Oscillatory dependence of magnetoresistance with bias voltage in Fe/MgO/Fe/MgO/Fe epitaxial double magnetic tunnel junctions with dielectric breakdown

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Double magnetic tunnel junctions present novel promising for applications devices in which electron transport through central nanometer size magnetic electrode could be influenced by charge quantization, quantum well effects, spin accumulation and spin torque.

Here we present detailed investigation at the room temperature electron transport in epitaxial Fe(100)/MgO/Fe/MgO/Fe double magnetic tunnel junctions (DMTJ´s) with dielectric breakdown in the barrier. Figure 1 shows magnetization of the MTJs, it´s TEM (Transmission Electron Microscopy) analysis and tunneling magnetoresistance (TMR) at room temperature. The reduced TMR is due the Nitrogen doping of the barrier which reduces effective barrier height of MgO and therefore minimizes the possible damage from the breakdown over the flatness of the central Fe electrode. As a consequence, the breakdown voltage of the barrier was always essentially below 1V. The tunnel magneto resistance (TMR) at zero bias in our "fresh" samples is close to 30% (Fig.1), however after application of about ~500mV the TMR decreases down to 4%. The change in the TMR and the magnetic transitions for the three electrodes, as shown in Fig.2, indicate indirectly that the dielectric breakdown in the barrier decreases the effective MgO thickness. We believe that the breakdown of the doped MgO barrier could result in the local displacement of the atoms where a local amorphization in the barrier appears near "hot-spot" concentrating the current. For the DMTJ´s with "pinhole" we observed periodic changes in resistance as a function of bias voltage which are in satisfactory agreement with recent first principal calculations by Wang *et al.* [1], that considering formation of quantum well states in the middle Fe free layer (see arrows in Fig. 3). The bias dependence of the tunneling magnetoresistance varies strongly with the direction of external magnetic field indicating possible local spin torque effects in the breakdown region

In conclusions, the oscillatory dependent TMR in the DMTJ´s with dielectric breakdown indicate the local resonant tunneling through the quantum well states in the middle free layer, possibly affected by spin torque effects. A simple model which suggests local amorphization of the MgO barrier and intact central free Fe layer close to the breakdown region qualitatively explains the main experimental observations.

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References:

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Figures:

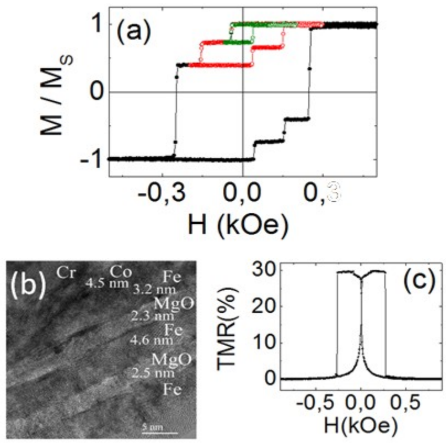

FIG.1 (a) Magnetization vs. field for unpatterned DMTJ. The black line corresponds to the top electrode, the green to the middle and the red to the bottom electrode. (b) Cross-sectional TEM image of the DMTJ. (c) Typical zero bias TMR measured before the breakdown.

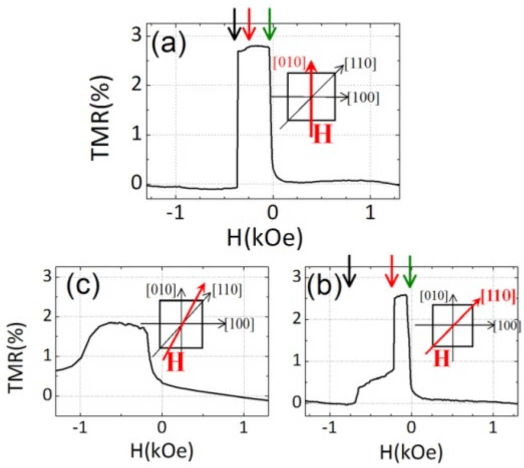

FIG.2 Zero bias TMR after breakdown: (a-c) show correspondingly TMR measured with magnetic field applied along the (easy axis (EA), hard axis (HA) and intermediate state (IA), respectively. The arrows show the coercive field of the different layers (green for the middle, red for the bottom and black for the top electrodes).

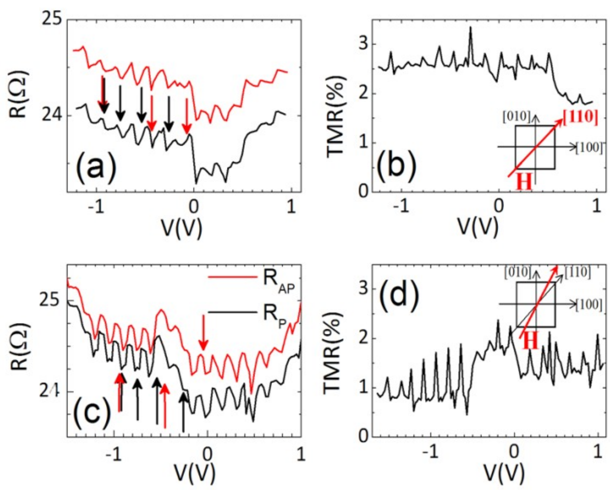

FIG.3 (a), (c) Resistance vs. bias measured for parallel (black line) and antiparallel (red line) states with magnetic field applied along the HA and IA respectively. The arrows show the theoretical predictions by Wang et *al*. [1] for the resonant tunneling in the parallel state with QWS above (red arrows) and below (black arrows) Fermi level. Parts (b,d) show TMR vs. bias for magnetic field applied along the HA and IA directions.