Analyzing Surfaces and Interfaces using Photoluminescence

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Abstract

When excited optically, some substances give forth light on their own. Excitation energy and intensity are utilized to probe sample areas and excitation concentrations. Multiple qualities of a material may be described via PL. For the purpose of electrical characterization, PL spectroscopy may selectively and sensitively investigate individual electronic states. Emission spectra are useful for characterizing alloys in terms of their degree of disorder, interface roughness, surface, and interface impurity. The strength of the PL signal provides information about the surface and interface. The lifespan of the nonequilibrium interface and bulk state during pulsed stimulation is determined by the strength of the transient PL. By manipulating the PL intensity while the sample is biased, the surface electric field may be mapped. PL intensity is temperature-dependent due to thermally induced processes. Analyzing PL without causing damage. There is minimal sample manipulation and no controlled environments required for this method. Optical excitation of the sample eliminates the need for low-permeability materials. In addition, time-resolved PL.

Keywords: Photoluminescence (PL), Temperature, Multilayer material, Thermally induced.

1. Introduction

Multilayer material solutions enable smaller, faster, and more efficient electronic and optoelectronic devices [1]. Multilayer designs change interface electron and hole potential energy. Heterojunctions limit excitation behavior in microelectronic devices. Smooth, atomically abrupt surfaces are ideal for optical and electrical reflection, quantum confinement, and high carrier mobility. Interface flaws and impurities impact electron, hole, and other charged particle mobility, lifespan, and transition energies. Photons and electronic excitations result from high-energy light hitting a substance. Electrons revert to ground state after excitation subsides [2-5]. PL is launched during PL can track any surface in any scenario. Unlike many surface characterization approaches, PL is usually insensitive to sample chamber pressure [6]. Thus, it can be used to study surface attributes in high-pressure semiconductor growing reactors. Many applications can employ room-temperature observations, but PL's maximum spectral resolution requires liquid helium. The surface minimally

impacts PL [7]. Modest excitation levels limit sample heating and photoinduced effects.

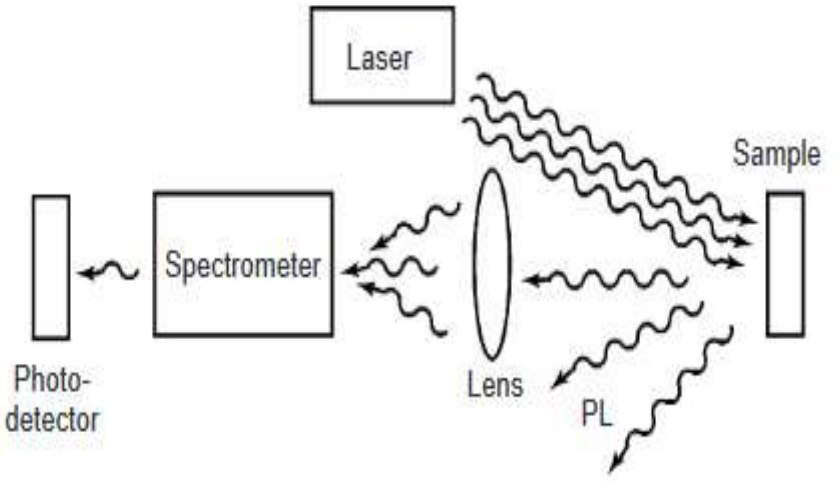

Figure 1 Typical experimental set-up for PL measurements.

Figure 1. Typical experimentally setup for Photoluminescence (PL) measuerments.

2. Photoluminescence Excitation

The absorption of a material depends on the energy of the incident light, which can be used to distinguish surface and bulk contributions [8]. Photoluminescence excitation spectroscopy (PLE) is used to study epilayers on opaque substrates, and Stoke's shift is used to test whether excitation at the higher energy peak yields emission from the lower energy peak [9]. Interface recombination velocity S is independent of carrier density and layer thickness, and can be used to compare interface recombination in a variety of materials. Surface passivation has been studied extensively, with techniques such as epitaxial growth and chemical surface treatments [10]. Quantitative information on S requires more sophisticated techniques, such as investigations of the excitation intensity dependence of PL [11].

Komiya et al. measured the excitation-intensity-dependent PL signal from a series of InGaAsP/InP double heterostructures to distinguish between two mechanisms for carrier generation in the buried layer [12]. An alternative technique has been developed to measure the absolute radiative efficiency of an InGaAs/InP double heterostructure with an integral substrate reflector [13].

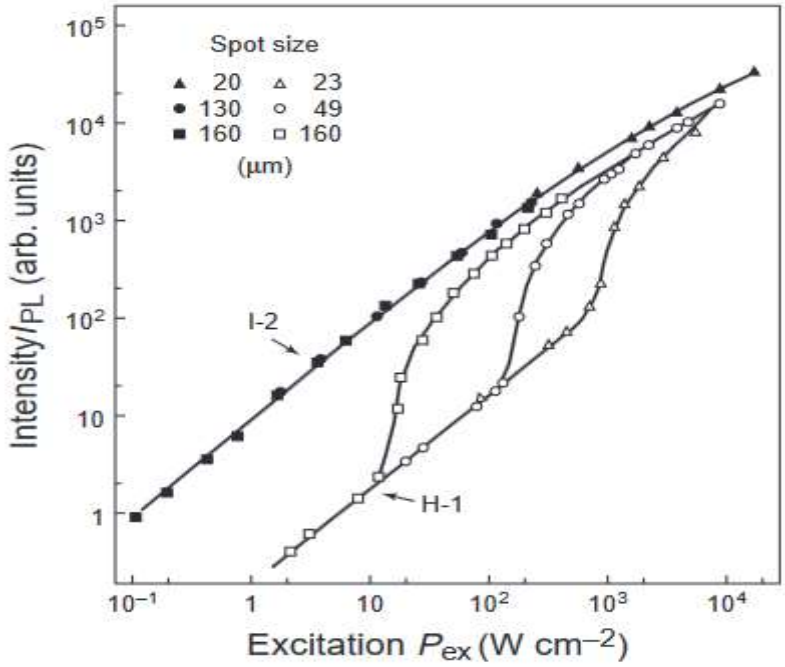

Figure 2. The relationship between excitation power and PL intensity for two distinct materials.

Saitoh et al. have developed an elaborate model of carrier behavior near the surface of the semiconductor that accounts for carrier transport, surface state occupation, band bending, and recombination [14]. Excitation-intensity-dependent PL can also be used to study the properties of QWs, estimate nonradiative decay time, determine the relative density of different radiative states, and evaluate interface band alignment. Vignaud et al. observed a dramatic blueshift in the PL from InAlAs/InP heterostructures due to spatially indirect type II transitions across the interface [15-16].

3. Photoluminescence Spectrum

Optical transitions provide direct access to the energy level structure of a system, with photons of a particular energy being absorbed or emitted by a sample. PL emission tends to favor sparse low-lying states, making it particularly effective in the analysis of interfaces where discrete defect and impurity states abound [17]. Defects and impurities break the periodicity of the lattice and perturb the band structure locally, resulting in a discrete energy level within the bandgap. Deep levels tend to facilitate nonradiative recombination by providing a stop-over for electrons making their way between the conduction and valence bands. Destructive depth profiling can be accomplished by step-etching and measuring the PL vs. etch depth [18].

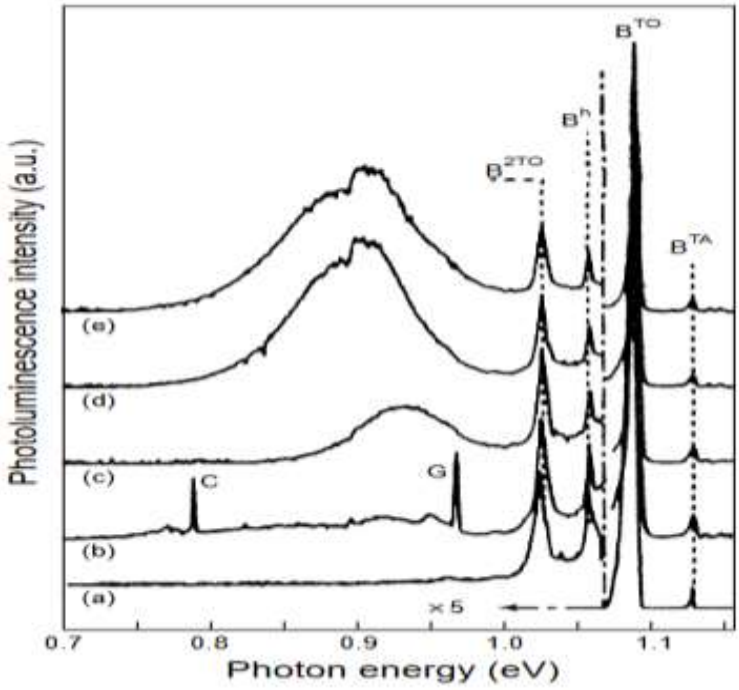

Figure 3. PL spectra of B-doped Si exposed to (a) 80% He-20% HBr, (b) CF4, (c) Ar, (d) Ar-D2, and (e) D2.

Reactive ion etching (RIE) can cause various types of defects in the near-surface region, and PL analysis is useful in identifying and controlling them. Mesrine et al. showed that line broadening and splitting in QWs can be explained by two growth-related mechanisms: As/P exchange at interfaces and surface segregation on GaInP layers [19]. Two mechanisms contribute to lateral variation in the QW properties: alloy disorder in the well or barrier layers, and interface roughness [20]. Fergusonet al. studied the effects of a misoriented substrate and growth interruption on the variation in QW line width against well thickness L. Woods et al. studied the PL of InGaAsP/InGaAsP QWs and found that the broadening was attributed to alloy composition variation in the well and barrier layers. Patane et al. found that alloy disorder and interface roughness are required to fit the L dependence of InxGa1-x As/GaAs PL lines.

4. Photoluminescence Intensity

The intensity of the PL signal has received the most attention in interface analysis due to its correlation with good interface properties. Chang et al. review the roles of the surface recombination velocity S and band bending at the surface in the PL measurement [21]. In situ PL intensity measurements are an important in situ evaluation tool, as they are nondestructive and environment-insensitive. Surface-adsorbate-induced changes in PL intensity can be used to infer the partial pressure of a gaseous species that adsorbs to a semiconductor surface. Excitation-dependent shifts in the flatband potential have also been reported for the GaAs/electrolyte interface [22-24].

Spatially resolved PL measurements are usually accomplished by scanning the optical excitation spot relative to the sample surface and detecting the PL signal in the far

field [25]. This application is particularly useful in the evaluation of substrate surfaces, where detection of electrochemically active features can help to control problems in epitaxial devices. Krawczyk et al. demonstrated this approach in an investigation of InP surface treatments [27]. High-speed rastering with resonant mirrors or acousto-optic devices can generate frames at standard video rates, allowing PL images to be observed in real time. The spatial dependence of the PL spectrum itself can be used to evaluate uniformity of alloy composition, epilayer thickness, and other material properties [28].

Photogenerated carrier lifetimes are obtained by monitoring the transient PL signal after pulsed excitation. There are three general mechanisms for recombination in semiconductors: SRH transitions via intermediate states, radiative events, and Auger scattering. Time-resolved PL can be used to distinguish between surface-state and depletion-layer contributions to PL quenching. In transient PL, accelerated nonradiative recombination is manifested as a decrease in the photoexcited carrier lifetime. Etchants yielding enhanced CW PL signals produce corresponding increases in carrier lifetime, indicating that the nonradiative recombination rate is effectively reduced [29].

Temperature is used to tune the thermal occupation of available states, and at the lowest temperatures, the PL signal is dominated by the lowest energy levels. Arrhenius plots can be used to study interface alloy formation in ZnSe/CdSe QWs, and the temperature dependence of carrier lifetime is determined by the recombination mechanism. Nonradiative recombination processes tend to accelerate with increasing temperature due to thermally activated multiphonon events.

5. Photoluminescence Polarization

Polarization is an important degree of freedom in optical measurements, and can be attributed to bond asymmetries, alloy composition modulation, and strain. Investigations of PL polarization in the analysis of interfaces are relatively sparse, but can be useful for identifying qualitative features of interfaces [30]. Vignaud et al. observed large polarization anisotropy in the PL from InAlAs/InP heterostructures, and ZnCdSe/ZnSe QWs grown on GaAs(110) surfaces have also shown marked PL polarization anisotropy [31]. PL analysis is a powerful tool in the characterization of surfaces and interfaces. The optoelectronics industry is focused on optical and electronic properties, and PL measurements are a simple and versatile technique that can provide detailed mechanical information about interfaces.

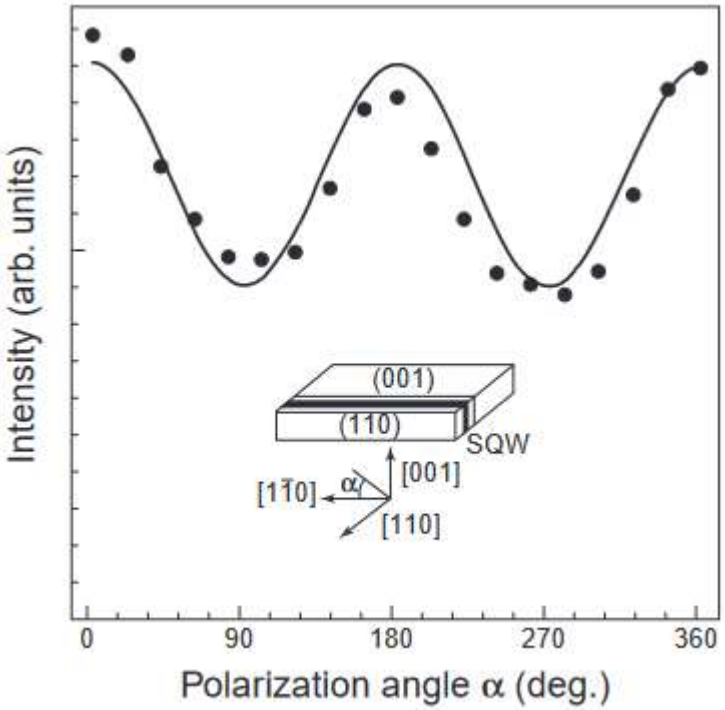

Figure 5. The PL intensity of a single (110) oriented ZnCdSe QW varies with its polarization angle.

The excitation energy and optical intensity can be chosen to study different regions and recombination mechanisms near interfaces. The PL signal is characterized by three essential features: energy, intensity, and polarization [1-4, 29]. Variation of the PL signal with external parameters such as temperature and applied bias can provide additional information on the nature of interfaces. PL measurements are not sensitive to the pressure in the sample chamber and can be performed at virtually any temperature.

6. Conclusion

Multilayer materials make electrical and optoelectronic devices smaller, faster, and more efficient. Heterojunctions limit excitation behavior, and smooth, atomically abrupt surfaces are ideal for optical and electrical reflection, quantum confinement, and high carrier mobility. PLE and Stoke's shift are used to evaluate epilayers, S can compare interface recombination, and surface passivation is popular. PL emission is beneficial for studying surfaces with many discrete defect and impurity states, and in situ PL intensity measurements are nondestructive and environmentally insensitive. Temperature changes the thermal occupation of accessible states, and Arrhenius plots can analyze interface alloy formation. PL analysis characterizes surfaces and interfaces at any temperature.

Conflicts of Interest: The authors have not any potential conflicts of interest. To collect and analyses data, to write a manuscript, and to decide whether or not to publish findings.

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