Optical methods for the detection of ESR in semiconductors

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Why do we use optical methods for the detection of electron spin resonance? The answer lies in a combination of sensitivity and optical selectivity. Many of the specimens that we study are in the form of ultra-thin epitaxial heterostructures, so that the sample volumes are very small. This, combined with the low spin densities, requires high sensitivity. Further, the structures are often complicated, so that selection of a specific region through appropriate choice of optical wavelength is a key asset. Optical techniques also enable us to investigate excited states which are inaccessible by conventional ESR. Our major interest in semiconductors is in their application to opto-electronic and magneto-electronic (spintronic) devices, so that insight into the interaction between the optical and magnetic properties is particularly important.

We shall outline recent work under two headings. First we shall describe magnetic resonance detected by monitoring the photoluminescence from semiconductor heterostructures. This optically-detected magnetic resonance (ODMR) approach has been used for many years, with particular attention to processes in which optically-excited electrons recombine with hole states. Such processes, which often lead to strong optical emission, are very common in semiconductors. The electrons and holes which participate are trapped at a multitude of dopant and defect states and identification of these states is of paramount importance in the control of device structures. We shall give examples of recent work on wide bandgap semiconductors such as GaN and ZnO, which are of current interest as blue and violet light emitters, and on materials such as CdMnTe, which are of spintronic interest.

The second heading involves ESR detected though optical heterodyne monitoring of coherent Raman scattering. We have adapted this technique, developed first by Stephen Bingham in the context of metallo-enzymes, to a range of semiconductor structures. In such structures, strong Raman scattering occurs during which the spin of an electron or of a hole is reversed (Spin-flip Raman Scattering, SFRS). When magnetic resonance is stimulated in the scattering centre, the scattering becomes coherent. If the Raman sidebands are mixed with a component of the original laser beam in a sufficiently fast optical detector, a beat signal can be detected. This beat signal, which is at the microwave frequency and which occurs only at magnetic resonance, can then be mixed with a component of the original microwave driving voltage in a similar way to the mixing that occurs in the bridge of a conventional ESR instrument. The occurrence of ESR can thus be detected, the sensitivity being up to 3 orders of magnitude greater than that of normal ESR. Optical selectivity is provided by the enhancement of the Raman scattering that occurs when the laser wavelength is adjusted to coincide with that of a selected optical transition.. We shall illustrate the technique with recent work on ZnSe and GaAs.