

# Random Laser

Wendy Lai Gar Yun, Grace Lau, Esther Lo Pui Yi, Ho Hoi Yi  
*Baptist Lui Ming Choi Secondary School*

## Abstract

It is known that **all** lasers comprise of two ingredients, which are a high gain active medium and a man-made cavity. Therefore, it is interesting to ask whether laser can form cavity by itself without any artificial implementation? In addition, is it possible to create a high gain medium by using a defective medium? Recently, laser action has been observed in polycrystalline ZnO and the laser cavity is self-formed.

The objective of this work is to study the basic optical properties of ZnO thin films by using temperature-dependent cathodoluminescence. Prior to the control of the laser, first, we have to know the light emitting properties of the material. We can do that by means of changing the temperature of the experiment environment, then using electrons of different energies to hit the sample. As a result, the sample emits different intensity of light. The method gives the temperature behavior of the various cathodoluminescence transitions observed in undoped ZnO in 80-260K ranges. Samples grown using different techniques have been assessed.

## Introduction

Semiconductor diode lasers have been widely used in the infrared and recently in the red spectral region, offering a relatively inexpensive instrument, but with a high spectral monochromaticity and modest to relatively high power. The excitation of alkali atoms and molecules having spectrum in the visible spectral region is certainly the first step to several interesting applications, like selective excitation leading to ionization. Cathodoluminescence (CL) spectroscopy is a useful technique for the study and characterization of materials and dynamical processes occurring in materials.

## Theory

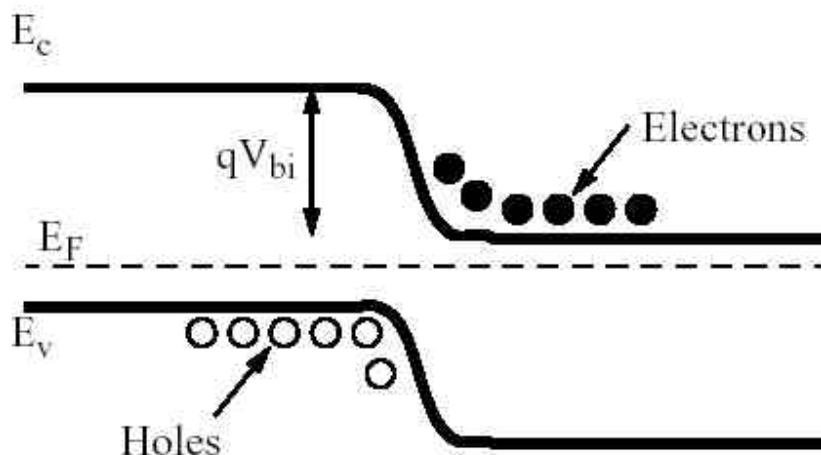
### *Band gaps*

The valence electrons of atomic species are responsible for the well-known energy levels and transitions of gaseous elements. These free- ion energy levels become significantly altered when a large number of atoms are assembled to form a solid. Every

semiconductor is fully and uniquely characterized by its band structure. At zero temperature, electrons occupy only the lower energy bands, and the highest such occupied band is called **valence band**. The next highest energy band is termed the **conduction band**. The two most important and useful quantities for characterizing semiconductor materials are the minimum energy difference between the conduction band minimum and the valence band maximum. If this momentum difference is **zero** then the semiconductor is termed a **direct-gap semiconductor**, and if this momentum difference is **non-zero**, then it is termed an **indirect-gap semiconductor**. Typical dispersion relations (energy vs.  $k$ ) for both direct-gap and indirect-gap semiconductors can be found in textbooks. These two quantities are important in characterizing the light-emission properties (e.g. photoluminescence) of semiconductors because the characteristic energy range of the emission is related to the band gap, and the relative intensity and temporal response of the emission is governed by the band structure.

In conventional devices, the same semiconductor is on both sides of the junction so forces on electrons and holes are proportional to the doping gradients (diffusion) and built in or applied electric fields (drift). The band-gap is a constant so the electrostatic forces are equal and opposite on electrons and holes.

If there is no applied voltage across the semiconductor junction, the Fermi levels are the same and the conduction and valence bands bend to meet each other. This is due to an exchange of electrons (and holes) across the junction (diffusion current) until an electric field opposing further buildup of the diffusion current is established.



When an external voltage is applied, the potential barrier ( $V_{bi}$ ) reduces if the junction is forward biased and increases if the junction is reverse biased.

## **Cathodoluminescence**

Cathodoluminescence (CL) is an important physical phenomena used to characterize semiconductors which depicts a sample's energy structure while possibly revealing other important material features. In brief, CL occurs when a sample absorbs electrons and emits light at a specific frequency corresponding to the material's specific structure, composition and quality. The theory of cathodoluminescence, in relation to semiconductor materials, and its use in understanding examined materials are going to be discussed here.

As the incident electron impinges on the sample, it causes electrons within the valence band to be elevated into excited states in the conduction band, which is a typical process for energy transfer. Since accelerated electrons can provide "power sufficient to excite an adequate signal" the incident electrons typically comes from an electron gun with an accelerating voltage of kilovolts. When the excited electron returns to its initial state in the valence band, it may emit a photon with energy  $h \nu_{CL}$  (and possibly multiple phonons emissions associated with  $h \nu_{CL}$ ).

Once the electron absorption has excited an electron to a higher energy state, the electron can relax to a lower energy state. Two emission processes participate in this relaxation, which can be categorized as either radiative processes (such as CL) or non-radiative processes (such as phonon emission, capture by deep centers, or the Auger effect).

In general, higher energy (higher current or voltage) excitation can cause more photons to be emitted. Similarly, lower excitation energy tends to reduce the photon emission. If the electron energy is less than the energy difference between the ground state and the first excited state (which is the band gap), then no electron absorption occurs, resulting in no CL.

CL can be observed from samples with structures that are more complicated in composition than just a bulk semiconductor material. It can investigate how well the samples are grown, and verify the growth composition. This is because the photon energies measured by CL change with impurities and structures.

An example of a slightly more complicated structure is the single quantum well, in which only transitions involving electrons and holes with the same quantum state can occur. Moreover, if the hole-state is degenerate, the electron can combine with either the heavy-hole or light-hole within the same quantum state. CL spectra would represent this as a pair of closely spaced lines corresponding to the pair of transitions for each quantum well state, with the lowest state dominating.

Some of the possible luminescence transitions include those due to defects. When

electrons and holes are bound together, they form excitons. If there are free carriers, then the exciton can move around the material and is called a free exciton. If the carriers are bound to a defect by Coulombic forces, then the exciton is a bound exciton.

Excitons, which are neutral in charge, do not contribute to the electrical conductivity but contribute to cathodoluminescence in both excitation mechanisms and radiative recombination. CL occurs when an exciton collapses radiatively for both direct and indirect band gap.

In semiconductors, luminescence is caused by radiative recombination of excited individual or coupled charge carriers. These may be:

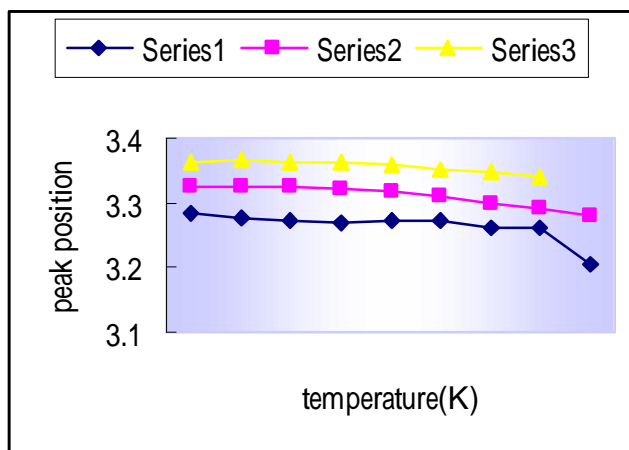
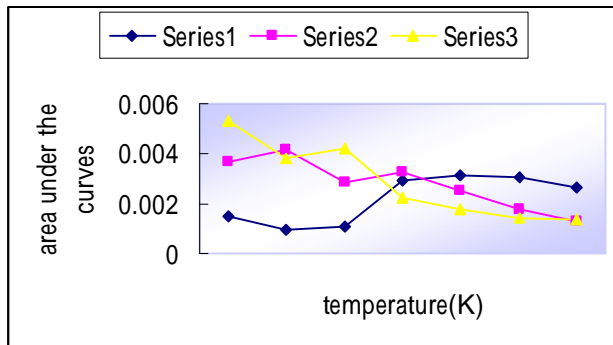
- 1) Free electrons or holes occupying the energy levels in the conduction and valence bands respectively
- 2) Electrons or holes bound to ionized impurities
- 3) Excitons (electron-hole pairs coupled by Coulombic interaction) which may move throughout the crystal lattice of the semiconductor (free excitons) or become localized by the interaction with an active point defect of the lattice or on interfaces occurring in the semiconductor (bound excitons)

## **Experiment**

Here is the apparatus for our experiment:



## Our Data



## Discussion

### *What is cathodoluminescence spectroscopy?*

The radiative emission of photons is in some ways the inverse of the absorption of photons. In an emission process an electron occupying a higher energy state makes a quantized (i.e. discrete) transition to an empty lower-energy state. For a radiative transition the energy difference between these two states is emitted as electromagnetic radiation, i.e. photons. This recombination is a non-equilibrium process and energy must be conserved.

Cathodoluminescence from semiconductors is most commonly characterized via spectroscopic techniques. These techniques involve measuring the energy distribution of

emitted photons after electron excitation. This energy distribution of light emission is then analyzed in order to determine the properties of the material, including defect species, defect concentrations, possible stimulated emission, etc. This technique for material characterization has achieved significant success and popularity at least partly due to the simplicity of the technique and the absence of sample processing requirements.

### ***The peak position and intensity change depends on temperature***

From the experiment and data that have been carried out it is found that when the temperature is increased the intensity of light emission decreases. When electrons excite the sample, other than the radiative effect (i.e. light emission) there is also non-radiative effect (i.e. heat releases) occurs due to the defects located inside the sample. When the temperature is increased, the non-radiative effect will be activated at the same time, some of the electrons are captured by the nonradiative deep level energy states. Hence, radiative effect decreases, and fewer light emission. So, the intensity of light emission increases when temperature decreases.

### **Conclusion**

A series of undoped ZnO samples grown using various techniques have been studied by cathodoluminescence as a function of temperature, in order to study the mechanisms for thermal quenching of the different transitions observed. Our data show that for lower temperature, and if the wavelength decreases, intensity will increase. The change in intensity is due to non-radiative defects.

### **Acknowledgments**

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### **References**

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