Electrically Detected Magnetic Resonance Study of Leakage Currents in a-SiN:H

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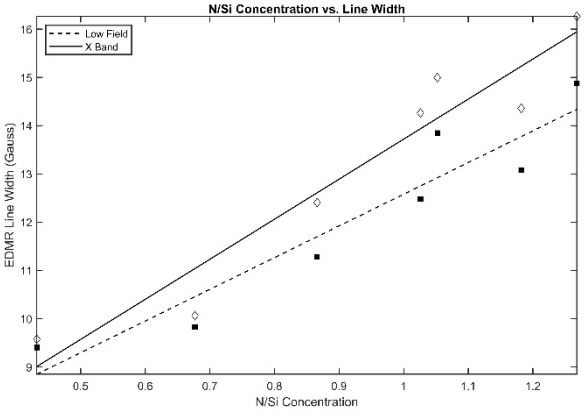
Electronic transport in dielectric thin films are important concerns in semiconductor device technology. We have initiated a study of the defects involved in electron transport through a-SiN:H thin films of various stoichiometries utilizing electrically detected magnetic resonance (EDMR) measurements at multiple frequencies. The primary defect responsible for electronic transport (the K center) through SiN films has been identified using conventional electron paramagnetic resonance (EPR), but a detailed understanding of the effects of varying nitrogen incorporation in very thin films is not complete on the atomic scale. The EDMR measurement involves spin dependent trap assisted tunneling (SDTAT) on a sample structure of p-Si/a-SiN:H/Ti where the N/Si ratio in the a-SiN:H film was varied from 0.432 (N poor) up to 1.268 (nearly stoichiometric). In EDMR, we detect spin-dependent changes in device current under the influence of a slowly varying magnetic field. When the resonance condition is met, defect spins "flip" and a forbidden tunneling event becomes allowed, resulting in a change in device current that allows us to identify the chemistry and local structure of the defect responsible for leakage current. These measurements were made at low frequency (v=350MHz) and high frequency (v=9.5GHz) over the entire range of film stoichiometries. Fig. 1 shows the EDMR results at low frequency (dashed line, filled squares) and high frequency (solid line, open diamonds). The trend of increasing linewidth with increasing N/Si ratio is observed in both sets of measurements. A comparison between the high and low frequency EDMR measurements allows us to determine the contribution to linewidth broadening from spin orbit coupling and electron-nuclear hyperfine interactions [1]. The linewidth broadening is nearly identical for both sets of measurements, so we can conclude that a majority of the linewidth comes from hyperfine interactions and not spin orbit coupling (we would expect a significant increase in broadening at high field compared to low field). This result is consistent with the prediction of increasing hyperfine interactions with increasing average number of nitrogen atoms in K center defects.



[1] M. J. Mutch, P. M. Lenahan, and S. W. King, Appl. Phys. Lett., vol 109, no. 6, 2016.

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Supplementary Pages

The EDMR technique is based on EPR, in which the sample is exposed to an oscillating magnetic field and a slowly varying magnetic field. The slowly varying field splits the energy levels of paramagnetic sites and when this splitting is equal to the energy of the oscillating field, electron spins can be "flipped". The basic resonance condition is primarily modified by spin orbit coupling and electron-nuclear hyperfine interactions to become:

$$h\nu = g\mu_\beta B \pm m_i A \quad (1)$$

Here, h is Planck's constant, ν is the frequency of the applied oscillating field, g is a second rank tensor consisting of the free electron Landé g value ($g_e = 2.00232\ldots$) modified by spin orbit coupling (which is influenced by the charge of the defect nucleus and the electron's orbital angular momentum), μ_β is the Bohr magneton, B is the magnitude of the applied magnetic field, and the $m_i A$ term comes from electron-nuclear hyperfine interactions (interactions between the paramagnetic site and nearby nuclei with magnetic moments). As discussed in the main abstract, we observe EDMR via SDTAT as shown in Fig. 2. On the left, the tunneling event is forbidden by the Pauli Exclusion Principle. When the resonance condition (1) is met, a spin flips at one of the paramagnetic sites and we observe a change in leakage current (right). Fig. 3 contains a schematic of our EDMR apparatus, including all supplemental equipment that is used. For the low field EDMR measurements, we replace the microwave bridge/cavity with an RF coil.

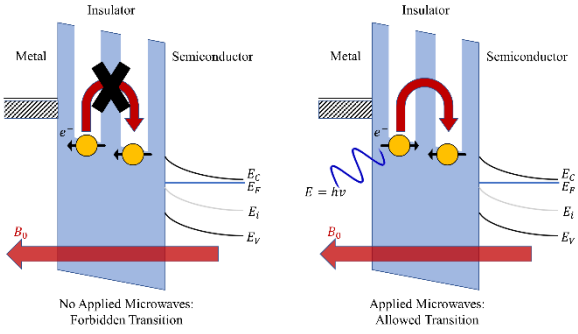

Figure 2 : A cartoon illustration of SDTAT.

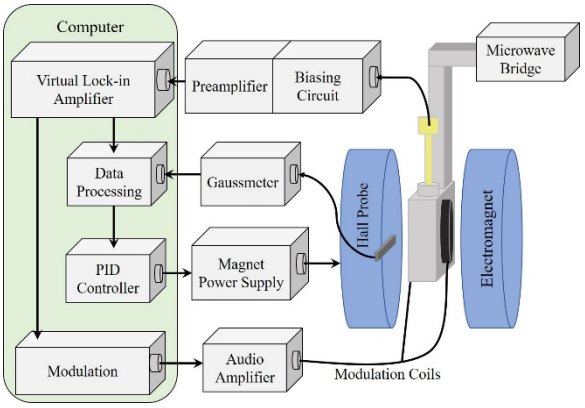

Figure 3 : Schematic of our EDMR setup.

Fig. 1 in the main abstract contains a compilation of every measurement made at each field/frequency combination. Fig. 4 displays each of these measurements separately. In Fig. 4 (left), we show the low field EDMR measurements over all seven stoichiometries of a-SiN:H. Fig. 4 (right) contains the same samples measured with high field EDMR. It should be noted that the x-axis covers the same magnetic field sweep (70 Gauss). As more clearly shown in Fig. 1, the linewidths at each stoichiometry closely track from low field to high field EDMR.

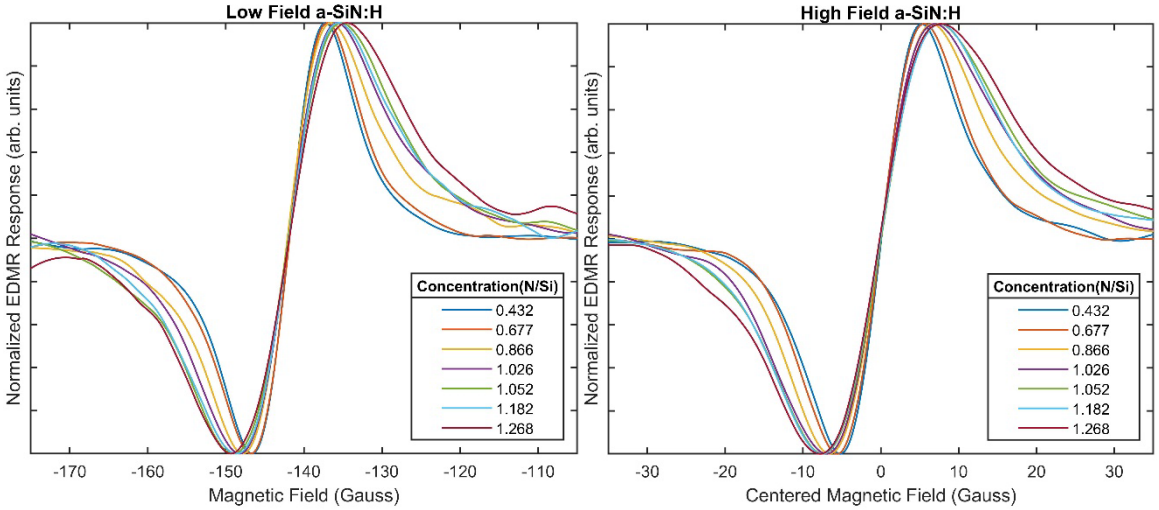

Figure 4 : EDMR measurements made at low field (left) and high field (right).

We can almost fully separate the contributions to our spectra from spin orbit coupling and electron-nuclear hyperfine interactions. Spin orbit coupling results in a frequency (linearly) dependent line broadening. Hyperfine interactions are very nearly frequency independent. By comparing the low frequency (v=350 MHz) and the high frequency (v=9.5GHz) EDMR measurements, we can determine if a majority of the broadening that we observe is from spin orbit coupling or from hyperfine interactions. The line broadening is almost entirely independent of field/frequency of the measurement, so we can conclude that a majority of the broadening is coming from hyperfine interactions. The primary elements present in our films are Si, N, and H. Silicon atoms have a 4.7% naturally abundant magnetic nucleus (spin 1/2) while nitrogen atoms have a 100% naturally abundant magnetic nucleus (spin 1). Keeping all other considerations the same, we would expect samples with higher nitrogen content to display stronger hyperfine interactions and thus broader EDMR spectra.