SAND2020-10529C

PennState

Electrically Detected Magnetic Resonance Study of High-Field Stress Induced Si/SiO_2 Interface Defects

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Introduction 1

It is widely accepted that the breakdown of SiO_2 gate dielectrics is caused by the buildup of stress-induced defects over time. Although several physical mechanisms have been proposed for the generation of these defects [1]–[3], very little direct experimental evidence as to the chemical and physical identity of these defects has been generated in the literature thus far [4]. Here, we present electrically detected magnetic resonance (EDMR) measurements obtained via spin-dependent recombination currents at the interface of high-field stressed Si/SiO_2 metal-oxide-semiconductor field effect transistors (MOSFETs).

Magnetic Resonance

- EDMR is perhaps the only analytical technique with the power to provide chemical and physical information about paramagnetic defect centers in semiconductor and insulator materials at the device level.
- EDMR's parent technique, electron paramagnetic resonance (EPR), has been used for decades to study such defects in bulk materials and large area thin films [5]–[9]. 2
- In both EPR and EDMR, electron spins in paramagnetic centers are aligned with a large, slowly varying magnetic field, which creates an energy splitting between spin states. This energy splitting is affected by spin-orbit coupling and electron-nuclear hyperfine interactions present at the paramagnetic defect sites. The sample is also exposed to microwave photons, and when the photon energy is equal to the magnetic field induced energy splitting, electrons spins can "flip".
- In EPR, an absorption of microwave power is measured and plotted against magnetic field. The EDMR response is detected through a spin-dependent current running through the semiconductor device itself. This provides orders of magnitude better sensitivity than that of EPR.
- A diagram of an EDMR spectrometer is shown below

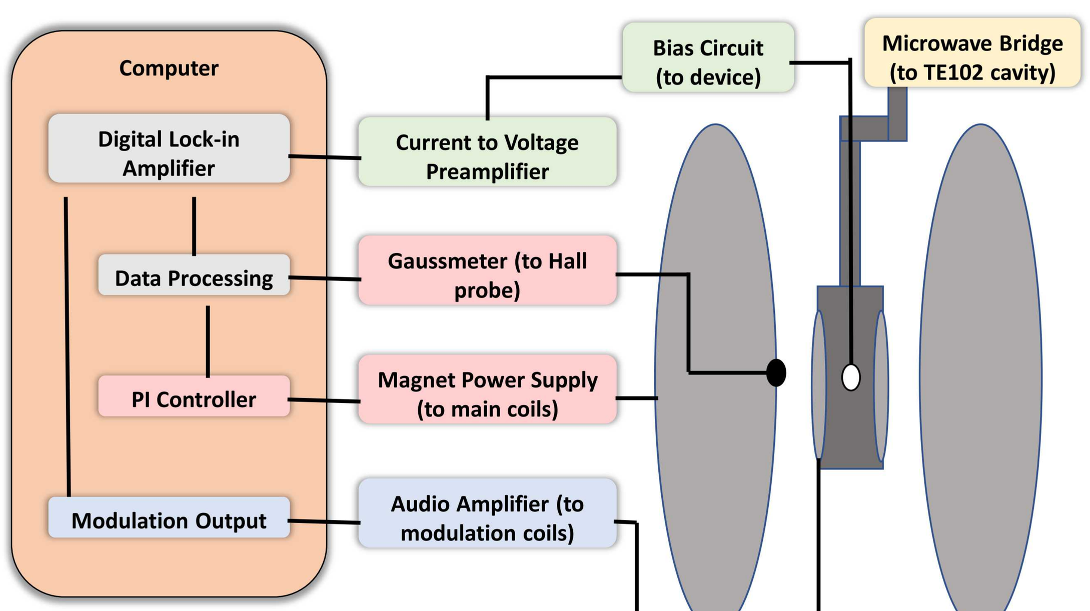

Figure 1. Block diagram of an EDMR spectrometer.

Spin-Dependent Recombination 3

The spin dependent current utilized in our EDMR measurements is spin-dependent recombination (SDR) current. This process is best understood by the SRH model for recombination [10], which is illustrated below.

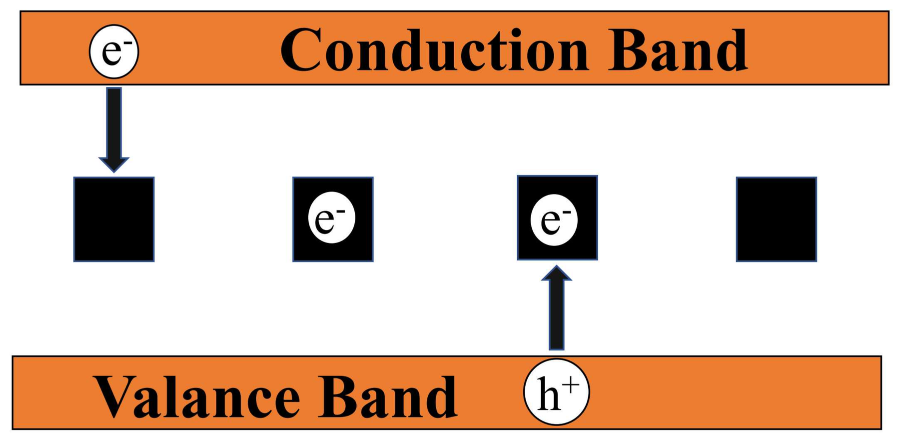

Figure 2. SRH model for recombination. First, an electron falls into a deep level defect from the conduction band. The electron remains captured until a valence band hole is also captured at the same defect site, and recombines with the electron. If the defect is paramagnetic, the recombination events can be forbidden by the Pauli exclusion principle if the defect electron and conduction electron have the same spin. Because of this, an increase in SDR current can be measured when the EDMR resonance condition is achieved.

DCIV Measurements 4

The devices used in this study are arrays of 126 MOSFETs with an oxide thickness of 7.5nm. Three devices were used: one fresh device, one device stressed for 5 mins at $V_g = 9V$, and one device stressed for 20 mins at $V_g = 9V$.

The SDR currents at the interface of our MOSFETs was created via the DCIV biasing scheme [11]. The DCIV biasing scheme is shown below in Figure 3, along with DCIV electrical data taken on the three devices of interest (Figure 4). The peak in recombination current is significantly increased by the gate stressing.

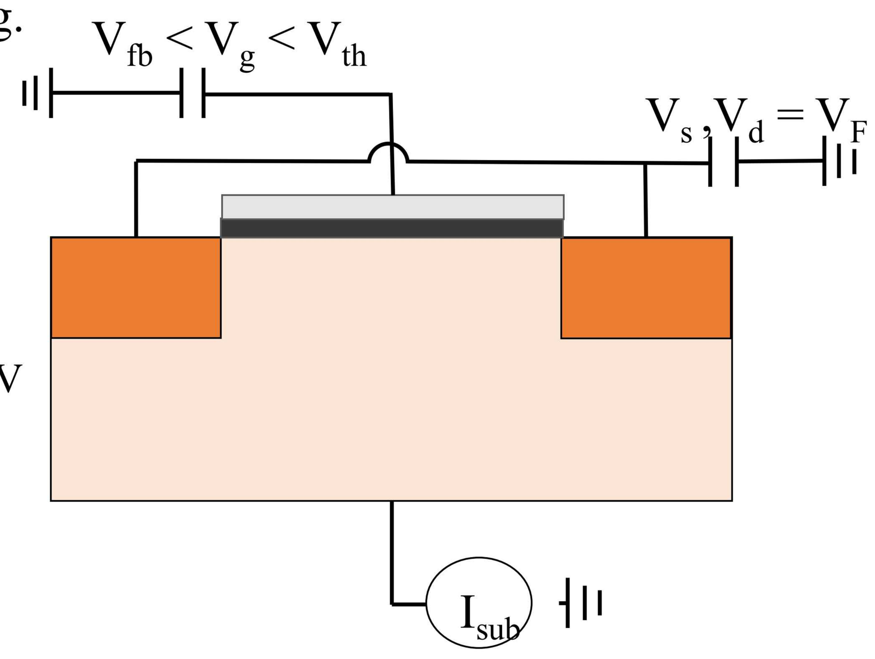

Figure 3. The DCIV biasing scheme. In our case, V_F = -0.33V

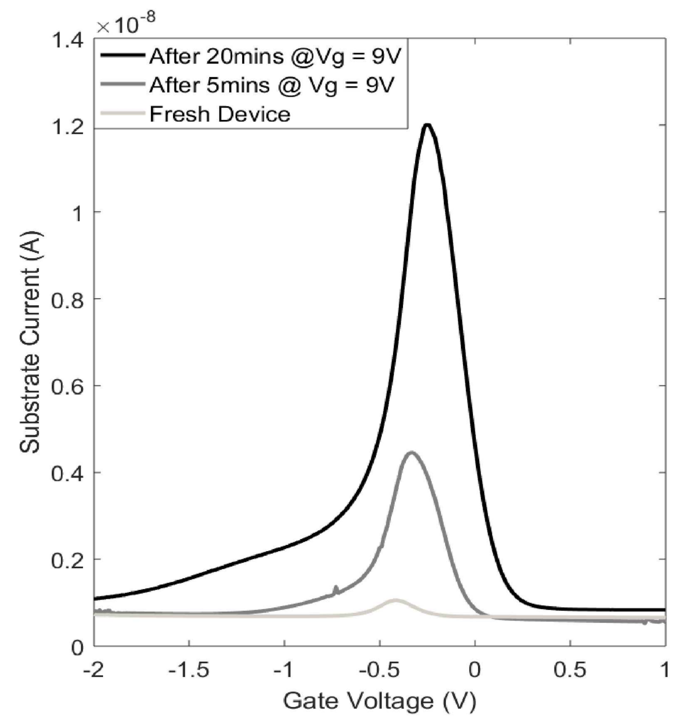

Figure 4. DCIV electrical measurements of the 3 devices under study. For our EDMR measurements, the gate was biased at the peak of the substrate current curves.

EDMR Results 5

- EDMR results obtained from all three samples with the magnetic field oriented perpendicular to the (100) interface are shown in Figure 5. The modulation amplitude used was 0.5mT. Each measurement was made with V_g set to the top of each respective DCIV current peak.
- EDMR traces were also taken on the sample stressed for 20 minutes at a lower modulation amplitude to reveal a more accurate lineshape. Figure 6a shows low modulation amplitude data taken with the magnetic field perpendicular to the interface, while Figure 6b shows the low modulation amplitude data taken with the magnetic field parallel to the interface.

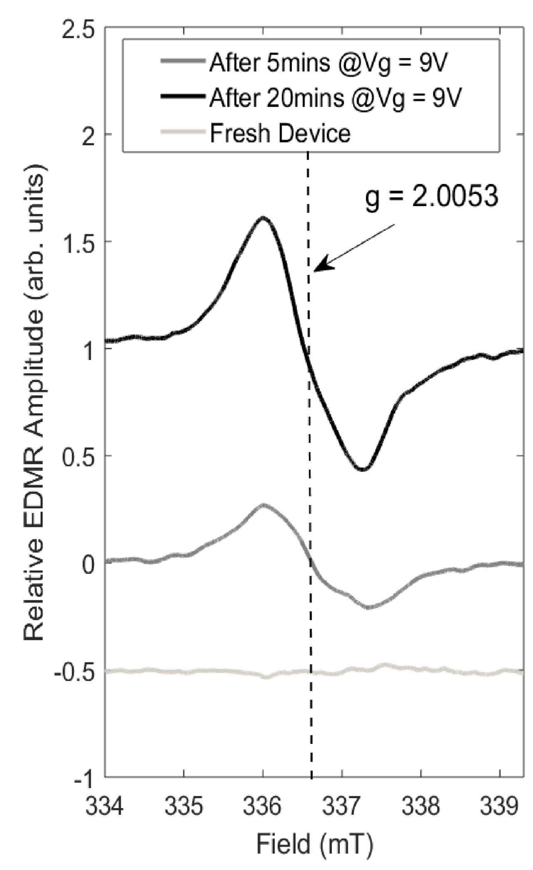

Figure 5. EDMR measurements with a 0.5mT modulation amplitude and with magnetic field oriented perpendicular to the interface

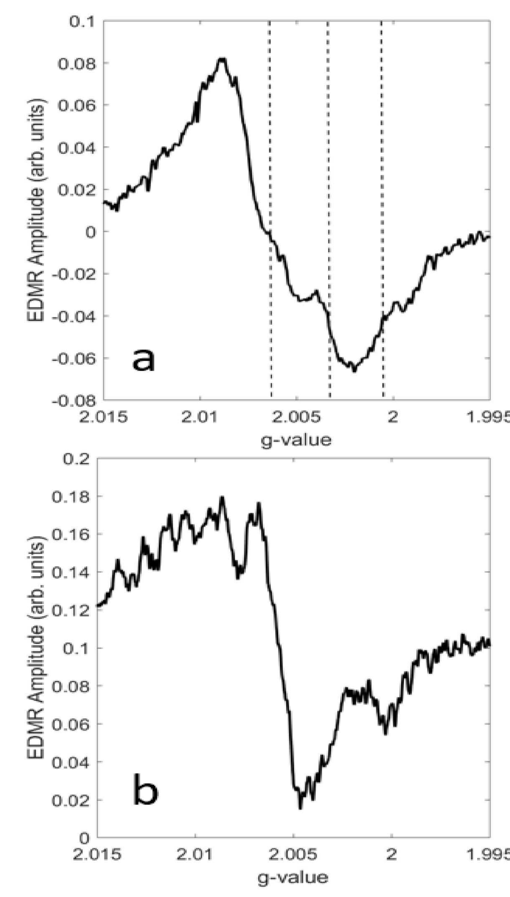

Figure 6. EDMR measurements with a 0.05mT modulation amplitude and with magnetic field oriented perpendicular to the interface (a) and parallel to the interface (b)

Discussion/Conclusion 6

- The DCIV electrical curves in Figure 4 and the EDMR responses in Figure 5 indicate that the increase in interface recombination current after high-field gate stressing is due to an increase in interface defect density.
- The dominating Si/SiO_2 interface defects are known to be P_{b0} and P_{b1} centers. With the magnetic field oriented perpendicular to the interface, we would expect the P_{b0} response to exhibit g = 2.0059 and the P_{b1} response to have g = 2.0032. the responses of both defect centers are highly orientation dependent, and the signals split into multiple lines at other orientations [12,13].
- DCIV EDMR measurements can also detect recombination in near-interface oxide defects [14]; in SiO_2 the dominating oxide defect is known to be the E' center. The E' center response has a non-orientation dependent g = 2.0005 [5].
- These expected g-values are shown in the low modulation EDMR response in Figure 6a as vertical lines. The P_{b0} and P_{b1} g-values both fall within the signal linewidth, but no E' response can be seen above the noise level.
- The low modulation amplitude trace with the magnetic field oriented parallel to the interface (shown in Figure 6b) demonstrates the orientation dependence of the response.
- **In conclusion, We report DCIV EDMR results in Si/SiO_2 MOSFETs before and after high field gate stressing. The g-values and orientation dependence of the response indicate that the post stress EDMR responses are dominated by P_{b0} and P_{b1} defects.**

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