of the spectra, is 3 K. This rules out the possibility that the shift in the 235-meV peak is due to heating of the lattice.[27] The half-width at half-maximum of the electron spectral density function required to fit the spectra is 0.35 meV.

The line-shape analysis becomes progressively worse for spectra taken at lower pump intensities. In particular there are two noticeable problems. First, the high-energy edge of the spectra becomes broader as the intensity decreases, but it assumes a shape that cannot be fit by simply increasing the carrier temperature. Second, the linewidth of the spectra does not decrease as rapidly as one would expect if the electron density were proportional to the pump intensity and the linewidth was determined only by the electron Fermi energy. Both of these effects are consistent with the line-shape anomalies expected of a system in which there exist both band-gap renormalization and a spatially dependent carrier density. These observations suggest that it may be interesting to convolve the standard theoretical PL line shapes with calculated carrier density profiles and the associated band-gap renormalization. Because the renormalization effects are reasonably well understood, such an analysis may prove useful as a means of inferring the actual carrier density profile; however, such a calculation is beyond the scope of this study.

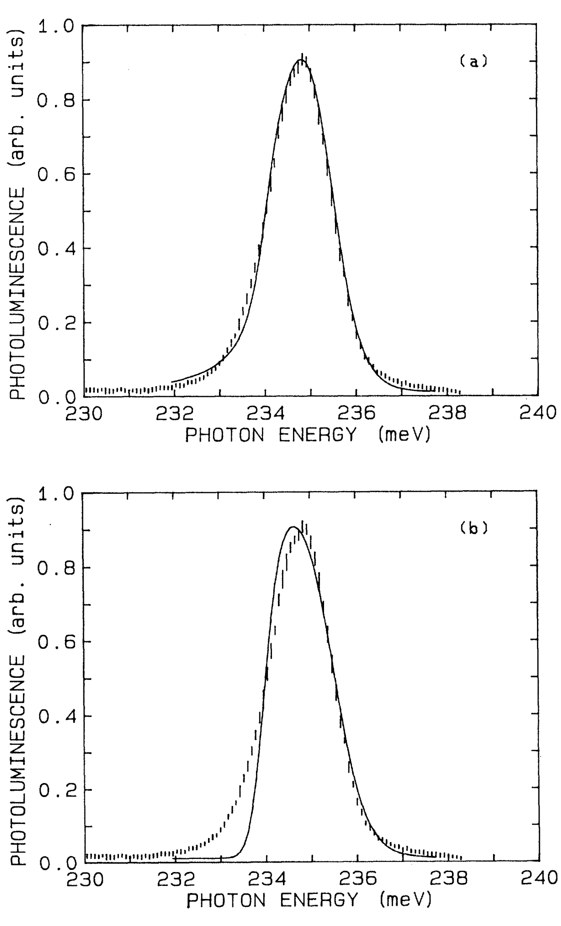

FIG. 4. The best fit of two theoretical line shapes to the PL spectrum of InSb at 2 K with 2 W/cm^2 pump intensity. (a) The line shape of Capizzi *et al.* and (b) the line shape of Mooradian and Fan. The relevant fitting parameters are $E_g=234.0$ meV, $n=4\times10^{14}$ cm^{-3}, and $T=3$ K.

E. Temperature dependence

We have also taken spectra at temperatures from 2 to 25 K. Shown in Fig. 5 is a fit of a spectrum taken at 15 K to the PL theory outlined by Mooradian and Fan. The only changes in the spectra observed by increasing the temperature are a broadening of the high-energy edge and a decrease of the band gap.[28] The exciton rydberg, $E_{\rm ex}=0.65$ meV, corresponds to an ionization temperature of 7.6 K ($E_{\rm ex}=k_BT$). One expects that a system of excitons would ionize in the temperature range investigated in this experiment. There is no change in the spectra that indicates such an ionization occurred. This further indicates that the photoexcited system is an electron-hole plasma at 2 K.

F. Comparison with previous photoluminescence experiments

We have summarized in Table I, to the best of our knowledge, all the low-temperature PL and MPL studies of low density ($n_0 < 10^{14}$ cm^{-3}) InSb that have been published within the last ten years. Also listed are the intensities of the photoexcitation sources used in these experi-

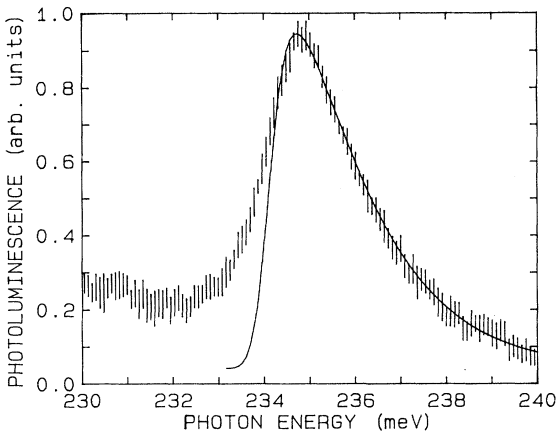

FIG. 5. Photoluminescence spectrum of InSb at 15 K with 1.1 W/cm^2 pump intensity. The solid line is a fit using the line shape of Mooradian and Fan. The relevant fitting parameters are $E_g=234.0$ meV, $n=3\times10^{14}$ cm^{-3}, and $T=15$ K. The dominant change in the spectra caused by raising the temperature is to broaden the high-energy tail

ments and the physical principles used by the authors to explain the data. All of the experiments are conducted at significantly higher pump intensity than this study (from 30 to 5×10^3 times more intensity). The results of these experiments break up into two distinct groups. Ivanov-Omskii *et al.*,[6] Seisyan and Yuldashev,[7] and Kavetskaya and Sibel'din[8] all base their interpretations of the spectra on the assumption that the ground state of the photoexcited system in zero-magnetic field consists of bound systems, either Wannier excitons (Refs. 6 and 7) or electrons bound to shallow donors (Ref. 8). It is worth noting that these experiments are conducted at excitation levels 300–5000 times larger than our experiment, as measured in terms of photons/cm^2 sec. Bresler and co-workers[9] conclude that the photoexcited system they study is an electron-hole plasma. They base this conclusion on the observation of band-gap renormalization when comparing the spectra of differently doped samples. Unfortunately, Bresler's experiments are conducted using two-photon absorption as the photoexcitation mechanism. This makes difficult a direct comparison of the photoexcited carrier densities generated in Bresler's experiments with the carrier densities photoexcited in the other experiments. Our experiment allows a direct comparison to the experiments of those in Refs. 6–8. In particular, our results provide strong evidence that the photoexcited system exists as an electron-hole plasma even at very low photoexcitation rates contrary to the analysis provided in the papers by the authors in Refs. 6–8.

IV. CONCLUSION

We have extended photoluminescence of InSb to pump intensities as low as 100 mW/cm^2, 30–5000 times less

TABLE I. Summarized here are the photoluminescence experiments on bulk InSb which have been published within the last ten years. We list the laser-pump intensities used in the experiments and the author's description of the photoexcited electron-hole system.

Reference	Intensity (W/cm^2) (at photon energy)	Intensity (10^{19} photons/cm^2)	Relevant physics of photoexcited system as described by the authors
Ivanov-Omskii *et al.*[a]	110–550 (at 1.38 eV)	50–250	Wannier exciton
Seisyan and Yuldashev[b]	441 (at 1.38 eV)	200	Wannier exciton
Kavetskaya and Sibel'din[c]	10 (at 0.366 meV)	17	Donor bound electrons
Kavetskaya *et al.*[d]	500 (at 1.24 eV)	250	Do not discuss zero-field state; however, they claim an electron-hole liquid exists at 4.6 T
Bresler *et al.*[e]	Not relevant; these experiments used two-photon excitation		Electron-hole plasma
Rowell[f]	3.17–25.4 (at 2.410 eV)	0.82–6.58	Noncommittal, but suggests exciton; the lowest temperature investigated in this study is 5 K
This paper	0.1–2.0 (at 1.24 eV)	0.05–1.0	Electron-hole plasma

[a]Reference 6.
[b]Reference 7.
[c]Reference 8.
[d]Reference 29.
[e]Reference 9.
[f]Reference 30.

than any previously reported result. We observed strong luminescence from free-electron to free-hole recombination and from free-electron to acceptor-bound hole recombination. From the intensity dependence of the PL we determine that nonradiative recombination is the dominant recombination process at 2 K. By correlating the results of a carrier density-profile calculation with PL line-shape analysis, we infer that the time constant for the nonradiative recombination is of the order of 25 nsec. Based on the PL intensity-dependence analysis, PL line-shape analysis, and carrier density-profile analysis, we conclude that the photoexcited system exists as an electron-hole plasma. In strong support of this thesis, we correlate the intensity-dependent shift of the band-edge PL with the universal model for band-gap renormalization proposed by Vashishta and Kalia. The value of the band gap extracted from this analysis, $E_g = 235.3$ meV, agrees very well with the recent magneto-optical results of Littler *et al.* The results of this study show that it is very easy to photoexcite undoped InSb to carrier densities larger than the Mott density without significantly heating the carriers. This suggests that magnetophotoluminescence studies of InSb may lead to the direct observation of magnetic-field-induced transition from an electron-hole plasma to an excitonic gas.

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