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Nanometer Effect of Magnetic Dot Size for 40nm Dot Pitch Patterned Media Prepared by Electron Beam Lithography and Ion Milling Measured Using Micro X-Ray Magnetic Circular Dichroism

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***Abstract*: The effect of difference magnetic dot size for 40 nm dot pitch arrays as measured by Micro XMCD has been studied. A 40-nm magnetic dot pitch with varying dot size has been fabricated. A 30 KeV Electron Beam Lithography was used to fabricate the Calixarene dot pitch on CoPt magnetic film. Dot resist was used as a mask to ion mill the CoPt magnetic film using ion milling equipment at 400 kV, 50 mA, and Ar for acceleration voltage, ion current, and gas, respectively. The ESMH curve of magnetic dot arrays was measured via Micro X-Ray Magnetic Circular Dichroism at Beam Line BL39XU in Spring-8. The results show that all coercive forces for magnetic dot arrays are the same at 0.35 kOe. There are no increments when the dot diameter size decreased. The ESMH curve also shows when the dot diameter became smaller, the intensity of XMCD drastically decreased. These results indicate that a dot diameter of less than 25 nm has no effect on the coercive force at 40 nm dot pitch.**

***Index Terms*: Patterned Media, EBL, Ion Milling, Micro XMCD.**

I. INTRODUCTION

Magnetic recording density has increased rapidly, at about 60% per year. Recently, the progress of fabrication in magnetic recording density has slowed in terms of both commercialization and research. Now the magnetic recording density with 700 Gb/in2 was commercialized by using perpendicular magnetic recording. Perpendicular magnetic recording has limitations in bit size due to the thermal instability, as each recorded bit is changed by neighbor bits, even at low temperature [1]. To overcome this, bit-patterned media was proposed [2]. Bit-patterned media offers the advantages of higher coercive force and thermal stability because every bit is stand-alone. Meth-ods to prepare bit-patterned media include FIB fabrications, self-assemble block polymers, and electron beam lithography [3]-[6]. Fabrication by FIB method is a straightforward process but fabricating a dot pitch of smaller than 50 nm remains difficult due to the low resolution of FIB. In the FIB process, the edge of magnetic dot is easily damaged by the Ar gas beam [7]. The self-assemble block polymer method is promising to fabricate dot pitch smaller than 25 nm with large area, but there are some difficulties to control the dot formation and transferring dot pattern to magnetic film because a polymer pattern is not strong enough than magnetic layer in ion milling during the transferring process. Fabrication using EBL is the easiest way to fabricate bit-patterned media with high density. It is easy to control the dot formation even though the process suffers from limitations of area due to exposure dosage [8]-[10]. In this experiment we have fabricated bit-patterned media using this method then transfer the resist dot formation to magnetic layer by ion milling. We studied the advantages of bit-patterned media in dot diameter from 40 nm to 120 nm with dot pitch more than 100 nm by preparing magnetic dot using this method [7], [10]. The results show that as dot diameter decreased, the coercive force increased. We also reported when the dot pitch decreased the coercive force decreased [7], [10]. These phenomena occurred due to the interaction between neighbor bits. The coercive force was saturated when the dot pitch more than 100 nm but when the dot pitch decreased form 100 nm to 25 nm the coercive was decreased constantly to be near the coercive of the magnetic film. There is no report about the effect of dot diameter less than 40 nm with dot pitch less than 40 nm. This experiment is important to confirm the suitable dot size for a very fine dot pitch of less than 40 nm for bit-patterned media.

II. EXPERIMENTAL

Fig. 1 shows the fabrication process of the magnetic dot arrays by EBL and ion milling. CoPt magnetic film was deposited on C/Ru/Pd/NiTi/glass substrate using Radio Frequency Sputter for 15 nm thicknesses. Ru was used as a material to fabricate perpendicular CoPt magnetic film and Pd/NiTi used to stick between Ru and glass substrate. 4 nm of Carbon was deposited on the CoPt magnetic layer to prevent it from oxidation.

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Negative calixarene resist was deposited on Carbon layer by spin coater at 3000 rpm for thickness of 25 nm then it was baked for 3 min at 110°C.

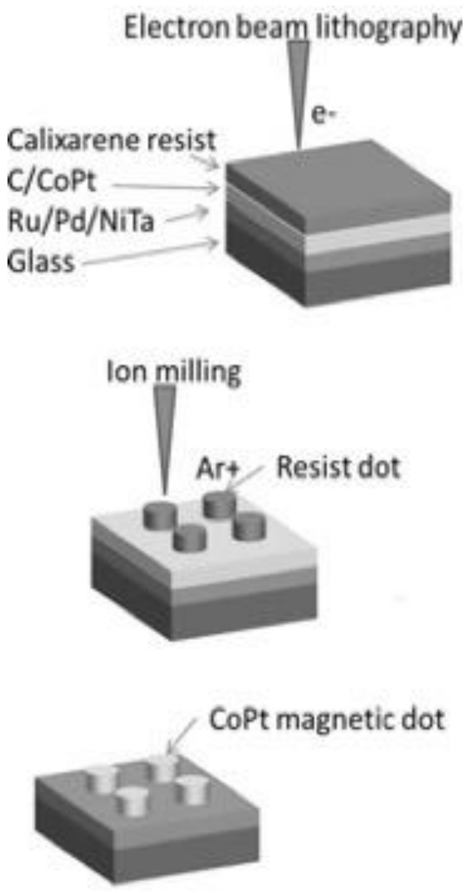

Fig. 1: Schematic diagram of CoPt dot arrays fabrication process

30 keV EBL was used to draw the 40-nm dot pitch with dot diameters of 20, 25, and 30 nm on calixarene resist. Incorporation of Field Emission Scanning Electron Microscope and drawing controller as the EBL system was used. The process was carried out at 500 pA, 2 mC/cm2 and 2 nm for current acceleration, exposure dosage, and beam size, respectively. The dot pattern was designing to be a hexagonal formation to pack the very fine dot arrays. To fabricate the calixarene resist dots, it was developed by IPA solution at room temperature for 3 min. As the mask, 40-nm pitch dot arrays were used. This process was done to transfer the dot to the CoPt magnetic layer by using ion milling process. For the mask's thickness, it was determined by checking the rates of the CoPt film and the resist that have been ion milled. Fig. 2 shows CoPt film and calixarene resist's ion milling rates. The resist layer was spin-coated at 3000 rpm for 90 sec and underwent a 3 min prebaked using an oven at 110ºC. An atomic force microscope was used to measure the resist film thickness. For the ion milling process, an inclination of 15 degree was chosen for the sample with the ion current and the acceleration voltage of 50 mA and 400 eV respectively. It can be seen from the Fig. 2 the ion milling rates for the CoPt film is 4.9 nm/min and for the mask is 5.5 nm/min. These result shows that calixarene resist is perfect to act as a mask for CoPt dot array fabrication using ion-milling technique. These results show that it is possible to fabricate isolated CoPt dots if 15 nm CoPt film is being ion milled for about 3 min from exact calculation. The thickness of the masks that need to be coated on the CoPt film can also be estimated, which is about 16.5 nm in thickness.

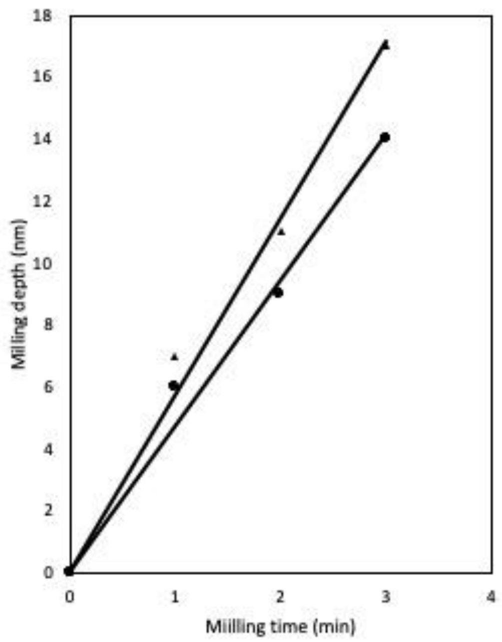

Fig. 2 CoPt and calixarene resist ion milling rate in 200 eV Ar ion bombardment.

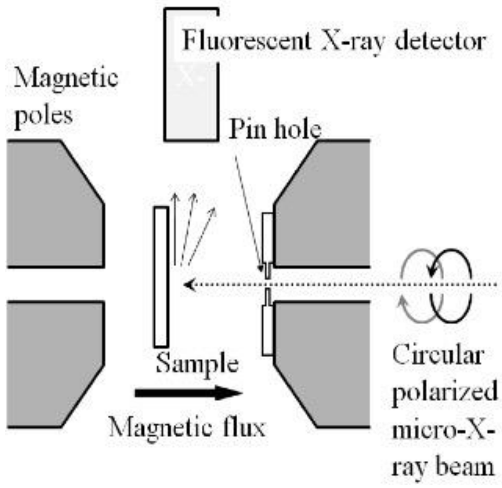

Fig. 3 Scheme of fluorescent yields using incident X-ray for micro XMCD signal.

XMCD with 11.56 eV edge energy of Pt L3 was used to measure the magnetic property of the dots. It is done in synchrotron radiation, SR in Spring-8. Fig. 3 shows the XMCD signal that is defined by Δµ =µ--µ+. µ- and µ+ are fluorescence yields that uses X-ray incident with right and left circular polarization. The XMCD signal will be directly proportional to the magnetization of CoPt nano dots at Pt L3 edge energy. This is because the signal will reflect the spin polarization of the material. An experimental result of a hysteresis loop property of was obtained by sweeping extra magnetic field, where the property corresponds to B-H loop. The coercive force of the dots was measured by the hysteresis loop. The measurement system consists of a micro-beam to focus the X-ray beam to about 3 x 3.5 µm2 on the sample.

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III. RESULT AND DISCUSSION

The 40-nm pitch CoPt magnetic dot array was fabricated by EBL and ion milling, and then measured by micro XMCD. Fig. 4 (a), (b), (c) show the SEM images of calixarene resist dot arrays before ion milling. Fig.5 (d), (e), (f) represents the CoPt magnetic dot arrays after ion milling. 40 nm pitch Calixarene resist dot arrays were successfully fabricated by EBL for 20, 25 and 30 nm dot diameter size.

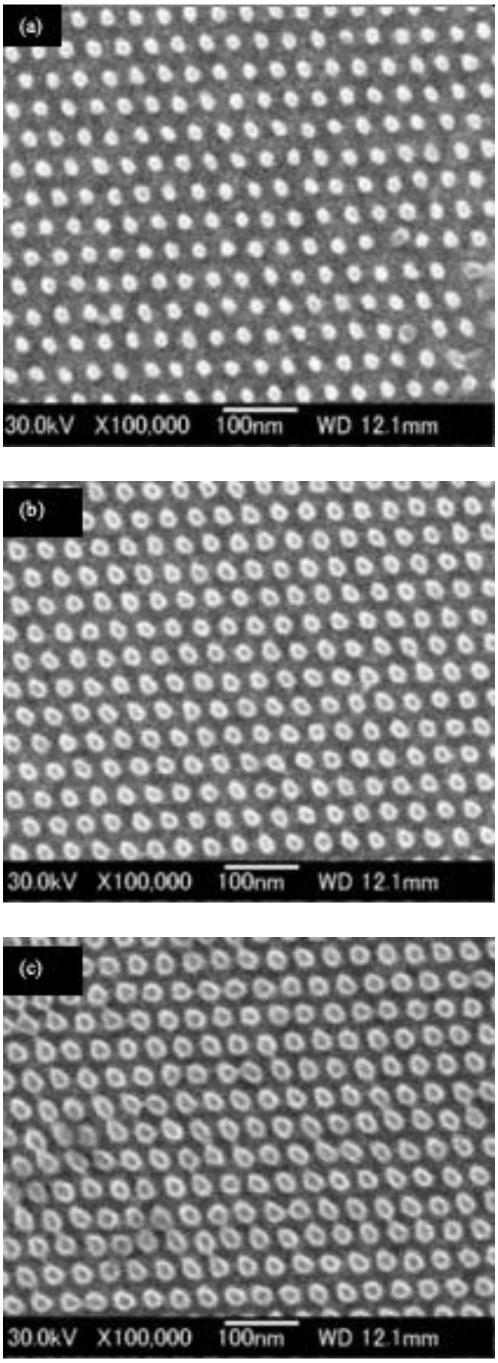

Fig. 4: Resist dot arrays with dot diameter (a) 20 nm, (b) 25 nm and (c) 30 nm.

CoPt magnetic dot arrays were also successfully fabricated by ion milling using calixarene resist dot arras as a mask. The diameter of CoPt magnetic dot arrays decreased by about 5 nm every dot size after ion milling to become 15, 20 and 25 nm. The decreasing of dot diameter size was happened due to the Carbon layer and the power of ion milling. Carbon is one of the hard materials in ion milling, compared to calixarene resist. To etch a carbon layer using ion milling, high power is needed. Using high power in ion milling at 400 eV and 500 mA is enough for etching the carbon, but for the calixarene resist the etching process is faster. The 25-nm thickness of calixarene resist dot arrays was etched faster and the dot diameter of the resist decreased before carbon layer was completely etched.

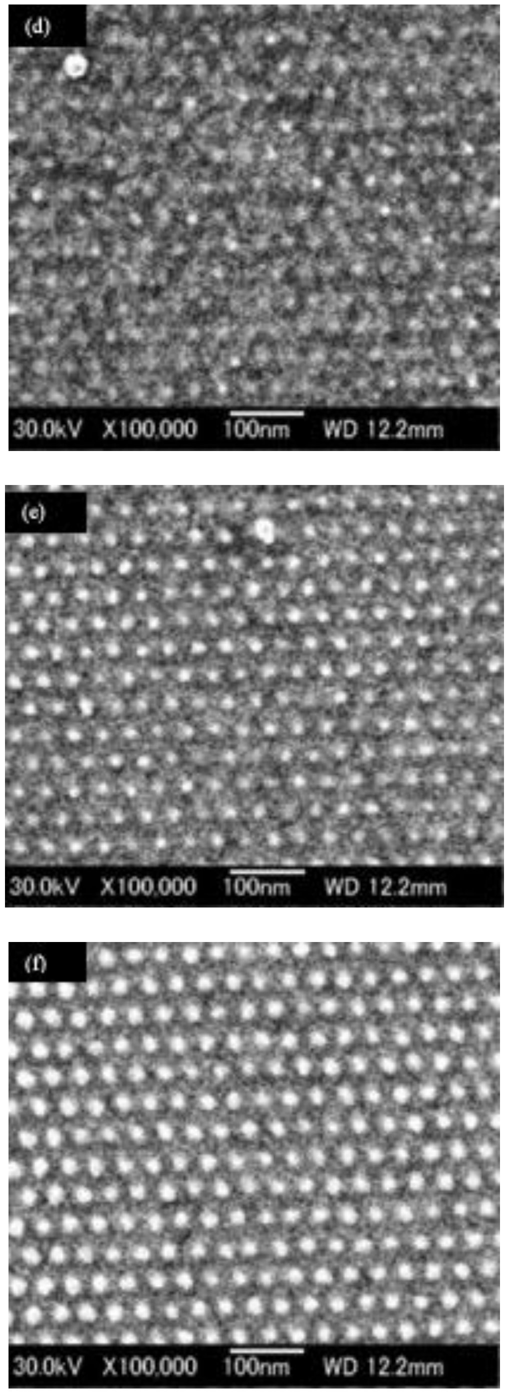

Fig. 5: Magnetic dot arrays after ion milling with dot diameter (d) 15 nm, (e) 20 nm, (f) 25 nm

When the carbon layer was etched at that time, the diameter resist dot arrays became smaller. This mask was then transferred to the CoPt magnetic layer. This is the reason the magnetic dot diameter was decreased after ion milling. To overcome this problem, the carbon layer must be thin enough at less than 2 or 1nm. Another way to prevent an in-creasing dot diameter is to remove the entire carbon layer, and then decrease the power of ion milling. Put another way, this method is not enough to address the CoPt layer in oxidation problem.

Fig. 6 shows the ESMH curve of 40 nm pitch CoPt magnetic dot arrays with dot diameter sizes of 15, 20, 25 nm and CoPt magnetic film as measured by micro XMCD in SPring-8. Coercive force for CoPt magnetic film is 1.25 kOe, while the forces for 15, 20, 25 nm dot diameter CoPt magnetic dot arrays were the same at 3.5 kOe. Fig. 7 shows the CoPt dot diameter vs Coercive force.

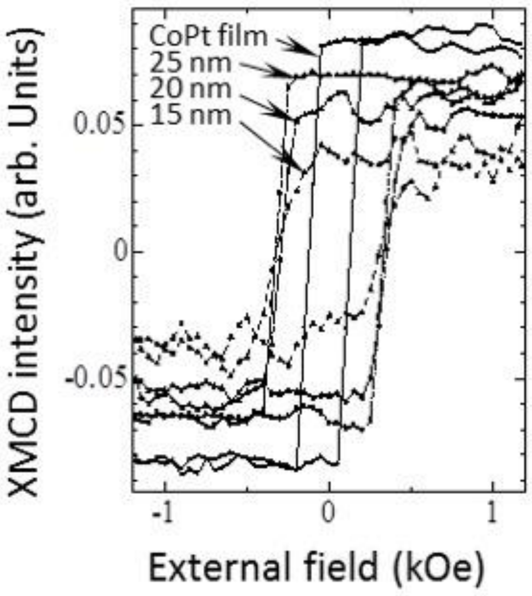

Fig. 6: ESMH curves of magnetic dot arrays with 15, 20, 25 nm dot size and CoPt film by Ar ions with energy of 400 eV.

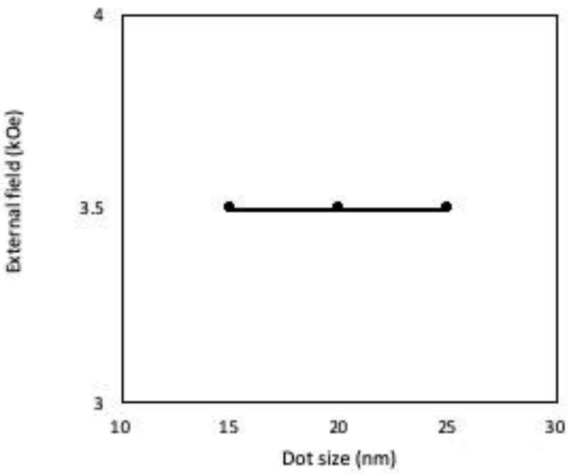

Fig. 7: Coercive force vs CoPt dot diameter at 15, 20 and 25 nm

There are no changes in coercive force for 40 nm dot pitch at 15, 20 and 25 nm dot diameter. These phenomena are due to the total number of magnetic grains in every magnetic dot column. When the dot diameter decreased, the total magnetic grains in dot column also decreased. For large dot diameters of more than 40 nm, there are many magnetic grains in one dot. This large magnetic dot diameter makes it easy to switch the magnetic direction. Conversely, for a small dot diameter of less than 25 nm there is only a few magnetic grains in magnetic dot. With a total of a few magnetic grains in the magnetic dot column, switching the magnetic direction become difficult and at one time the total grains are not affect to the coercive force. Note the magnetic grain from the figure 3 at the XMCD intensity. When the dot diameter decreased, the XMCD signal also decreased. The difficulties of switching magnetic direction are also shown in the angle of the hysteresis curves. When the dot diameter become smaller, the angles of dot diameter become lower because of the difficulty of switching the magnetic direction with poor magnetic gain. The results indicate that dot size had no effects on dot diameters of less than 25 nm in terms of coercive force. However, switching difficulty increased when the dot diameter decreased.

IV. CONCLUSION

The fabrication of 40 nm dot pitch magnetic dot arrays by EBL and ion milling and the nanometer effect of dot diameters of 15, 20, and 25 nm as measured by micro XMCD have been studied in this paper. Based on the experimental results, the conclusions are as follows:

1. 40 nm dot pitch magnetic dot arrays with dot diameters of 20, 25, and 30 nm were fabricated via EBL and ion milling.
2. Dot diameter decreased after ion milling due to the high power of ion milling on the carbon layer as an oxidation prevent layer.
3. A dot diameter of less than 25 nm has no effect on the coercive force in dot pitch 40 nm magnetic dot arrays.

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