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Early-Stage Mechanisms in Time-Dependent Dielectric Breakdown in Si/SiO_2 MOSFETs

F. V. Sharov[1], S. J. Moxim[1], D. R. Hughart[2], G. S. Haase[2], and P. M. Lenahan[1]

[1]The Pennsylvania State University, University Park, PA, 16802
[2]Sandia National Laboratories, Albu… 87123

Sandia National Laboratories

Time-dependent dielectric breakdown (TDDB) and stress induced leakage currents (SILC) are important MOSFET reliability issues [1]. Although these phenomena are widely investigated, the understanding of the specific atomic-scale processes are not completely understood [2,3]. Electrically detected magnetic resonance (EDMR) and near-zero-field magnetoresistance (NZFMR) have provided significant information about atomic-scale traps in Si/SiO_2 devices [3-5]. In this study, we use EDMR and NZFMR results utilizing both spin dependent trap assisted tunneling (SDTAT) and spin dependent recombination (SDR) to explore the mechanisms involved in the initial stages of TDDB.

The SDR EDMR data is shown in Fig. 3 (a) for a device that was stressed at a gate bias of -9 V for 30 minutes. The SDR measurements used the Fitzgerald and Grove dc I-V technique to probe defects at and near the Si/SiO_2 interface [6]. The experimental results of Fig. 3 (a) are compared to a simulated spectrum utilizing EasySpin [7], which used g-values of 2.0065 and g =2.0032; these values are what would result from a combination of P_{b0} to P_{b1} interface silicon dangling bond centers [9]. The agreement between the simulation and experiment are excellent, with a P_{b0} to P_{b1} ratio of 3:1 and zero-crossing g-value of 2.005. Fig. 3 (b) shows the dc I-V EDMR amplitude and calculated interface trap densities as a function of gate stressing times, with excellent agreement.

The SDTAT results in Fig. 4 show the SDTAT response at three different stressing times: 20 minutes, 40 minutes, and 60 minutes. The SDTAT results obtained from the SILC generated in the oxides have only modest signal to noise ratios but, surprisingly, are also consistent with P_b center interface traps, with zero-crossing g-values of 2.005. Fig. 5 shows the normalized integrated SDR NZFMR response at several different stressing times. The SDR and SDTAT EDMR results both indicate a build-up of P_{b0} and P_{b1} centers as a function of stressing time.

One might expect—especially in the case of SDTAT through the gate oxide—that the EDMR response due to SILC would include a strong contribution from oxide defects, such as the E' center (g =2.0007) [8]. However, only a weak E' SDR response can be observed in measurements optimized for E' detection. Surprisingly, the interface silicon dangling bonds dominate the EDMR spectra for the high-field stressed MOS devices. These results indicate that the P_{b0} and P_{b1} silicon dangling bonds play a crucial role in TDDB. Presumably, P_b to oxide defect tunneling events serves as a rate-limiting step in the leakage current phenomenon.

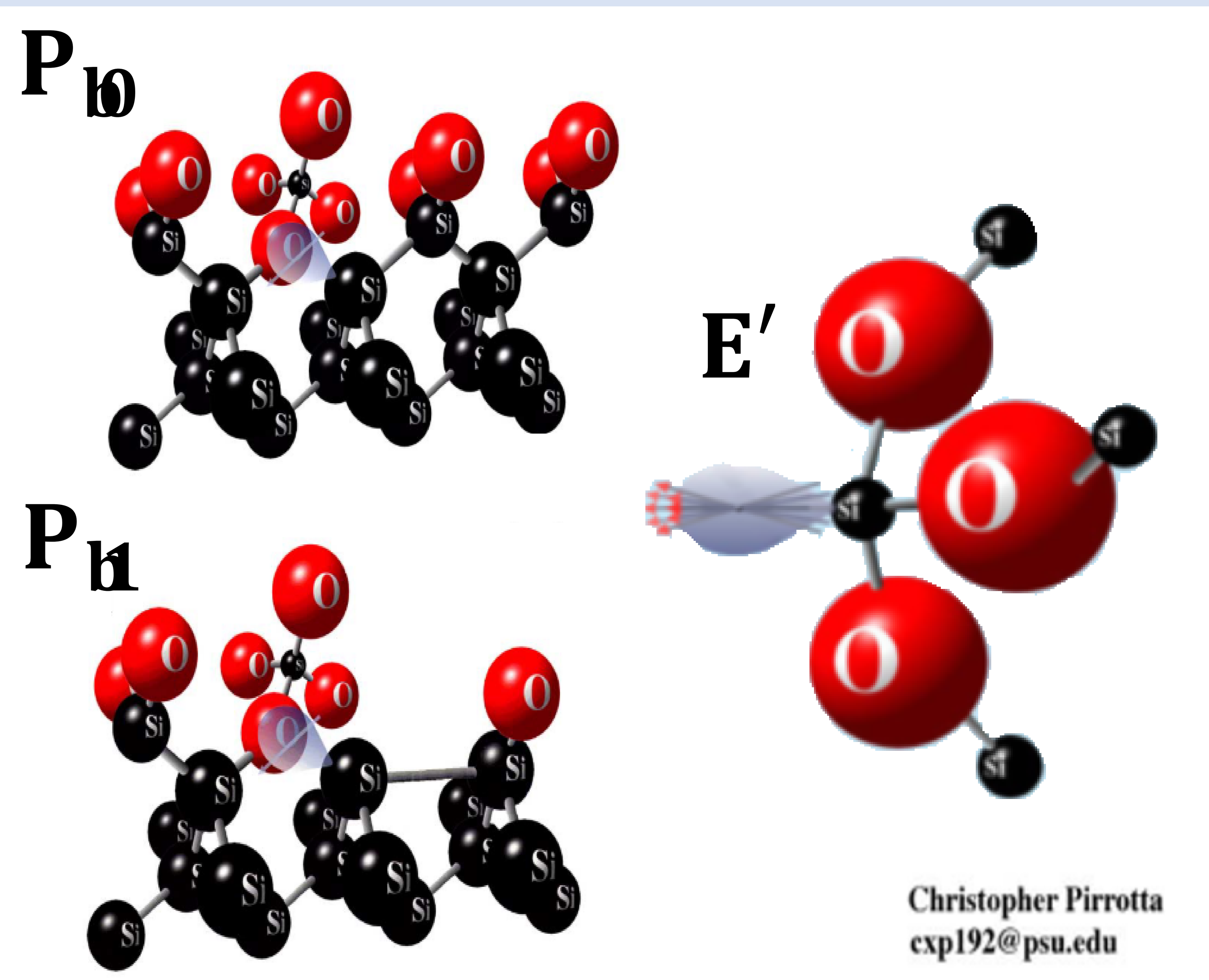

Fig. 1. Molecular models for the various defects in Si/SiO_2, including the two interface defects—the P_{b0} and P_{b1} centers—and the E′ oxide defect.

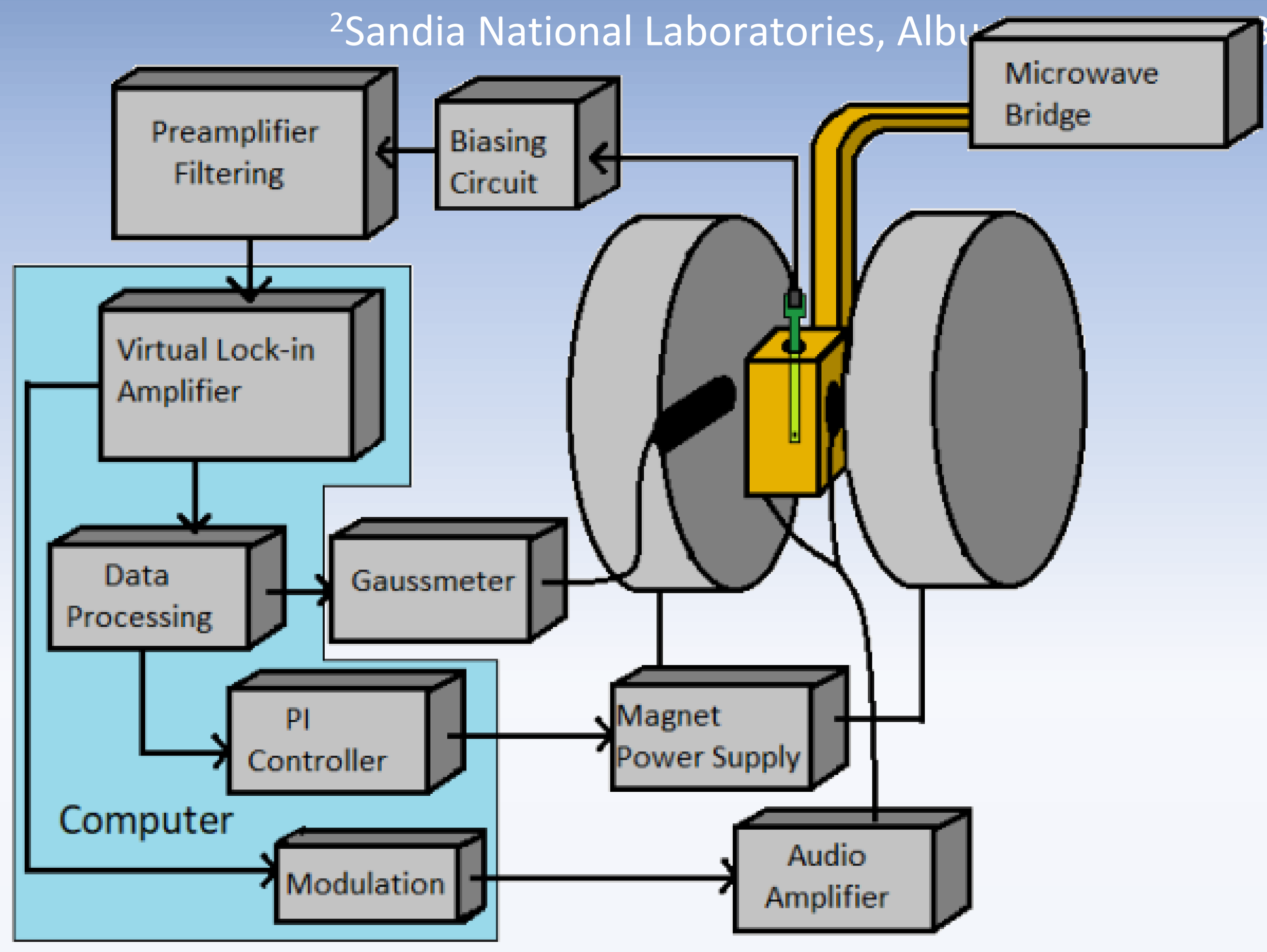

Fig. 2. Schematic of an *X*-band EDMR spectrometer.

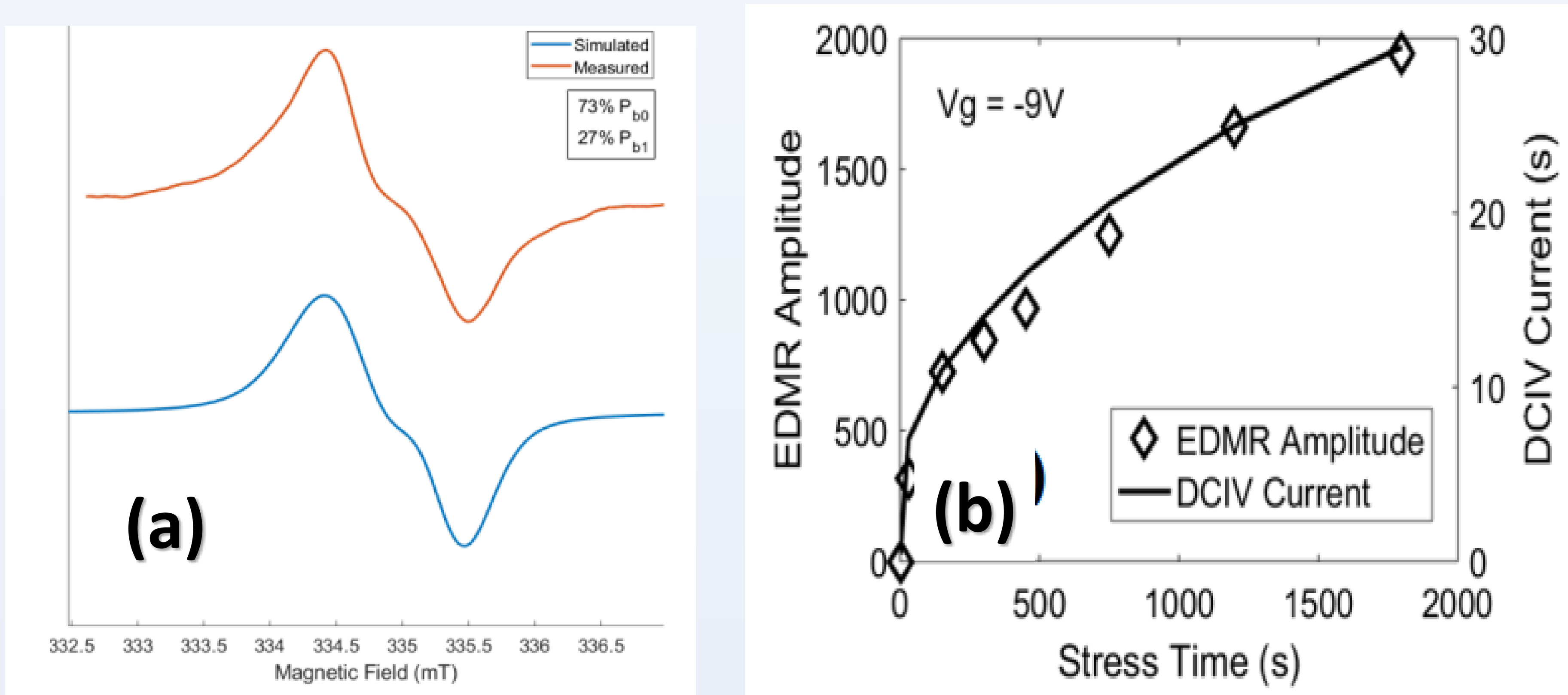

Fig. 3. The (a) experimental and simulated dc I-V EDMR spectra for a high-field stressed Si/SiO_2 nMOSFET device and the (b) comparisons of the dc I-V EDMR amplitudes and interface trap densities for varying stress times at -9 V of gate bias.

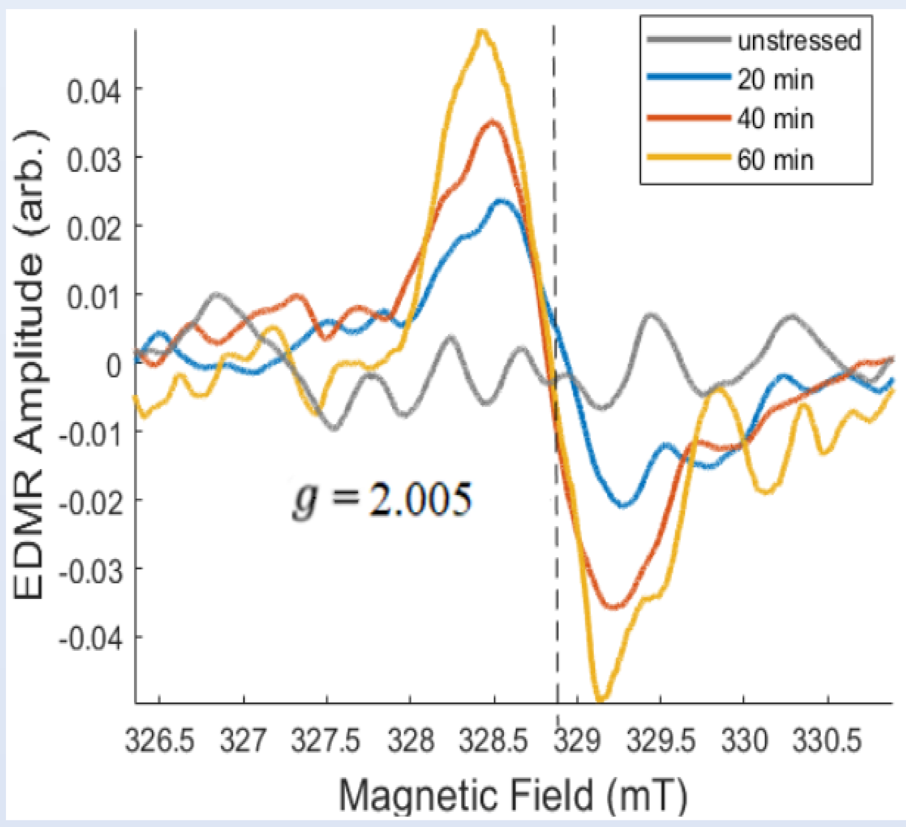

Fig. 4. Comparisons of SDTAT EDMR spectra for devices stressed at -9 V for: 20 minutes, 40 minutes, and 60 minutes. The only clearly identifiable signal is due to a combination of P_{b0} and P_{b1} silicon dangling bonds with a zero-crossing g≈2.005.

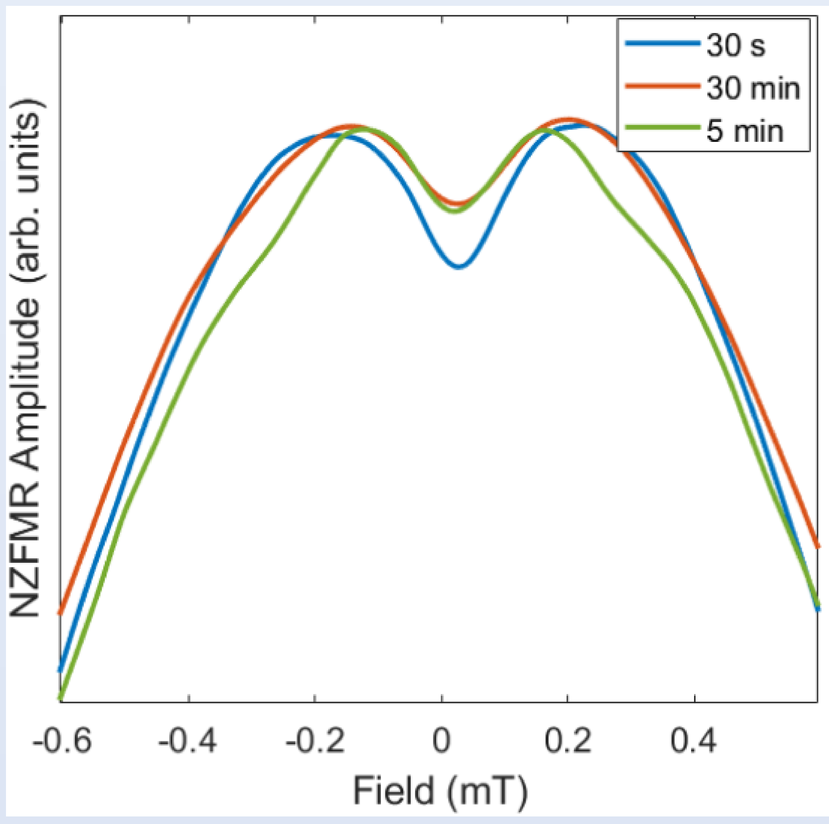

Fig. 5. Normalized comparisons of the integrated SDR NZFMR response for devices stressed at -9 V for: 30 seconds,5 minutes, and 30 minutes. The small changes in the central response are due to changes in the hyperfine interactions near the interface, indicating a redistribution of hydrogen throughout the stressing process.

Additional insight is provided by the integrated NZFMR traces in Fig. 3. The NZFMR line shape is primarily determined by two factors: trapping center kinetics and electron-nuclear hyperfine interactions [9]. Since the trapping kinetics are determined by bias conditions which are matched in all cases, the differences must almost certainly be due to changes in the interactions between nearby magnetic nuclei. Oxygen nuclei are non-magnetic. Although 4.7% of silicon nuclei are magnetic, it is extremely unlikely that these atoms move significantly at room temperature. Hydrogen atoms have 100% abundant nuclear moments. The redistribution of hydrogen nuclei and hydrogen atoms is the only plausible explanation for the changes in the NZFMR traces. This data indicates directly that a redistribution of hydrogen atoms takes place in the early stages of TDDB.

Acknowledgements

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