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Photoluminescence measurement system using fiber optics

A. K. Srivastava

Tata Institute of Fundamental Research, Homi Bhabha Road, Bombay 400005, India

A. Bandyopadhyay

Institute of Radio Physics and Electronics, Calcutta University, 92 A. P. C. Road, Calcutta 700009, India

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We describe a novel photoluminescence measurement apparatus which incorporates an optical fiber for carrying both the excitation beam and the luminescence from the sample. The advantages of the optical fiber makes the system very versatile and suitable for sensitive measurements. The collection efficiency of the setup is demonstrated to be the same as that of a conventional setup. Several photoluminescence spectra of III-V compounds recorded using the apparatus are also included to demonstrate its applicability over a wide wavelength range (0.8–2.0 μm).

INTRODUCTION

Photoluminescence is a very widely used technique for optical characterization of semiconductors.[1] In a conventional measurement setup, the sample is excited by a laser and the luminescence from the sample is collected by a lens and the spectral analysis is done using a monochromator. Availability of high quality silica fiber having very low transmission loss in the wavelength range 0.5–2.0 μm, has made a strong impact on optical instrumentation. In addition to the high transparency of the fiber, its ability to carry the optical signals in and out of cryogenic apparatus dispenses with the need of optical windows for low temperature studies. Recently, cathodoluminescence[2] and photoluminescence[3] spectrometers based on optical fiber, have been reported. In the photoluminescence apparatus reported by Whalen *et al.*,[3] the excitation laser beam and the luminescence emitted from the sample are transmitted through the same fiber. The excitation beam is coupled to one of the four ends of a directional coupler and half of the intensity reaches the sample which is placed at one of the remaining three ports of the coupler. The luminescence emitted by the sample is collected by the same port and half of this intensity arrives at one of the remaining two ports and is fed to a monochromator for spectral analysis. While the measurement system has many advantages including high collection efficiency and ease of operation, it suffers from two drawbacks: (i) the luminescence intensity available for measurement corresponds to only a quarter of the power launched in the excitation port and (ii) strong wavelength dependence of the transmission through the directional coupler requires the measured spectra to be corrected. We demonstrate a novel design for the photoluminescence measurement system which overcomes the above drawbacks. The collection efficiency of the setup, using a microlensed fiber, is shown to be nearly the same as that of a conventional instrument with $f/1.0$ collection optics, where the sample is placed at the focus of the collecting lens. This combined with the advantages of fiber optics, like the ability to carry an optical signal in and out of environments like low or high temperatures, high magnetic field etc., make the apparatus very versatile and suitable for high sensitivity measurements. We have used this spectrometer to obtain photoluminescence spectra of several III-V compounds both at room temperature and liquid nitrogen temperature.

I. EXPERIMENTAL APPARATUS

A schematic diagram of the experimental setup is shown in Fig. 1. A 4 mW Helium-Neon laser is used as the excitation source. The excitation beam is passed through an optical chopper and a laser line filter (LF) which selects the 632.8 nm line. After the line filter, the laser beam (1.5–2.0 mm diam) falls on a small (2×2 mm) mirror (M) which deflects it along the axis of a lens (L1). The lens is 25 mm in diameter and it has a focal length of 30 mm. The beam is focused onto a cleaved multimode fiber end (core diameter 50 μm). To facilitate proper alignment and focusing, the fiber is attached to an x-y-z translator. The laser power available on the other end of the fiber is about 2 mW which is consistent with the losses due to the line filter, mirror reflectivity and reflections at the lens and fiber ends. The other end of the fiber is either cleaved or microlensed. The microlensing is achieved by etching the fiber end in hydrofluoric acid and fire polishing. This end of the fiber is also attached to an x-y-z translator for controlled variation of its position with respect to the sample. The sample is attached to a metal block inside a liquid nitrogen dewar. The luminescence emitted from the sample is collected by the fiber end and is transmitted. The luminescence exiting from the other end of the fiber diverges in a cone governed by the numerical aperture (NA = 0.2) of the fiber. The luminescence is collimated to nearly 12 mm diam beam by the lens (L1). A small fraction ($\simeq3\%$) of the luminescence is obscured by the mirror (M). A second lens (L2) having a focal length of 63 mm focuses the beam onto the input slit of a monochromator. The $f/\#$ of lens L2 is matched with that of the concave mirror (4.7) inside the monochromator. The luminescence is detected by either a silicon or a liquid nitrogen cooled germanium detector depending upon the sample. Conventional phase sensitive detection technique using a lock-in amplifier is employed to measure the signal. The data can be recorded either by a strip chart recorder or by an IBM compatible PCXT interfaced to the lock-in amplifier and monochromator driver/indexer.

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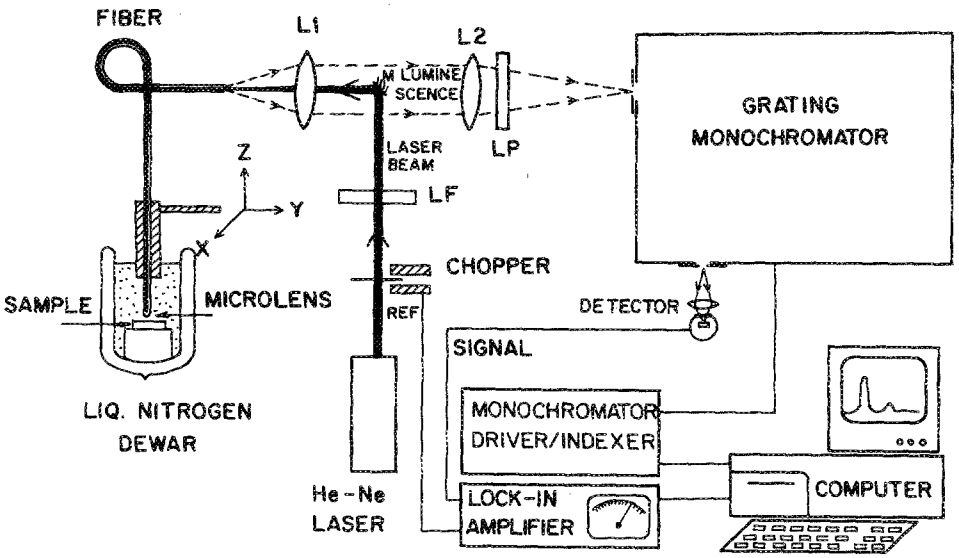

FIG. 1. A schematic diagram of the optical fiber based photoluminescence measurement system.

II. RESULTS

The luminescence spectrum recorded using the above described system for GaAs:Zn ($p = 7\times10^{17}\,\mathrm{cm}^{-3}$) at room temperature is shown in Fig. 2. The fiber is cleaved and it is placed butt against the sample. The measured intensity of luminescence is nearly 3–4 times smaller than that recorded in a conventional measurement system with F No. 1 collection optics[4] and using identical excitation power. On making a microlens at the sample end of the fiber, the collected luminescence intensity increases by a factor of 3.3 (as compared to cleaved fiber case). The enhancement in the luminescence intensity in the case of the microlensed fiber is due to the reduction in the excitation spot size and the efficient collection of luminescence by the microlens. The effect of microlensing is shown in Fig. 3 where the luminescence intensity for GaAs sample at peak wavelength (0.90 μm) is plotted as a function of distance Z between the sample and the fiber end. For a plain cleaved fiber, the luminescence intensity monotonically reduces as a function of the distance. For the two microlensed fibers having different radii of curvature (R),[5] the intensity goes through a maximum at a distance corresponding to the focal length of the microlens. The maximum in the intensity occurs at a larger distance for a microlens having a larger radius of curvature. Moreover, the laser beam diverges after the focal plane of the lens. The divergence is larger for a lens with a smaller focal length. The effect of this divergence is also evident from the Z dependence of luminescence. After the focal plane, the luminescence intensity decays sharply with distance for the lensed fibers. The sharpness of decay is larger for the smaller focal length microlens. The maximum intensity (3.3 times that of the cleaved fiber) was recorded for the smaller focal length lens. For comparison, the PL intensity for the same GaAs sample recorded at peak wavelength (0.90 μm) in a conventional setup using identical excitation power is also indicated in Fig. 3. The signal recorded using a microlensed fiber with sample at its focal plane is essentially the same as that obtained in the conventional system.

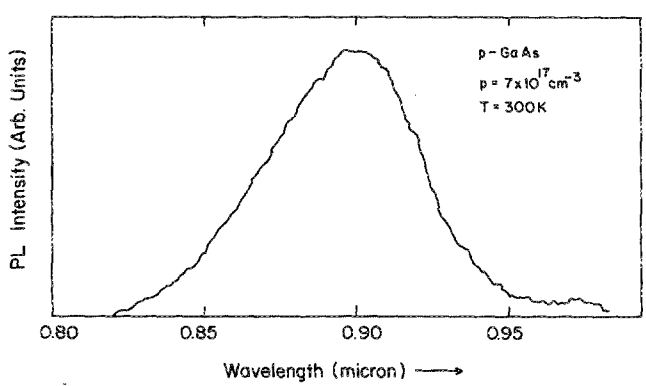

FIG. 2. Room temperature photoluminescence spectrum of p-GaAs, recorded using the novel setup and a silicon detector.

Figure 4 shows the PL spectra of undoped InP ($n = 2$–$3\times10^{16}\,\mathrm{cm}^{-3}$) at room temperature and liquid nitrogen temperature. At low temperatures, the emission due to residual Zn acceptor is clearly seen (at 0.90 μm) in addition to the band-to-band emission (at 0.88 μm). The LO phonon replica of the band-to-acceptor transition is also clearly seen (at 0.93 μm). Figure 5 shows the luminescence spectrum of an undoped GaSb sample ($p = 2\times10^{17}\,\mathrm{cm}^{-3}$) at 77 K, recorded using a liquid nitrogen cooled Ge detector. Here again, a well resolved acceptor peak (at 1.58 μm) is visible in addition to the band-edge luminescence peak (at 1.55 μm). The fiber used in both cases is microlensed and the intensity of luminescence is similar to that recorded in a conventional system. This clearly demonstrates the ability of the system to measure longer wavelength luminescence. For our fiber which has a loss of 2 dB/km at 1.8 μm, we expect that the measurement system should work up to well beyond 2 μm wavelength without noticeable transmission loss. For longer wavelength measurements, however, strong absorption peaks of water vapor and carbon dioxide would require that the entire luminescence beam path, in conventional setup, be purged with dry nitrogen. With the availability of fluoride glass fiber having low transmission loss in the mid infrared

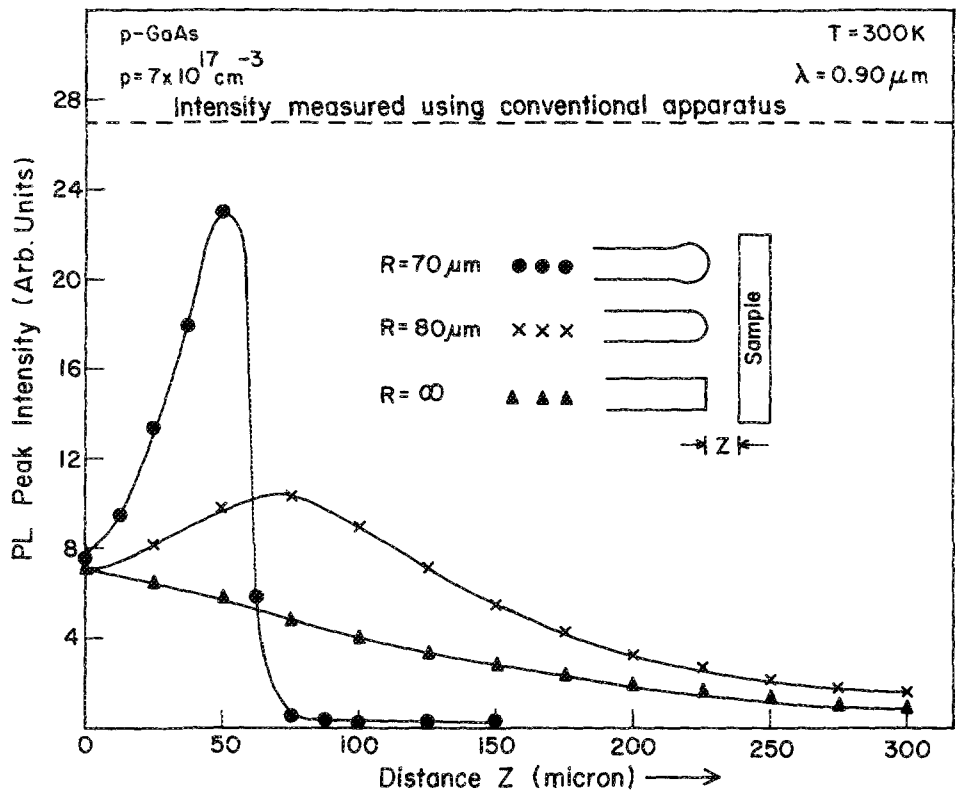

FIG. 3. Dependence of the measured luminescence intensity on the separation Z between the sample and fiber for both the cleaved and microlensed cases. The sample is p-GaAs and the measurements are made at the peak wavelength of 0.90 μm. The intensity recorded for the same sample in a conventional measurement setup under identical excitation condition is also shown by a dotted line.

(2–5 μm) wavelength range, the above measurement system can be easily extended for longer wavelength studies.

The system can be very easily adapted for measurements at very low or high temperatures or under high magnetic fields. Unlike a conventional system, there is no vacuum chamber required for housing the samples. This allows a large throughput for measurements and is very useful in industrial environments.

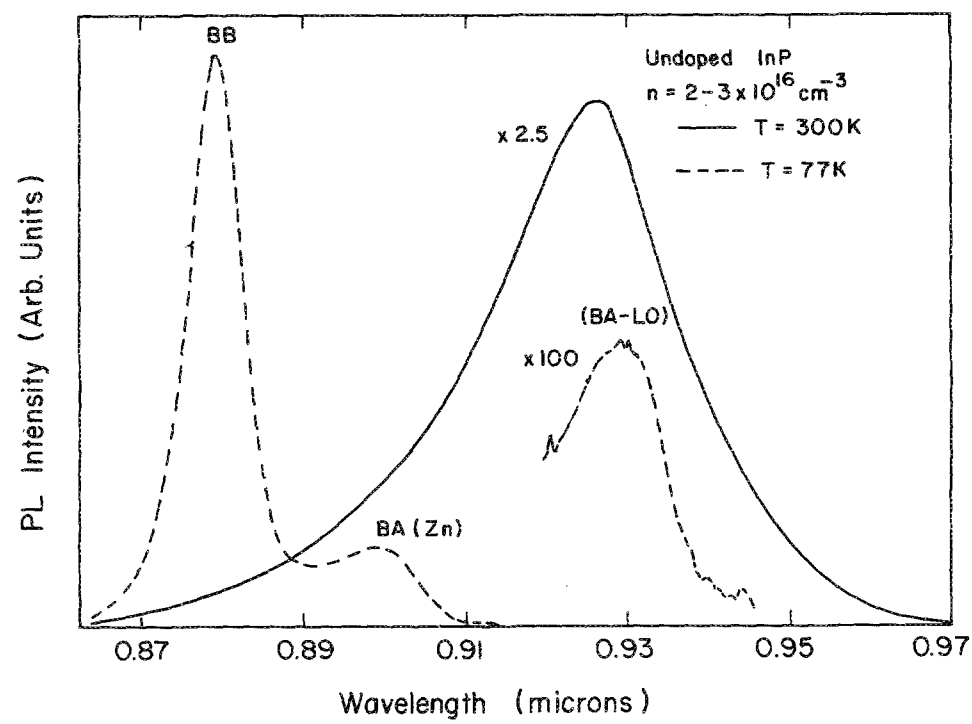

FIG. 4. Photoluminescence spectrum of undoped InP at room temperature and liquid nitrogen temperature, recorded using the novel setup and a silicon detector.

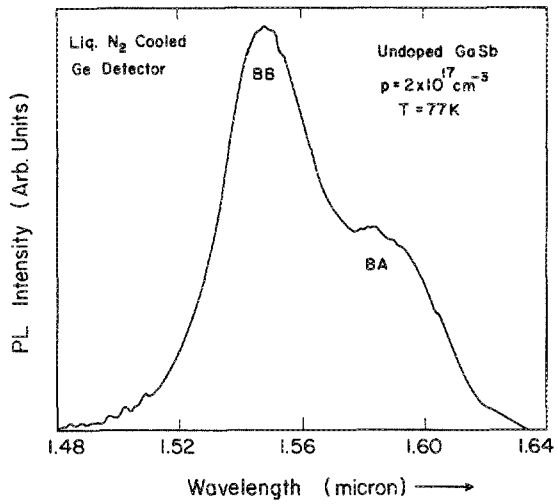

FIG. 5. Photoluminescence spectrum of undoped GaSb at liquid nitrogen temperature, recorded using the optical fiber based setup and a cooled germanium detector.

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[1] P. J. Dean, Prog. Cryst. Growth Charact. **5**, 89 (1982).
[2] M. E. Hoenk and K. J. Vahala, Rev. Sci. Instrum. **60**, 226 (1989).
[3] M. S. Whalen and M. J. R. Martyak, Appl. Phys. Lett. **53**, 1162 (1988).
[4] For details see A. K. Srivastava, Indian J. of Pure Appl. Phys. **26** (in press).
[5] The microlenses are highly non-spherical in shape and thus the radii of curvature of the microlenses given here are approximate and indicate the relative curvature of lenses.