Free-Carrier Radiation Peak in GaAs Due to Valence-Band Maxima Arising from Terms Linear in *k*

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A new peak has been observed 0.4 meV above the direct band-to-band–transition radiation at 1.5202 eV in the 1.4°K photoluminescence spectrum of high-purity epitaxial GaAs. This new peak is attributed to the recombination of free electrons of nonzero **k** with free holes in the linear-*k* valence-band maxima, which are estimated to be $\approx 3\times10^5$ cm^{-1} away from and $\lesssim 1\times10^{-4}$ eV above the $\mathbf{k}=0$ maximum.

IMPROVED experimental technique has resulted in the observation of a radiation peak additional to those already reported[1] for low-temperature (1.4°K) photoluminescence in high-purity GaAs.[2] The signal-to-noise ratio of the detector system has been increased by cooling a photomultiplier of smaller photocathode area (RCA C70102B) with liquid N_2 instead of solid CO_2.

The new peak L is observed about 0.4 meV above the line $E_G=1.5202$ eV ± 0.3 meV, which we previously identified[1] with the direct band gap at Γ (Fig. 1). That L is not due to a splitting of the free-carrier line by a residual strain is demonstrated by its observation at the same position, both absolute and relative to E_G, in different samples. The possibility that L, rather than E_G, should be identified with the direct gap at Γ is ruled out because the remaining intrinsic lines observed, which must be free-excition lines, do not yield a hydrogenic energy spectrum relative to L, whereas they do relative to E_G.[1]

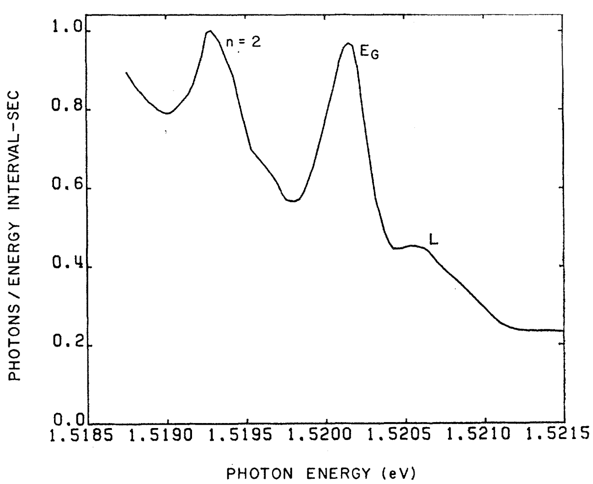

FIG. 1. Near-band-gap photoluminescence spectrum of high-resistivity GaAs (619940-5) at 1.36°K with 0.15-meV resolution. A neutral optical density 1 filter was present in the illuminating beam.

We believe that L arises from the recombination of free electrons of nonzero **k** with free holes in the linear-k valence-band maxima. Most of the energy difference between L and E_G is attributed to the large curvature of the conduction band ($m_e^*\approx 0.066$). Neither the position k_m nor the energy ϵ_m of a [111] linear-in-k maximum in GaAs is known, but they are expected to be smaller than the corresponding values $k_m\approx 3.8\times10^5$ cm^{-1}, $\epsilon_m\approx 1\times10^{-4}$ eV for InSb,[3] since[4,5] $k_m\sim\Delta_{so}a/Z$ and $\epsilon_m\sim(\Delta_{so}a/Z)^2$. Here Δ_{so}, a, and Z denote, respectively, spin-orbit splitting of the valence bands, lattice parameter, and atomic number. From our data, we can estimate k_m in GaAs if we assume first that $\hbar^2k_e^2/2m_e^*\approx 0.4$ meV, i.e., $\epsilon_m \ll L-E_G$, and secondly that $k_e\lesssim k_m<k_e+k_{h\nu}$, where e and $h\nu$ indicate electron and photon, respectively. We choose the latter inequality rather than $k_e+k_{h\nu}=k_m$ because $k_{h\nu}$ affects the position of both the E_G line and the L peak, not just the position of L alone. Taking the refractive index of GaAs as ≈ 3.5, we find $2.6\lesssim k_m<5.3\times10^5$ cm^{-1}. Since this estimate is of the right order, it follows that $\epsilon_m\lesssim 1\times10^{-4}$ eV for GaAs.[6]

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[1] M. A. Gilleo, P. T. Bailey, and D. E. Hill, Phys. Rev. **174**, 898 (1968).

[2] The GaAs was supplied by F. V. Williams and K. L. Lawley.

[3] C. R. Pidgeon and S. H. Groves, Phys. Rev. Letters **20**, 1003 (1968).

[4] G. Dresselhaus, Phys. Rev. **100**, 580 (1955).

[5] E. O. Kane, J. Phys. Chem. Solids **1**, 249 (1957); in *Semiconductors and Semimetals*, edited by R. K. Willardson and A. C. Beer (Academic Press Inc., New York, 1966), Vol. 1, p. 95.

[6] W. E. J. Pinson [Bull. Am. Phys. Soc. **14**, 417 (1969)] has studied intervalence-band infrared absorption in GaAs whose acceptor concentration was $N_A=2.5\times10^{16}$ cm^{-3}, much higher than that of any of our samples. Pinson concluded that $k_m\approx 5\times10^6$ cm^{-1} and $\epsilon_m\approx 5\times10^{-3}$ eV.