Duty Cycle Effect on Barrier Breakdown in MgO Magnetic Tunnel Junctions

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Spin-transfer torque magnetoresistive random access memory (STT-MRAM) is a promising memory technology because of its non-volatility, high speed operation, unlimited endurance, high density and compatibility with the standard CMOS process [1]. As the magnetic tunnel junction (MTJ) size shrinks, the MTJ resistance increases compared with the resistance of the selection transistor in a one transistor-one MTJ (1T-1MTJ) design. Hence, a thinner tunnel barrier that does not compromise on reliability is required. Oxide barrier breakdown is one of the key integration and reliability issues for advanced semiconductor memory technology. Notwithstanding its excellent potential, the breakdown mechanism of ultrathin MgO-MTJ has not been completely understood although a thorough understanding is essential for the success of STT-MRAM. In this work, we studied the lifetime of junctions using a time dependent dielectric breakdown (TDDB) [2] technique. Studies of time-dependent dielectric breakdown in magnetic tunnel junctions (MTJ) are usually carried out by applying a DC voltage while recording the time to breakdown [3]. This work reports on the breakdown behaviour of MgO tunnel barriers when submitted to consecutive voltage pulses with different time delays between consecutive pulses.

The studied junctions structure was buffer/ PtMn 20/ CoFe 2/ Ru 0.8/ CoFeB 2/ MgO 1.1/ CoFe 2/ NiFe 3/ cap (thickness in nm) with a plasma oxidised MgO layer. The measured devices were patterned into 200nm circular pillars showing 130% TMR and an R×A value of 30Ω.μm².

The experimental procedure consisted in applying successive pulses of 30ns with constant amplitude (~1.5V) at zero magnetic field until barrier breakdown occurs. The time interval, i.e. the delay, between consecutive pulses was a variable parameter. Experiments were repeated for time delays between pulses from 1ns up to 10μs. The pulse amplitude was 1.48V, corresponding to an electric field of 14 MV/cm. The data are well described by a Weibull distribution with scale parameter η, representing the total cumulated pulses when 63.2% of MTJ have failed.

The value of η is plotted in Fig. 1 as a function of the delay between consecutive pulses in Fig.1. Each point represents the average value for 20-40 junctions. This experiment shows that η has three different regimes.

For short delays <30ns between pulses, there is an increase in barrier lifetime, as the delay between pulses is increasing allowing for some cooling between pulses, which reduces the mean temperature on the cell. For pulse delays between 50ns to approximately 100ns, there is a significant increase in barrier lifetime as the dots completely cool to their pre-pulse temperature. However, this increased lifetime value is not maintained for longer delays. This behavior was observed for both pulse polarities of different amplitudes but it disappears with alternative polarity pulses as represented in the figure. The peak also depends on the pulse amplitude. For 1.48V the maximum lifetime is attained for 100ns delay time between pulses. The difference of behavior between unipolar pulses and alternative pulses excludes the possibility for the effect to be only temperature related. To interpret this result, we assume a model that combines thermal and electric charge-discharge phenomena.

For pulse delays shorter than 30ns, there is not enough time for the cell to return to its initial temperature. The cell temperature undergoes steady oscillations around an average value significantly higher than the ambient temperature. This increased average temperature renders the breakdown event more likely.

The second regime, for pulse delays between 50 and 100ns, corresponds to a significant increase of the barrier lifetime. This is followed by a decrease of barrier lifetime as the delay is further increased. We tentatively associate this intermediate behavior with an electric charge-discharge phenomenon, occurring as charges become trapped in barrier defects. The characteristic time for trapped charge release seems to be around 100ns. Therefore, if the delay between pulses is of the order of 100ns, a steady balance takes place between the amount of additional charges trapped in the barrier at each pulse and the amount of trapped charges released to the electrodes between two successive pulses. The barrier therefore reaches a sort of charged steady state during which the oxide barrier is not too much stressed.

The last regime for delays longer than 100ns can be explained as a second breakdown behavior of structural origin. The lattice dynamics of the magnesium oxide barrier is changed as a result of the electrostatic interactions between charges on traps. Because the charges have enough time to be released from the traps between successive pulses, a strong variable internal stress of electrostatic origin is exerted within the barrier. This variable stress facilitates the diffusion of metallic species from the metallic electrodes within the barrier especially through dislocations. According to our assumption, the electrostatic interactions between trapped charges can cause lattice vibrations of amplitude approximately 0.2A.

We have studied the duty cycle effect on barrier breakdown in MgO Magnetic Tunnel Junctions.

Three regimes were observed as a function of delay between voltage pulses. The results were interpreted in terms of temperature variation of the tunnel barrier and charge-discharge phenomenon impacting the barrier structure.. Further investigations of these phenomena are in progress on other samples and with other pulses amplitudes in order to further improve the resistance of these ultrathin MgO barriers to electrical breakdown.

References :

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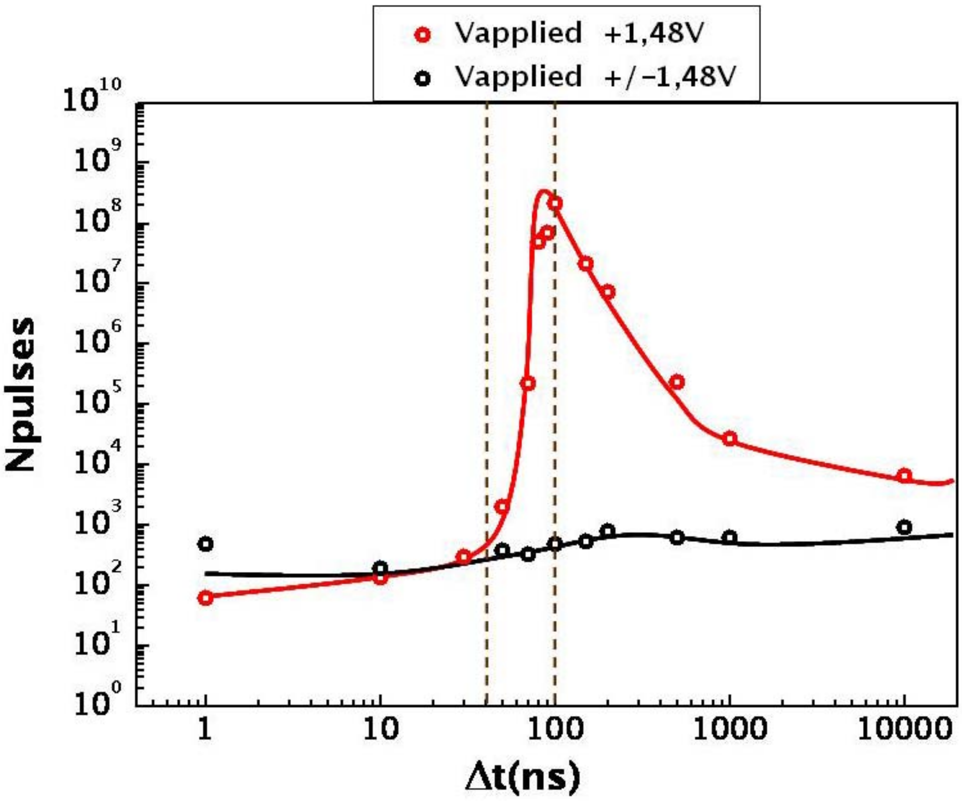

Fig.1: Time dependent barrier breakdown failure in 1.1nm MgO barriers. The stress voltage was applied in pulses of varying time gap between pulses maintaining constant amplitude.