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Instability of storage and temperature increment in nanopillars due to human body model electrostatic discharge

C. Surawanitkun[a], A. Kaewrawang[a], V. Imtawil[a], C.K.A. Mewes[b], T. Mewes[b], A. Siritaratiwat[a,*]

[a] Department of Electrical Engineering, Khon Kaen University, 123, Friendship Road, Khon Kaen 40002, Thailand
[b] Department of Physics & Astronomy, University of Alabama, Tuscaloosa, AL 35487, USA

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ABSTRACT

MRAM relevant to current induced magnetization switching (CIMS) is studied due to thermal increment caused by CIMS. In this paper, the instability of storage and the thermal increment caused by the transient current from the HBM ESD in nanopillars of MRAM are studied. We determine the voltage which can cause erroneous switching in MRAM by inducing CIMS. The finite element method is used to calculate the temperature increase caused by the discharge. Results indicate that this voltage is not sufficient to cause permanent physical or magnetic damage to MRAMs but only affects the reliability of the stored information.

1. Introduction

Nowadays, magnetic random access memory (MRAM) is a highly reliable memory technology [1,2]. MRAM was originally invented by Daughton and Pohm [3]. It possesses many advantages, such as high write/read speed, durability, nonvolatility, and high recording density [4–6]. MRAM based on magnetic tunnel junction nanopillars is a very promising future memory technology. In the considered geometry each magnetic tunnel junction (MTJ) nanopillar has three main layers. These layers consist of two thin ferromagnetic layers which are separated by an insulating barrier layer. The tunneling magnetoresistance (TMR) effect occurring in this geometry was first discovered in 1975 by Julliere [1,3,6]. TMR is defined as the ratio $[R_{AP} - R_P]/R_P$, where R_P is the differential resistance for parallel orientation of the magnetic moments in the two ferromagnetic layers and R_{AP} is the differential resistance for anti-parallel orientation [1,7].

The structure of MRAM has been continuously developed to increase the TMR ratio. The efficiency of the write/read process is increased according to the increasing TMR ratio [1,3,6]. Results show [1,3,6] that MgO-based MTJs have a high TMR ratio. Therefore, the MgO-based MTJ is widely used in MRAM structures. The theoretical predictions of current induced magnetization switching (CIMS) based on the spin-transfer torque effect can be utilized in MRAM to write the information [1,3,6]. CIMS has been studied extensively in recent years [2,4,5,8], in particular the aspect of the large current density, J, (several MA/cm^2) [2,4,5] required to achieve switching. The large current density in turn could cause an increase of the temperature in the MTJs [7], which might affect the thermal stability [2].

Electrostatic discharge (ESD) is the cause of major problems in electronic technologies [9,10]. It can lead to physical and magnetic damage in electronic devices [9]. For example if the temperature of the materials exceeds the melting temperature, T_m, or the Curie temperature, T_C, then this is considered to result in physical and magnetic damage, respectively [11]. Presently, there are three basic ESD models covered by standard models: the Human Body Model (HBM), the Machine Model (MM), and variations of the Charged Device Model (CDM). The intention of these models is to reproduce a discharge of a charged source to a device with at least one pin grounded [10]. For example, the discharge of a charged human into a device is called HBM. Furthermore, the ESD phenomenon arising in a device can be considered as the current flowing through the device [10]. The current caused by ESD can cause CIMS if its magnitude and time duration are sufficient. Therefore, undesired CIMS can occur from ESD and the reliability of storage is reduced.

The goal of this work is to explore the effect of ESD current transients due to HBM on MTJ nanopillars of MRAMs. This work indicates the minimum value of HBM voltage, V_{HBM}, that causes

* Corresponding author. Tel.: +66 4334 7442; fax: +66 4334 8853.
E-mail address: apirat@kku.ac.th (A. Siritaratiwat).

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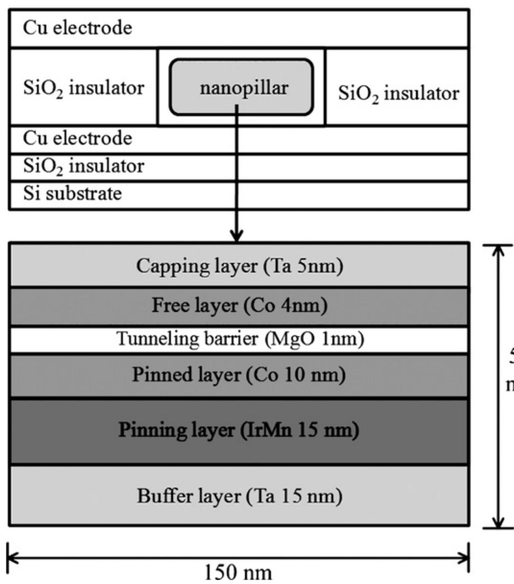

Fig. 1. Schematic diagram and details of the nanopillar structure used for the simulation.

damage to MRAM cells. We also study temperature increments caused by currents in the nanopillars at this minimal voltage. The outline of this paper is as follows. Section 2 presents the details of the structure of MTJ nanopillars used in this paper. The finite element method (FEM) used for the thermal analysis is also described in this section. The simulation results are shown in Section 3. Finally, the conclusions are given in Section 4.

2. Model and calculations

2.1. Thermal calculation

Numerical calculations based on the finite element method were performed using the program package multiphysics finite element method COMSOL. This package is used to estimate the temperature increment, ΔT, of the MTJ nanopillar caused by Joule heating. In this work, the quadratic interpolation in FEM was used for the thermal calculation based on heat conduction equation. The mesh type was defined by triangle and a high mesh density was specified for in the MTJ nanopillar. The general structure of the MTJ nanopillar in an MRAM is typically elliptical in shape [1], however for the calculations of the temperature increase a cylindrical symmetry is assumed. The multilayer structure of the MTJ nanopillar considered in this paper is obtained from that reported in the literature by Ha et al. [5]. The multilayer structure consists of two Cu electrodes, Co pinned and free layers, IrMn pinning layer, SiO_2 insulator layer, MgO tunneling barrier, and the Si substrate, as shown in Fig. 1. The thickness of structure examined is 12.5 μm and an electrode radius of 12.5 μm, which is suitably large to substitute the real size of the electrodes. The resistance-area and area of the nanopillar are 25 Ωμm^2 and 0.017 μm^2, respectively [5] with a nanopillar radius, r, considered in this paper is 75 nm.

Table 1
The electrical and thermal conductivity for the materials in nanopillar of MRAM [13].

Materials	σ (Ωm)$^{-1}$	K (W/(mK))
Ta	6.5×10^5	58
Co	1.6×10^7	692
Cu	5.9×10^7	400
IrMn	6.8×10^5	35.6
MgO		45

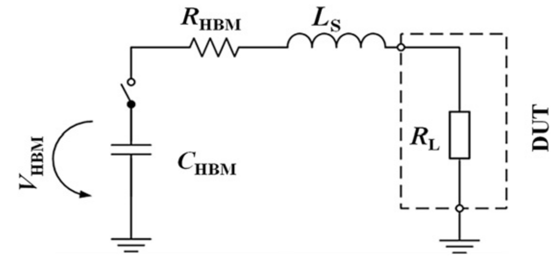

Fig. 2. RLC circuit according to HBM [10].

Table 1 presents the values of the electrical conductivity, σ, and thermal conductivity, K, of the various layers. The σ of MgO was estimated from the junction resistance [12,13]. The problem of finding ΔT can be reduced to a two dimensional problem because of the axial symmetry of the nanopillar structure along the z-direction. In this work, it was assumed that the HBM ESD current transient flows from the bottom electrode to the top electrode and from the top electrode to the bottom electrode of the nanopillar. The initial temperature was assumed to be 298.15 K (ambient temperature).

2.2. Analysis for CIMS caused ESD current

The electrical circuit of the HBM shown in Fig. 2 consisting of HBM capacitor, HBM resistor, load resistor, parasitic series inductance in the discharge path, and device under test denoted as C_{HBM}, R_{HBM}, R_L, L_s, and DUT, respectively [10]. The values of these parameters used in the present study are C_{HBM} of 100 pF, R_{HBM} of 1500 Ω, L_s of 8 μH and R_L is the resistance of the nanopillar [10,14]. The values of C_{HBM} and R_{HBM} were obtained from the ANSI/ESDA/JEDEC JS-001-2010 Standard. The inductance L_s in the discharge path determines the rise time for the current waveform. Verhaege (1993) showed that for the HBM, typical values of L_s of ESD testers are in the range of 5–10 μH [10]. These parameters produce a current waveform having a rise time, t_r, of 5 ns which is corresponding with HBM standard having t_r between 2 and 10 ns [14,15]. The t_r is measured between the time the pulse reaches 10% of its peak current to the time the pulse reaches 90% of its peak current. The ESD current waveform, shown in Fig. 3, has a duration of the discharge waveform of HBM ESD of 200 ns [14,15]. This figure also shows the peak current, I_p, t_r and the duration for which the current exceeds a value I_1 which we refer to as τ_{HBM} (I_1).

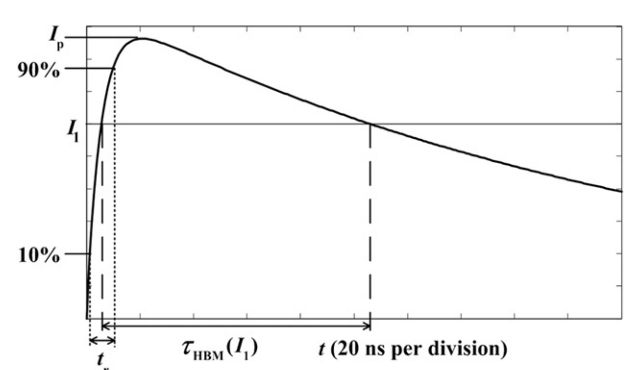

Fig. 3. The ESD current waveform.