TEMPERATURE DEPENDENT TRANSPORT PROPERTIES OF MgO-BASED ULTRA-THIN MAGNETIC TUNNEL JUNCTIONS: EXPERIMENT AND MODELING.

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Magnetic tunnel junctions (MTJs), constituted by two ferromagnetic (FM) layers separated by an insulating barrier, are currently used as magnetic sensors in high density recording media. The characteristics of the tunnel junctions implemented in read heads include a low resistance-area product ($R \times A$), to achieve a high readout speed, and a high enough sensitivity to read the ever smaller magnetic bit. To achieve the desired $R \times A$-values, the thickness of the insulating barrier is decreased to less than one nanometer, towards a few atomic planes thick. This leads to the possible existence of metallic paths across the insulating barrier (pinholes), with consequences in device reproducibility, performance and reliability. Furthermore, the presence of pinholes can have important impact on the MTJ-spin transfer driven magnetization dynamics, or on the MTJ-magnetoresistance sign.

Recently, tunnel junctions with crystalline MgO(001) barriers displaying very large tunnel magnetoresistive (TMR) ratios were successfully fabricated, opening new opportunities to develop read heads for ultrahigh density hard drives. The large TMR ratio of crystalline MgO tunnel junctions arises from the different symmetry-related decay rates of the Bloch waves for majority and minority spin channels. For sensor applications, MTJs with tunnel magnetoresistance above 50% and $R \times A$ as low as 0.4 $\Omega\mu m^2$ were recently obtained using thin MgO barriers.[1] However, a significative TMR-decrease is usually observed with decreasing MgO thickness,[2] showing the importance of studying the impact of pinholes on the magneto-transport properties of ultra-thin magnetic tunnel junctions.

To probe the absence of pinholes in MTJs one usually uses the three applicable Rowell criteria. However, both the exponential dependence of resistance with insulator thickness and the non-linear current-voltage characteristics were found to be non-reliable even in high resistance tunnel junctions ($R \times A \geq 1$ kΩm^2).[3] On the other hand, the third criteria [the weak insulating-like temperature dependence of the electrical resistance ($dR/dT<0$)], although insensitive to the presence of few or small pinholes in low resistance MTJs (≤ 10 $\Omega\mu m^2$),[4] can be used to probe if sizeable pinholes are present in the barrier.[5]

Here we study the temperature dependence (300-20 K) of the transport properties of low resistance magnetic tunnel junctions with an ultra-thin MgO barrier (7.5 Å). Our samples display $R \times A \geq 40$ $\Omega\mu m^2$ and TMR ~ 60-75% at room temperature. Temperature dependent electrical resistance measurements [R(T)] allowed us to observe different behaviors depending on the MTJ-magnetic state. The studied samples showed positive dR/dT for the parallel (P) state (Fig. 1), indicating a metallic-like behavior, so that pinholes are already present in the barrier. However, in the antiparallel (AP) state, the R(T) curves exhibit a mixed character, with dR/dT negative at sufficiently high temperatures but changing to positive at low temperatures (Figs. 1 and 2b). These results show an interesting competition between tunnel and metallic transport in the studied samples.

In order to understand this transport behavior, we propose a simple model of two conducting channels, metallic and tunnel, acting in parallel. We assume a linear temperature variation of the electrical resistance for both conducting channels, as observed experimentally over a broad temperature range. The model also takes into account the experimentally observed dependence of the linear coefficients on the MTJ-magnetic state (parallel and antiparallel). According to the model, the sign of the *dR/dT* derivative does not illustrate the dominant conductance mechanism and the crossover temperature (T^*) at which *dR/dT* changes sign in the

AP state depends strongly on the linear temperature coefficients. Fittings performed to the experimental *R*(*T*) data, using the developed model, reproduce the data quite well, illustrating the validity of the model.

References:

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Figures:

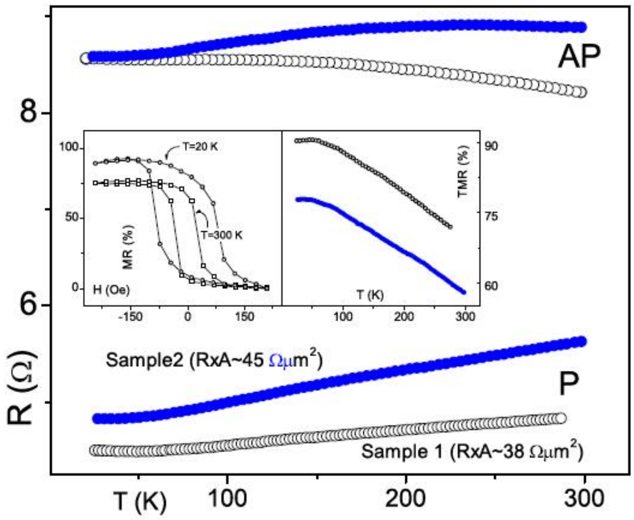

Fig. 1: Temperature dependence of the electrical resistance of samples 1 and 2 in the parallel and antiparallel states. Insets: Room and low temperature magnetoresistance cycles (sample 1) and MR-temperature dependence.

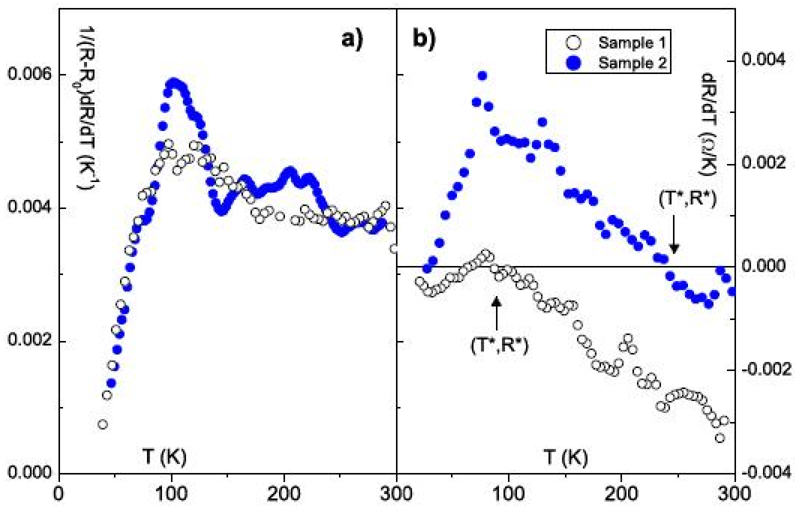

Fig. 2: Temperature derivative of (a) the normalized electrical resistance in the parallel state and (b) the electrical resistance in the antiparallel state.