Microsc. Microanal. 8 (Suppl. 2), 2002
DOI 10.1017.S1431927602103370

Surface Nano-oxidation of Ferromagnetic Thin Films Using Atomic Force Microscope

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A recent progress in lithography techniques has enabled us to fabricate nano-scale structures and devices. Nano-scale fabrication techniques are significant for developments of magnetic devices such as high density recording system, memories and a new class of spin-related devices. The scanning probe microscopes (SPM) such as scanning tunneling microscope (STM) and atomic force microscope (AFM) have recently attracted much attention not only as observation tools but as noble tools for fabricating electron devices with well defined structures of a nano-meter scale. It has been reported that surfaces of metal and semiconductor are selectively oxidized by applying a negative bias on the SPM tip as shown in Fig. 1(a) [1, 2]. This anodic oxidation process is an electrochemical reaction between metals and water in air. As this fabrication technique does not require any pre-treatments such as resist coating, it is a useful tool for fabricating nano-structure devices [3].
We fabricated nanodots of NiFe-oxide by applying a pulse voltage from 6 to 9 V for 0.1 s to the AFM cantilever in air [4]. Figures 2 and 3 show AFM image and size of the nanodots of NiFe-oxide fabricated on 20 nm NiFe film, respectively. With increasing voltage, the height and diameter increased in the range from 3.5 to 14 nm and from 60 to140 nm, respectively. In order to evaluate the size of the nano-oxidized structure quantitatively, the electric field emitted from the AFM cantilever is calculated. Figure 4 shows the calculated field strength for various curvature radius of cantilever, *R*c. The experimental value of the size of nanodots fabricated with using the cantilever of *R*c=10-20nm, typical values of the commercial products, suggests that the electric field of the order of 10^7-10^8 V/m is required to promote the electrochemical reaction. The experimental results on the characteristics of pulse-duration dependence, scan speed dependence and others also agree with the calculation. It is suggested that smaller oxidized nanostructures can be fabricated with using the cantilever equipped with carbon nanotube, which is advantageous in fabricating planar-type magnetic tunnel junctions as shown in Fig. 1 (b) [3].

References

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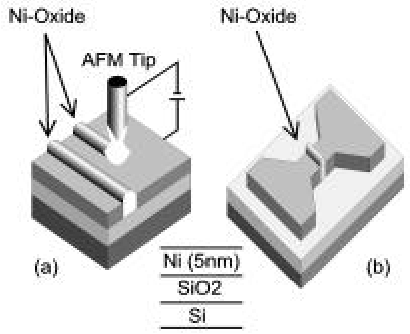

Fig. 1 Schematics of AFM nano-oxidation technique (a) and planar-type ferromagnetic tunnel junction (b).

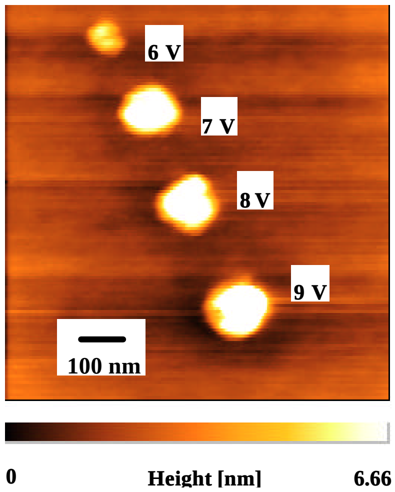

Fig. 2 AFM image of NiFe-based nano-dot structures fabricated by AFM nano-oxidation technique. The pulse voltage of 6, 7, 8 and 9 V for 0.1 sec duration was applied.

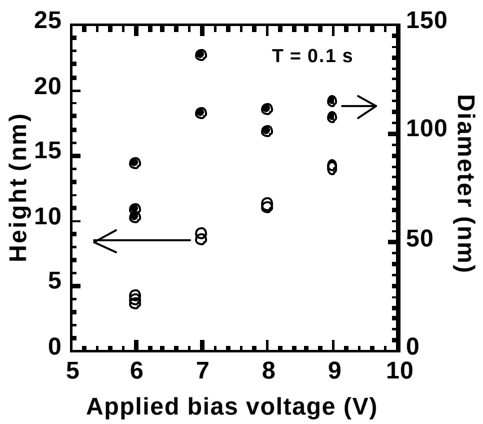

Fig. 3. Height (○) and diameter (●) of NiFe-based nano-dot structures fabricated by AFM nano-oxidation technique as a function of the applied pulse voltage for 0.1 sec duration.

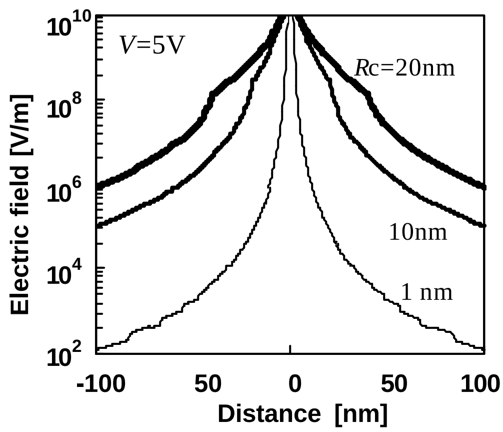

Fig. 4 Calculated electric field at film surface generated from biased AFM cantilever with its various curvature radius, *R*c.

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