

High-Resolution Low-Temperature PL of Semiconductors

OSD-110

ELEMENTAL ANALYSIS
FLUORESCENCE
GRATINGS & OEM SPECTROMETERS
OPTICAL COMPONENTS
FORENSICS
PARTICLE CHARACTERIZATION
RAMAN
SPECTROSCOPIC ELLIPSOMETRY
SPR IMAGING

Characterize defects and
impurities in semiconductors

Introduction

Temperature-dependent photoluminescence (PL) spectroscopy is a powerful optical method for characterizing materials. PL can be used to identify defects and impurities in Si and III-V semiconductors, as well as determine semiconductor bandgaps. At room temperature, PL emission is usually broad—up to 100 nm in width. When samples are cooled, structural details may be resolved; a small spectral shift between two samples may represent a difference in structure. For cooling, two types of cryostat typically are used: a cryostat using liquid N₂ or liquid He, or a closed-cycle cryostat in which cryogenic liquid is included as part of the cooling system. The cooled sample is excited by a laser, and the PL is coupled to a spectrometer via an optical interface. In this Technical Note, sample data are shown from a high-resolution PL system.

Experimental setup

A 1 m focal-length monochromator (1000M Series II, 600 gr/mm grating) scanned from 800–1650 nm. The detection system was a thermoelectrically cooled InGaAs detector with chopper and lock-in amplifier. Semiconductor samples were mounted in a closed-cycle cryostat mounted above the optical table, and cooled to 4.5 K. A HORIBA Scientific Low Temperature Cryostat Interface optimized the optical coupling into the monochromator. The excitation source was a 10 mW HeNe laser ($\lambda = 632.8$ nm). Fig. 1 shows the experimental apparatus.

Results

Fig. 2 shows spectra of the same sample measured at room temperature and at 4.5 K. In PL spectroscopy, a material absorbs light, creating an electron-hole pair. An electron from the valence band jumps to the conduction band, leaving a hole in the valence band. The photon emitted upon recombination corresponds to the

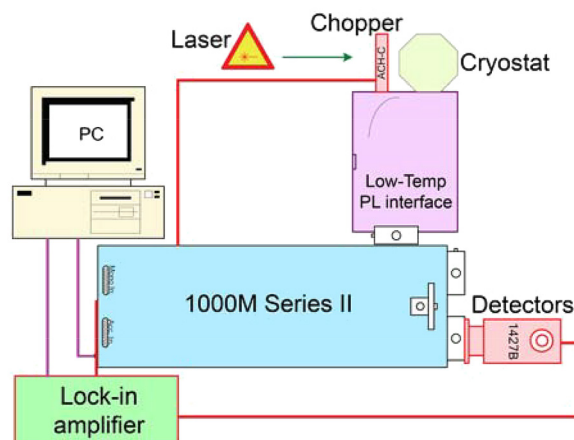
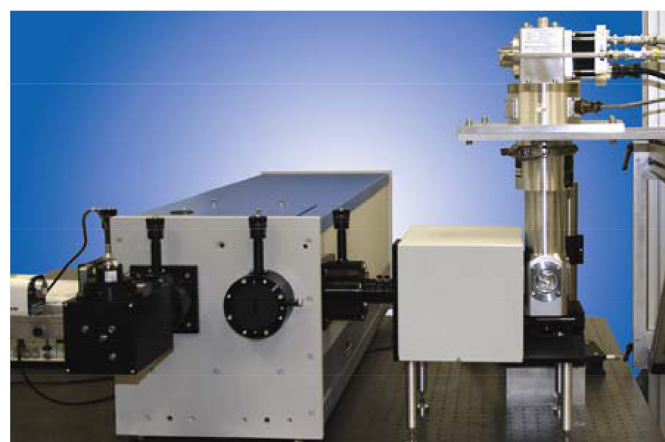


Figure 1. Experimental system.

energy-difference between the valence and conduction bands (bandgap), and is hence lower in energy than the excitation photon, so that the emission is red-shifted with respect to the excitation light. At low temperatures, a PL peak is quite sharp. As the temperature increases, the peak broadens and shifts to lower energy. This red-shift, typical for such materials, indicates bandgap

shrinkage as a function of temperature. The decrease in peak intensity indicates that electrons escape via non-radiative processes.

Fig. 3 compares PL spectra from a sample of Nd:YAG laser-glass, using the 1000M Series II (1 m focal length) and the iHR320 (0.32 m focal length) spectrometers. Note the sharper peaks recorded with the 1000M system.

System components

In order to measure photoluminescence of semiconductors, the following are needed: a stable, powerful monochromatic light source, optics to focus light on the sample, a sample holder, collection optics, a spectrometer, and a detector for spectral analysis. The Low Temperature PL Optical Interface from HORIBA Scientific provides a stable collection-optics system, to collect the maximum amount of light from the sample inside either type of cryostat, and couple it efficiently into the spectrometer. Benefits include:

- Reflective optics for maximum light collection
- Compatible with M-Series, iHR320/550, and FHR640/1000 spectrometers
- Mounts directly on the spectrometer entrance slit
- Compatible with most cryostats with 90 mm dia. bodies
- Input f/1.5, output f/7.5
- Filter-holder included [standard 1" (2.5 cm) filter]

HORIBA Scientific component	Part number
Low Temperature PL Optical Interface	ACC-CRYO-1000M
1000M Series II, 2 entrance and 1 exit slits	1000M II
Optical Chopper	ACH-C
Lock-in Amplifier	SR810
Solid-state detector interface	1427C
Thermoelectrically cooled InGaAs photodiode	DSS-IGA020T
SynerJY® spectroscopy software	CSW-SYNERJY
Closed-cycle He cryostat	Contact us
Cryostat-mounting hardware	Contact us

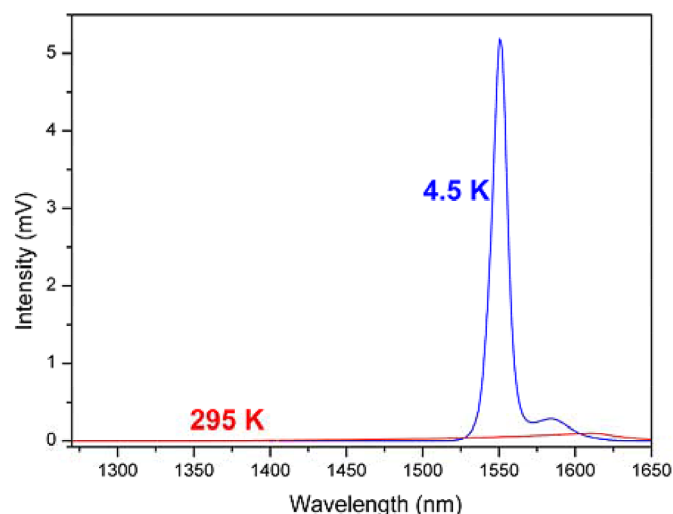


Figure 2. PL from typical semiconductor sample at room temperature, and also cooled to 4.5 K.

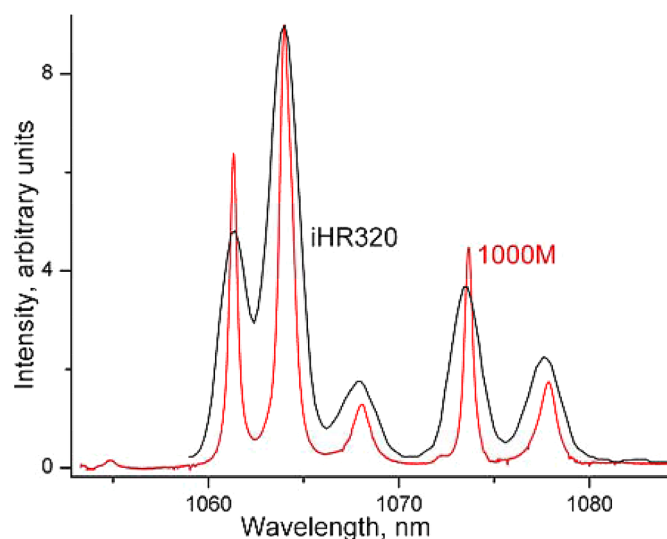


Figure 3. PL spectra of Nd:YAG laser-glass, taken with (black) iHR320 spectrometer and (red) 1000M spectrometer.