Stability of magnetic tunnel junctions

R. Kinder a, b, *, L. Bär a, G. Rupp a, U.K. Klostermann a, b, J. Bangert a, G. Bayreuther b, J. Wecker a

a Siemens AG, CT MM 1, Paul-Gossen-Str. 100, D-91052 Erlangen, Germany
b Department of Physics, University of Regensburg, Universitätsstr. 31, D-93040 Regensburg, Germany

Abstract

When magnetic tunnel junctions (MTJ) are built into a memory device they will be arranged in a matrix; therefore some of the not addressed elements will be exposed to a significant field during the switching of one element. It has to be avoided that the state of not selected MTJ is changed during this process. Here we present data on the stability of MTJ against small fields which occur during a writing process. © 2002 Elsevier Science B.V. All rights reserved.

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1. Introduction

As magnetic tunnel junctions (MTJ) provide a possibility for a fast, non-volatile solid-state memory, there has been much interest on this subject in the last years since large TMR at room temperature was discovered [1,2].

In a memory device, the MTJ (each presenting one bit) will be arranged in a matrix, where the elements are placed at the cross points of the bit- and word-lines. The switching of a single element cannot be done with an external field in this case, as this would switch all the elements in the array. The switching with a field generated by a single current is not possible because in this case all the elements on the selected line would switch. Therefore the switching has to be done with two currents, one on the bitline and one on the wordline; both currents must be below a certain critical current to avoid switching or disturbance of the neighboring elements. Only at the cross point, the superposition of the two fields is high enough to switch the storage layer of the selected element.

Provided that the single elements have an uniaxial (shape and/or induced) anisotropy, it is possible to induce a rotational magnetization reversal if the currents are shifted against each other. First the current which generates the field perpendicular to the easy axis rotates the magnetization out of the easy axis and then the second current with the field parallel to the easy axis finishes the switching of the element. In this way, a switching with fields below the coercivity field of the elements is possible. Furthermore this rotational like switching is advantageous for the stability of the reference layer which can be damaged by fringing fields [3].

Here we present data on the stability of the soft magnetic (storage) layer against subcritical fields i.e. fields which are below the switching field of the storage layer itself. The MTJ used for the measurements were fabricated by a four mask optical lithography process. The multilayers were grown on an SiO2 substrate in a sputtering machine. The layer sequence was Ta/Cu/AAF/AlOx/Py/Ta with an artificial antiferromagnet structure consisting of CoFe/Ru/CoFe as reference layer and a 1.3 nm thick Al layer which was plasma-oxidized without breaking the vacuum. The AAF structure was aligned in a field of about 400 kA/m before the measurements.
2. Results

The measurements were done in the following way: First the storage layer was saturated parallel to the reference layer to reach the state of minimum resistance. As we are interested in the stability of the remanent state of the junction we applied a constant bias field to compensate the shift of the minor loops due to the ferromagnetic Néel coupling. Then an additional field along the easy axis was applied and switched of again. The resistance in the remanent state (where still the overlaying bias field was active) was then measured and compared to the first measured resistance. The field cycle between the test field and the bias field was repeated 100 times to see if there is a change in the behavior with increasing cycle numbers.

A typical result of such a measurement is shown in Fig. 1. Both junctions have the same size but the shape is different; one elliptical (left) and one rectangular (right). The plots show the mean value of the remanent TMR after the field cycling at a certain field value; the dotted lines show a minor loop measurement of the junctions for comparison.

Both measurements show a sharp transition between a stable state at low fields and a stable switching at higher fields. This sharp transition is in good agreement with the switching field taken from the minor loop measurements. The stable state for lower field values indicates that the increasing resistance at fields below the switching field can be seen in the minor loop which can be seen in the minor loop on the way back. This indicates that there are still domains inside the storage layer. To gain the real remanent point of the antiparallel state the field has to be significant higher than the switching field.

These measurements are different from our previous results [4] where the remanent state changed already for fields significantly below the switching field of the junction. We think that this improvement is due to the different buffer layers. The samples from [4] were grown on a magnetic Fe buffer to get flat interfaces. On the other hand, the domains in this buffer layer generated strong stray fields. These clearly influenced the switching of the storage layer [5]. It is likely that these stray fields were also responsible for the observed instability at low fields which are not seen with the non-magnetic buffer.

First measurements with switching by a current through the wordline indicate that this behavior remains the same if the number of field cycles is increased to $10^8$ and higher (see Table 1).

As mentioned above there are not only elements which are exposed to a single field, but also the junctions diagonal next to the addressed junction are exposed to two fields from the neighboring current lines. Therefore this measurements on subcritical fields were also done with two crossed fields pulses which are shifted in time against each other. The procedure of the measurement is similar to the measurements mentioned above: First the junction is saturated and then the switching cycle for one specific field combination is done. The sequence of the applied fields is like mentioned in the introduction. In this measurement, the orange peel coupling was not compensated. The resistance was then measured in the remanent points. The field cycle was repeated 50 times.

Fig. 2 shows a typical result of such a measurement, in this case for an element of $2 \times 1 \, \mu m$ with pointed ends.

Table 1

<table>
<thead>
<tr>
<th>N(%)</th>
<th>$2 \times 10^8$</th>
<th>$10^9$</th>
<th>$4 \times 10^9$</th>
<th>$9 \times 10^9$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R/R_0$ (0.67 $H_{SW}$)</td>
<td>0</td>
<td>0</td>
<td>—</td>
<td>0</td>
</tr>
<tr>
<td>$R/R_0$ (0.91 $H_{SW}$)</td>
<td>0</td>
<td>0</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>$R/R_0$ (0.97 $H_{SW}$)</td>
<td>5</td>
<td>16</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>$R/R_0$ (1.03 $H_{SW}$)</td>
<td>16</td>
<td>16</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

*aThe remanent resistance normalized to the parallel magnetized remanent state is shown. There is a sharp transition between the stable region and full switching ($H_{SW}$: switching field; reduction factor:0.55).
The plot shows the maximum change in the remanent resistance during one cycle as a function of the applied easy axis field. The different curves belong to different perpendicular fields $H_{pp}$. Without perpendicular fields there is a sharp transition between a stable state for low fields and a stable switching for high fields. For intermediate perpendicular fields a different behavior is observed: Here the switching occurs only at a certain ratio of the cycles. The more the fields get to the switching value, the higher is the ratio of switched cycles. This can be seen on the dotted curve for $H_{pp} = 0.5 \text{kA/m}$ where for easy axis fields of 1.6 and 2.0 kA/m the junction is switched two times whereas for 1.6 kA/m easy axis field no switching can be observed. At this point it is important to note that there is no switching into intermediate resistance states for not too high perpendicular fields. The storage layer either switches completely to the antiparallel remanent state or it returns to the parallel remanent state. For higher fields perpendicular to the easy axis and low fields parallel to the easy axis the magnetization of the storage layer gets trapped in a not saturated state.

3. Conclusion

We presented data on the stability of MTJ against small fields which occur in a matrix arrangement of the junctions when the magnetization of one single element is reversed by two fields perpendicular to each other. The data show a good stability up to fields near the switching field.

Acknowledgements

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References