Magnetic Random Access Memories (MRAMs)

Personnel

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Magnetic-Random-Access Memories, MRAM's are solid-state non-volatile magnetic storage devices in which each bit of data is stored an a small, elongated magnetoresistive sandwich element. A typical MagnetoResistive (MR) sandwich consists of two magnetic layers of different coercivity, one hard and one soft.

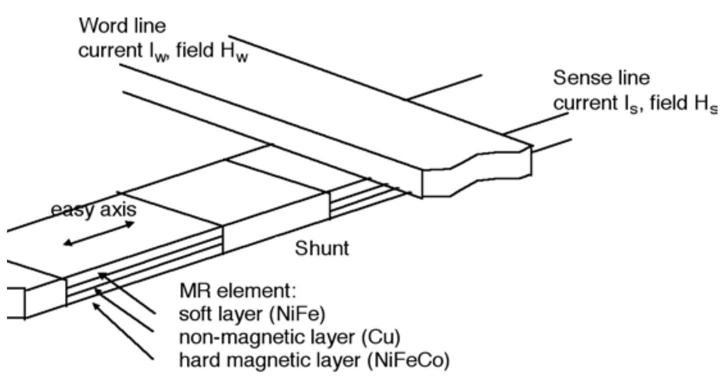

Fig. 3: Schematic of MRAM structure, which consists of an array of parallel sense lines and parallel word lines. The MR elements are connected in series. Magnetic fields generated by currents passed simultaneously through a sense line and a word line write the element at the intersection of the two lines. To read, resistance changes in the sense line caused by a smaller wordline current are measured.

As illustrated in Figure 3, the direction of magnetization of the hard layer is used to represent the data bit. To write data, a magnetic field is applied by passing a current through a conductor line (word line) adjacent to the element, such that the field is large enough to change the magnetization of the hard layer. To read, a smaller current is passed, which can change the magnetization of the soft layer only. The resistance of the element depends on whether the hard and soft layers are magnetized parallel or antiparallel, hence changes in the resistance resulting from the reversal of the soft layer can be used to probe the magnetic state of the hard layer. Elements are arranged in a rectangular array and connected with conductor lines, allowing individual elements to be selected.

We have used interference lithography combined with reactive ion etching and ion-milling to produce arrays of Co/Cu/NiFe, Co/Cu/Co and NiFe/Cu/NiFe spin-valve elements and prototype MRAM structures. The aim of this research is to investigate the behavior of sub-100 nm elements, much smaller than those used in present-day MRAM devices.

To tailor the properties of the Pseudo Spin Valve (PSV) elements for MRAM devices, we analyzed the hysteretic behavior of large-area arrays of rectangular and elliptical PSV dots. Elongated elements of sub-100nm widths and aspect ratios ranging from 1:1 to 1:10 were fabricated by exposing and etching a first grating into an SiO_2-layer, and then spin-coating the sample with new resist and exposing a second grating of different period perpendicular to the first one. The hysteresis obtained from an series of 70-nm wide PSV dots with different aspect ratio exhibits two distinct steps, as shown in the Figure 65, corresponding to the separate switching of the Co and NiFe layers. The switching of the two magnetic layers and their antiparallel alignment at remanence leads to the conclusion that the layered PSV-structure is preserved through the pattern transfer process. Upon increasing the aspect ratio of the PSV-dots, the magnetic field at which the soft layer switches to antiparallel alignment decreases and eventually the two magnetic layers align parallel at remanence, as required for MRAM devices.

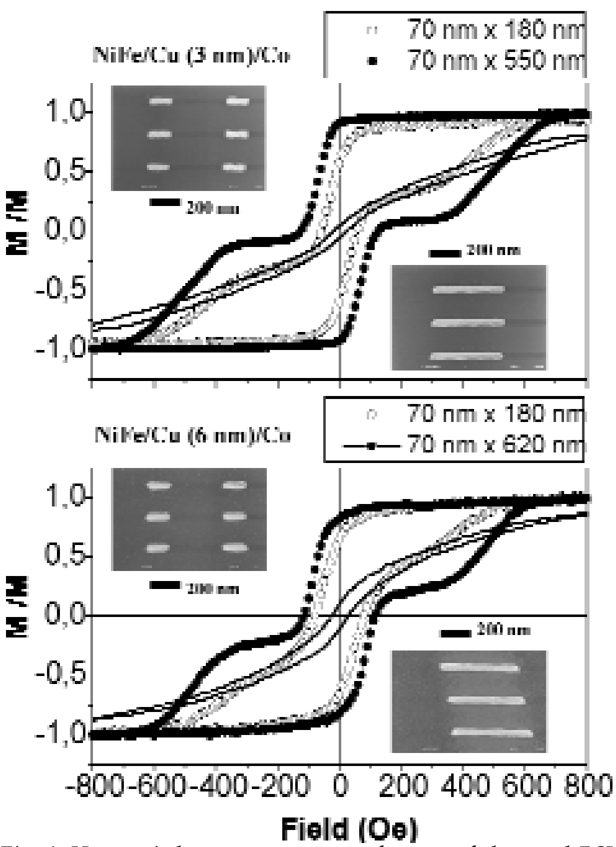

Fig. 4: Hysteresis loop measurements of arrays of elongated PSV elements with different Cu spacer thickness. Dotted loops (open and full circles) correspond to an applied magnetic field parallel to the longer side of elements. Hard axis loops obtained on applying a magnetic field perpendicular to the longer side of the lower aspect ratio arrays (solid lines) are also depicted. SEM images of the samples are shown as insets.

In Figure 5, an MRAM structure is shown. The PSV elements are located where the horizontal word lines and the nearly vertical sense lines intersect, sandwiched between the sense lines and a 30nm SiO_2-insulation layer. The buried PSV elements form a large-area array of 80x180nm PSV dots, as indicated by magnetic measurements. Their magnetic behavior is similar to that of large-area PSV-dot arrays of the same dimensions. Both word and sense lines were found to be conductive.

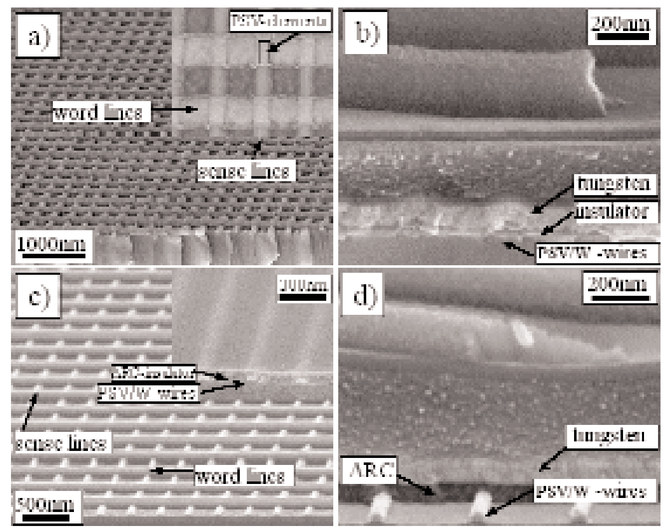

Figure 5: a,c): MRAM-type structures fabricated using IL. The PSV-elements are located where the vertical sense and the horizontal word lines intersect. Sandwiched between an insulator and the sense lines, the buried PSV elements form a large area array of PSV elements. a): The undulated word lines on top are insulated from the PSV stack by a 30nm thick silica layer. Word and sense-lines were found to be conductive. c): Before depositing the word line material, the sample was planarized using ARC, see inset. The word lines are perfectly planar. b,d): These SEM micrographs were taken just after developing the second grating, later forming the word lines. PSV/W-wires are resolved in cross-section at the substrate interface. Following pattern transfer by RIE and ion milling, the MRAM-type structures in a) and c) were obtained.