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SEMICONDUCTORS AND DEVICES UNDER STRESS

(*Invited)*

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ABSTRACT

Lattice constant is the most intrinsic parameter in determining the various energy band gaps of semiconductors. It will not be unwise to foresee considerable changes in their band structures and also their electronic and optical properties as the lattice constant is somehow altered from its equilibrium value at atmospheric pressure.

Among the thermodynamic variables, pressure is often regarded as a poor parameter of a material. Today, it is known beyond doubt that the effects which can be observed in solid state materials under both hydrostatic and uniaxial pressures can be magical and highly informative as the lattice constant is changed. A wide range of structural, optical and electronic properties are exhibited as the materials are subjected to high pressures. Under pressure the atoms of the solid may also rearrange themselves in an interesting way and their packing density may change with pressure. So many solids have been observed to undergo such changes as conversion of diamond into graphite, InAs with zincblende structure into NaCl type structure and so on. Under pressure, insulators have been found to behave like semiconductors and semiconductors like metals etc.

Some of the areas where the application of pressure has been noticed are: (i) observation of new phase transitions in solids (ii) NMR phenomenon in alloys (iii) controllable Gunn effect (iv) observation of tricritical points in ferroelectric materials (v) metal-semiconductor transitions and band structure determination of chalcopyrites for optical devices (vi) high sensitivity pressure sensors and (vii) 2-DEG in hetero-structures. Such studies may require pressures approaching the order of a few hundred kbar (1 kbar=1000 times the atmospheric pressure). Some of the pressure generating techniques and experimental results will be presented.

Out of all the ternary semiconductors, AlGaAs ($0< x<1$) can be grown almost lattice matched to GaAs with a minimal lattice mismatch of ~ 0.16 %. Multilayer structures of GaAs and GaAlAs have, therefore, been used in fabricating many novel devices. To project the device characteristics prior to fabrication, it is absolutely necessary to know the magnitudes of band off-sets. In the present work, we report determination of these off-sets from DLTS and PL measurements, respectively on MBE grown quantum well structures.

The potential variations of quantum wells are similar to a deep energy state in the energy gap of a semiconductor. Therefore, DLTS can be used to observe the carrier emission and capture

from the well in a similar way as for a deep trap although with some deviations. If a Schottky barrier diode is made on the quantum well structure, a bias pulse can be used to study the capture and emission kinetics by the well, considering it equivalent to a 'giant' trap for the diode under reverse bias. We have also carried out DLTS under pressure ($T<300$ K) to distinguish the bulk and quantum well emissions with the well acting as a 'giant' trap.

It has been suggested that the lattice mismatch at the interface also contributes to band off-sets. In such an eventuality, GaAs-GaAlAs system naturally becomes the best choice to test this suggestion because of almost perfect matching at the interface. However, one has to be extremely careful in identifying and separating the GaAs well and other bulk traps (particularly EL-2 and DX centers in GaAlAs). It has also been possible to locate the physical position of the well under the top surface and establish some strange properties of well emission, not found to be associated with a bulk trap.

A much faster FRCS technique working at room temperature has also been proposed. In FRCS, the diode mounted in a cryostat forms one of the arms of a capacitive wheat stone bridge. A signal generator in series with a d.c bias is connected between two opposite nodes and the output from the diode is taken across the other two nodes, which are in turn connected to a lock-in amplifier. A reference signal from the generator is also fed to the amplifier in such a way that it has quadrature phase w.r.t the output from the diode.

The distribution obtained is symmetric showing a maximum at $\omega\tau=1$, from which τ can be determined. From such measurements as a function of temperature, the data about the level (ionization energy and density) could be found. We have applied this quadrature technique on Si and InP deep levels and compared the results with those obtained from DLTS with a fair agreement. The behavior of some of these levels under hydrostatic pressure and low temperatures was also studied to learn about their characteristics. On the contrary, the in phase technique response does not show any critical behavior to find the time constant, hence it is normally not preferred in comparison to quadrature method. Full theory of FRCS has also been developed.

In summary, the application of pressure can alter the band structure of semiconductors and devices to obtain noble characteristics. For example, it is possible to convert Ge and GaAs into Si like structures, opening the possibility of integrating optical and electronic devices on the same chip and providing a series of new materials for microwave/optical/electronic devices. It is shown that capacitance spectroscopy (DLTS) on quantum well hetero-structures using Schottky barrier diodes under pressure, combined with photoluminescence (PL) measurements provides a powerful tool in determining conduction and valence band discontinuities, a parameter of utmost importance in controlling hetero-structure device performance. Further, capacitance spectroscopy under hydrostatic pressure has been used to identify the quantum well and bulk trap emissions. An improved FRCS technique has also been described.