Spin Dependent Recombination: An ESR Detection Technique

Spin dependent recombination (SDR) is an ESR technique in which one can make ESR measurements on fully processed devices including devices in integrated circuits. In SDR, the spin dependent nature of recombination events is exploited so that one may observe ESR through measurement of recombination currents. A qualitative explanation of SDR, first proposed by Lepine, is sufficient for a basic explanation [3]. The Lepine model combines the Shockley-Read-Hall (SRH) recombination model and Pauli Exclusion Principle.

In the SRH model, recombination of electrons and holes takes place through deep level defects in the semiconductor bandgap. An electron is trapped at a deep level defect, then a hole is trapped at the same deep level defect. (The sequence could obviously be reversed, with a hole being trapped first at a deep level defect, then an electron.) This process is illustrated in figure 8.

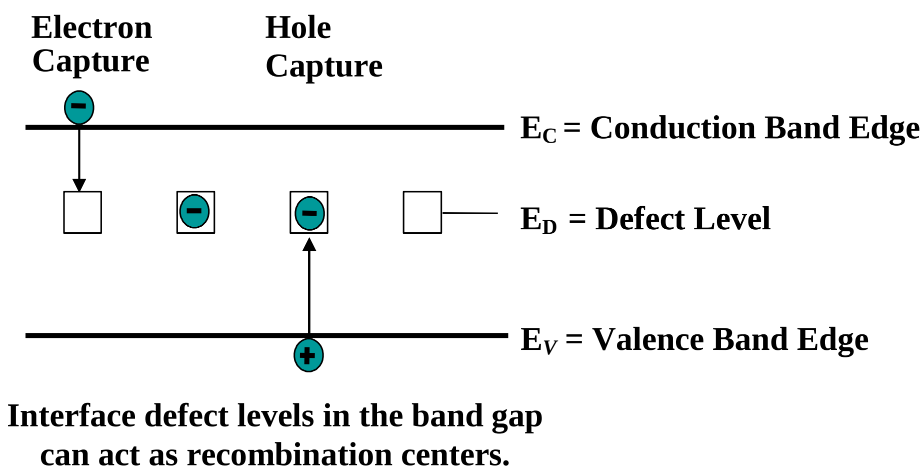
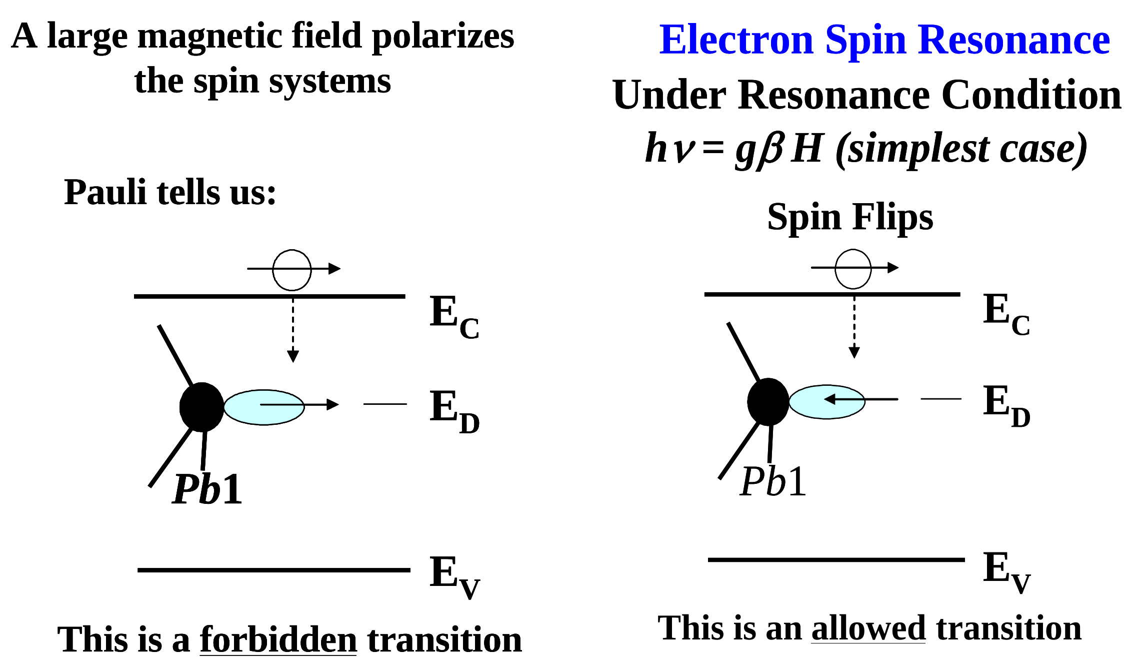


Figure 8. A schematic representation of the SRH model.

Suppose that the deep level defect is a "dangling bond." The dangling bond has an unpaired electron when it is electrically neutral. In SDR, the semiconductor device is placed in a strong magnetic field which polarizes the spins of the dangling bond electrons as well as the conduction electrons and holes. (That is, the electron spins tend to orient with the applied magnetic field.) The SRH recombination process begins with the electron capture (or hole capture) at the deep level site. If both the dangling bond and conduction electrons have the same spin orientation, the conduction electron cannot be captured at the site because two electrons may not occupy the same orbital with the same spin quantum number.

Thus, placing the semiconductor sample in the magnetic field reduces the average trap capture cross section of the traps. In ESR, electron spins are "flipped" from one spin orientation to the other when the resonance condition is satisfied. The spin flipping at the trap site increases the probability of oppositely oriented traps and conduction electron spins, allowing the trapping event and recombination. This process increases the recombination current. This process is illustrated in figure 9.



(a) (b)

Figure 9. This figure illustrates the SDR phenomenon. If both conduction electrons and deep level electron spins point the same way, the trapping event will be forbidden (a). By satisfying the ESR condition, we flip the deep level spin, allowing the capture event (b). This increases the current when the ESR condition is satisfied.

Thus, if a semiconductor device is placed in a strong slowly varying magnetic field and microwave radiation, the recombination current will increase when the applied magnetic field and microwave frequency satisfy the resonance condition. The device current plotted versus magnetic field will have the same pattern as that of the ESR spectrum of the defect under study. An SDR spectrometer is schematically illustrated in figure 10.

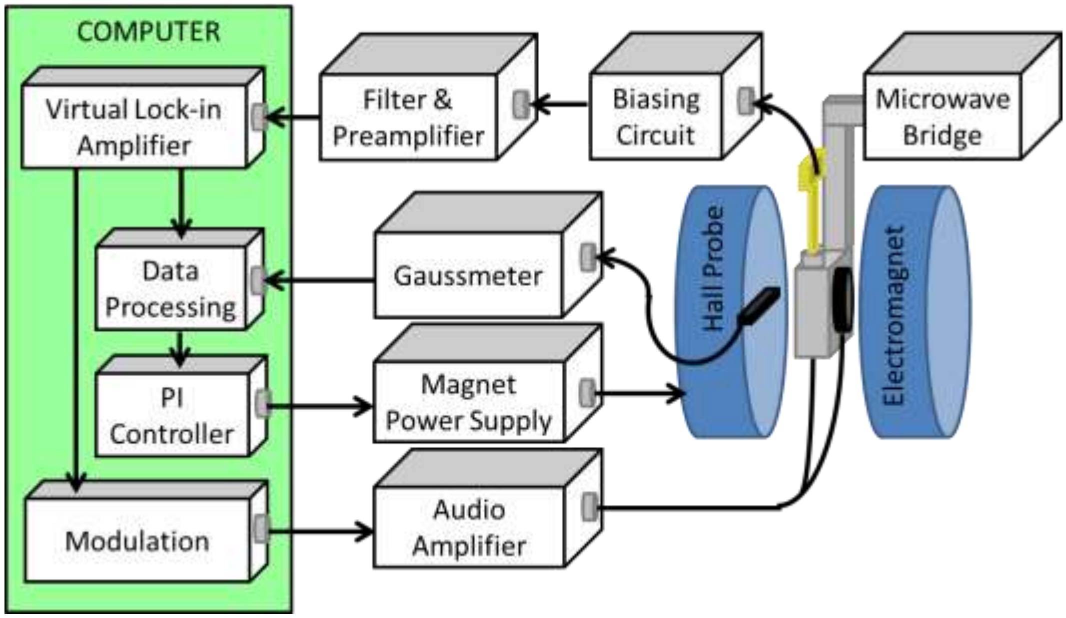


Figure 10. A schematic representation of an SDR spectrometer.

A more accurate model for SDR has been developed by Kaplan et. al [4].

In SDR measurements, the device needs to be configured in such a way that the measured current would be strongly influenced by recombination events. For MOSFET's this can be done by connecting (shorting) the source and drain to act as a gate controlled diode and biasing the device across the gate in such a way as to form a depletion region at the semiconductor-oxide interface. One could then measure the recombination current from the substrate to the source-drain junction. One way in which SDR could be measured in a BJT would be to simply measure base-collector current with the base-collector junction slightly forward biased. Such measurements have been made in our laboratory on SiC BJTs [30]. SDR measurements could provide quite useful information about reliability and performance limiting defects in an extremely wide variety of devices including solar cells, p-n junction diodes, bipolar junction transistors, and MOSFETs.

References in text can be found on page labeled "References" *on website*