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Magnetic tunnel junctions with large tunneling magnetoresistance and small saturation fields

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There is a continuing need for greater sensitivity in magnetic tunnel junction (MTJ) sensors. We have found a new approach to achieving large tunneling magnetoresistance (TMR) with a very soft free layer. The high TMR is achieved by conventional means of annealing a bottom pinned MTJ that has Ta and Ru capping layers. The soft free layer is achieved by etching almost to the MgO tunnel barrier and depositing a thick soft magnetic film. The results are far superior to annealing the MTJ with the thick soft layer already deposited. © *2010 American Institute of Physics*. [doi:10.1063/1.3358609]

One property that is important for some classes of magnetic sensors is high sensitivity. In the case of magnetic sensors based on magnetic tunnel junctions (MTJs), the sensitivity generally increases with increasing tunneling magnetoresistance (TMR) and increases with decreasing saturation field (B_{sat}) of the free layer in the MTJ. In systems with linear response, the low-field sensitivity is, to a first approximation, proportional to the ratio of TMR to B_{sat}.

Here we report an approach that leads to MTJ structures at the wafer level that have TMR values in excess of 100% and B_{sat} values below 1 Oe. The ratio appears to be the largest ever reported for a MTJ structure at the wafer level.

The approach we have used is to fabricate and anneal MTJs of a rather conventional type (the structure is illustrated at the top of Fig. 1.), then etch down into the free layer of the MTJ, and deposit a thick (100 nm) and very soft magnetic film to lower B_{sat}. We have found that incorporating the soft film in the initial structure lowers the TMR significantly upon annealing. Maintaining a large TMR depends on depositing the soft film after annealing.

Figure 1 presents data illustrating the approach. As the depth of the Ar ion etch (500 eV) nears the MgO tunnel barrier, the TMR and RA (measured after deposition of the soft film) fall off abruptly. The falloff does not occur until the surface is less than about 1 nm above the MgO tunnel barrier. The depth of the ion milling was calibrated using x-ray photoelectron spectroscopy to observe how deep into the structure the milling had gone.

Figure 2 illustrates the TMR data for one such sample measured using a current in-plane tunneling instrument, as described in Ref. 1. The magnetically soft layer is 100 nm $Ni_{77}Fe_{14}Cu_5Mo_4$, a material found earlier to produce small values of B_{sat}.[2] A capping layer of 7 nm Ru helps make good electrical contact for measurements. The accuracies of the resistance and magnetic field measurements are ±1% and ±3%, respectively.

Figure 3 shows the data taken with a BH looper (where B is the measured magnetic flux and H is the applied magnetic field) to examine the detail of the low-field loop. Here a static field of 1.8 Oe is applied perpendicular to the sweep field (i.e., in the hard axis) to suppress the hysteresis of 1.3 Oe. This technique is described in Ref. 3. The sweep field is in the easy axis of the free layer and the side field is in the hard axis of the free layer. The low-field loop is linear, nonhysteretic, and extrapolates to saturation at 0.8 Oe.

Simulations of ion-beam damage in this system by the Stopping and Range of Ions in Matter (SRIM) code[4] indicate that the ion-beam damaged region, defined as the depth of energy deposited, goes into the MgO tunnel barrier. This result indicates that the MgO tunnel barrier appears to be somewhat tolerant of ion damage. Figure 4 illustrates the point in (a) the thickness of CoFeB is 2 nm, i.e., at the Ta/CoFeB interface. Ions are already depositing energy as deep as the CoFeB/MgO interface. In Fig. 4(b), the CoFeB thickness is 0.5 nm, and most of the energy is deposited in MgO. Our etch rate calibrations are only accurate to about ±0.5 nm (based on x-ray photoelectron spectroscopy). How-

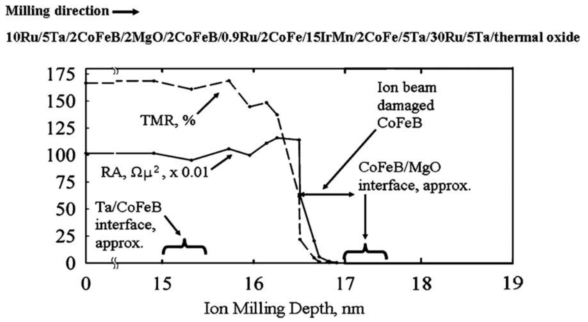

FIG. 1. Data illustrating how the TMR and RA fall off as a function of the ion milling depth when a MTJ of the type above is milled to the indicated depth, followed by the deposition of 100 nm $Ni_{77}Fe_{14}Cu_5Mo_4/7$ nm Ru.

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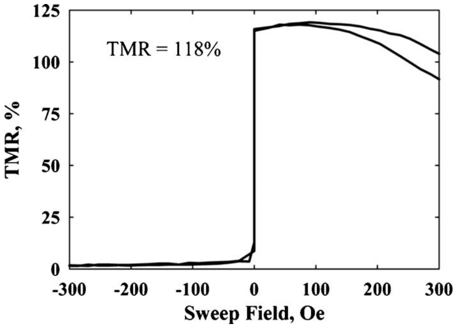

FIG. 2. TMR data measured by current in-plane tunneling after ion milling to a depth of 16.3 nm, followed by the deposition of 100 nm $Ni_{77}Fe_{14}Cu_5Mo_4/7$ nm Ru.

ever, we can say that at the end of the milling, we certainly have something closer to Fig. 4(b) than Fig. 4(a). It is interesting that the tunnel barrier is still quite functional.

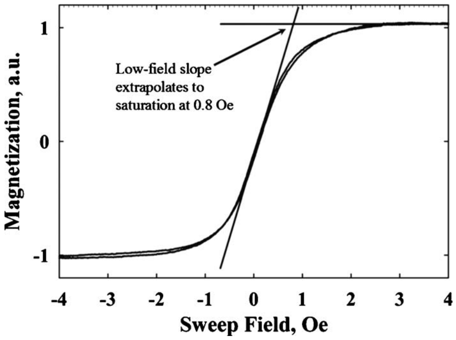

FIG. 3. An extrapolation of the low-field loop to saturation on the sample in Fig. 2 using a BH looper for high resolution at low fields.

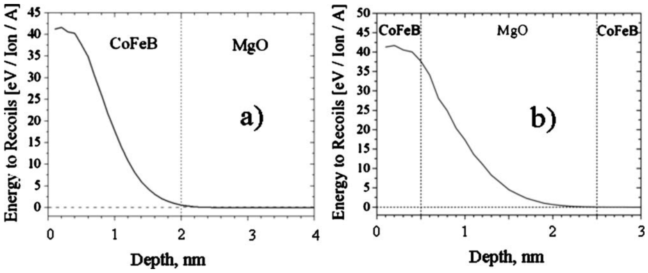

FIG. 4. SRIM simulations of the depth of energy deposition during the ion milling for (a) having 2 nm CoFeB at the surface and (b) for having 0.5 nm CoFeB.

It appears that these results represent the first time a MTJ structure at the wafer level has exhibited a TMR larger than 100% and a B_{sat} under 1 Oe, thus constituting the highest sensitivity ever reported for a MTJ structure at the wafer level.

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