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Investigation of Laser Direct Writing as a Novel Method of Permalloy Patterning

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Investigation of Laser Direct Writing as a Novel Method of Permalloy Patterning

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Abstract. The abilities of laser direct writing have been explored on thin films of permalloy ($Ni_{81}Fe_{19}$) for range of film thicknesses with two types of substrates for creating micro-scale magnetic structures. The thin films of Permalloy were deposited on both silicon and glass substrates using thermal evaporator with ranging from 5 to 100 nm. The permalloy films were successively patterned using a laser system containing of a pico-second pulsed laser with an 800 ps pulse width and wavelength of 532 nm. A series of magnetic wires were patterned then characterised by Magneto-Optic Kerr Effect system and Scanning Electron Microscopy. The patterned magnetic wires showed good responses to an applied magnetic field. The corresponding coercivities of the patterned magnetic wires were affected by their observed quality. These results can improve the understanding of laser direct writing technique to fabricate the micromagnetic structures for future application as easy, low cost and high throughput technique.

Keywords: laser ablation, Permalloy, coercivity and magnetic wires.

1. Introduction

The micro/nano-scale magnetic structures are very important in a lot of magnetic applications; such as; sensors [1], biomedical devices [2], [3], Micro-Electromechanical System (MEMS) [4], devices for data storage[5]. A number of lithographic techniques are used for producing these structures such as; e-beam [6], [7], focused-ion-beam [8], X-ray[9]). These techniques involve of tens or hundreds of complex steps that need hours to weeks to complete and at high cost [10], [11].

Developing nano-bars with widths of nano-scale and relatively long guided to create a new class in magnetic structures- nanowires. These structures showed interesting potency in devices based on domain wall which used the motion of walls to represent different states as a new alternative to devices of single domain. [12], [13]. The motion of domain walls can be used in lots of magneto-electronic devices because of its potential conjunction. Accordingly, this phenomenon has been used for new concepts such as racetrack memory and has indicated significant capabilities for use in data storage "ultra-high storage densities".

Laser Direct Writing (LDW) uses laser beam to form a controlled localized deformation on the surface. This technique is categorized for three types; LDWM (Modification), LDW - (Subtraction) and LDW + (Addition) [14]. This work aims to use the LDW for patterning the micro-scale magnetic wires from Permalloy thin films.

2. Experimental Procedures

Range of Permalloy (Ni81Fe19) thin films with thicknesses of: 5, 10, 25, 50, 75 and 100 nm were deposited onto substrates by thermal evaporator (Wordentec system). These thin films were individually grown onto glass and silicon substrates simultaneously.

A custom LDW- system illustrated in Figure (1) consisting of Alphalas Q-switched solid-state pulsed laser (Alphalas; PULSELAS) was used to patterned the Permalloy thin films. The picosecond laser was set up on pulse energy of 5.1 μJ with pulse width of 800 ps and maximum repetition rate of 40 kHz. The laser beam has been delivered to a band pass filter for selecting the wavelength of 532 ±2 nm together with a variable neutral density filter to attenuate the laser beam. The laser beam passed through beam expander then reflected by an elliptical mirror into the objective lens to focus to a 10 μm spot diameter. Finally, the laser beam hitting the permalloy thin film for potential ablation through a glass carrier mounted on a computer-controlled stage. The scan stage is computer controlled with three dimensions; x, y and z (Aerotech ANT130-XY and PRO115 system) to scan the sample relative to laser spot to produce the desired structures. Additionally, shutter under computer-controlled (UNIBLITZ LS6ZM2-nl) has been used to control exposure time during the fabrication process.

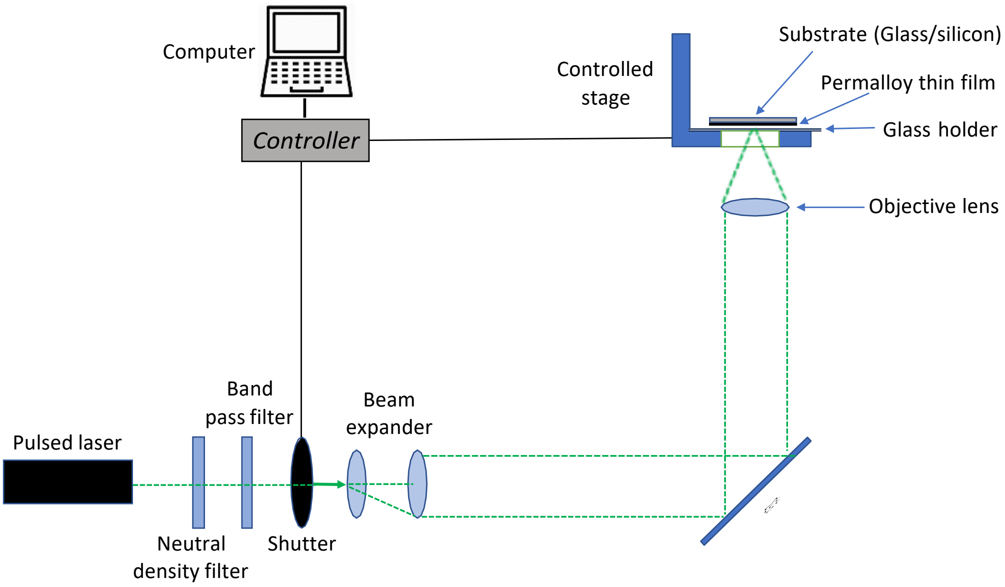

Figure 1. Illustration of DLW equipment set-up.

Sets of 20 magnetic wires with a length of 2 mm and line spaces between wires of 50 μm was created on each thickness: 5, 10, 25, 50, 75 and 100 nm using pulse energies of: 83, 167, 250, 333, 417 and 500 nJ respectively and scan speed of 10 mm.s^{-1}. The structures were fabricated with two forms of magnetic wires with the same lengths and processing parameters, but either disconnected wires with the film or connected with the film with only one end or both two ends.

3. Results and discussion

The SEM images of the micro-magnetic wires patterned on the silicon and glass specimens respectively shows in figure 2 and 3. These sets of wire were fabricated the same design outline shown in Figure 4 a, except some differences in the wire dimensions (length and width) on the micron scale because of the differences seen in the ablated zone. These differences can possibly be linked to the variations in an ablation threshold, where, a higher difference between the threshold fluence and applied fluence led to increase in the amount of material ablated. The distances between each fabricated wire were 50 μm and the width of the ablation line was 10 μm which is the same as the diameter of the laser spot and this means that the width of each wire is 40 μm.

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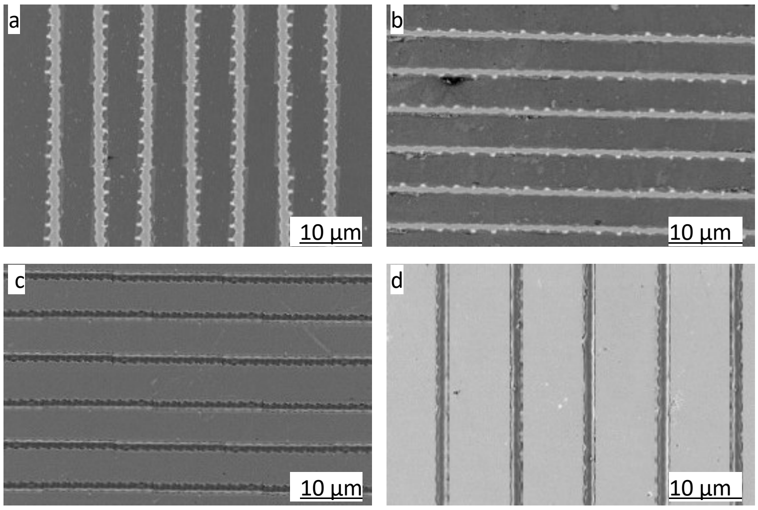

Figure 2. SEM images of permalloy wires on silicon substrates: a) 25, b) 50, c.) and d) 100 nm thin film thicknesses.

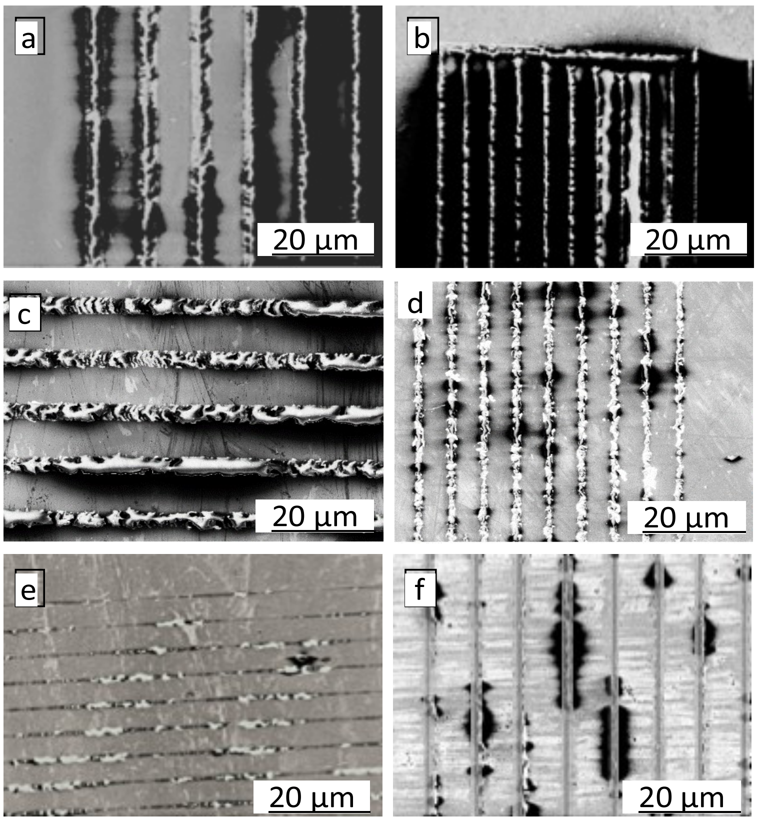

Figure 3. SEM images of permalloy wires on the glass substrates: a) 5, b) 10, c) 25, d.) e) 75 and f) 100 nm thin films thicknesses.

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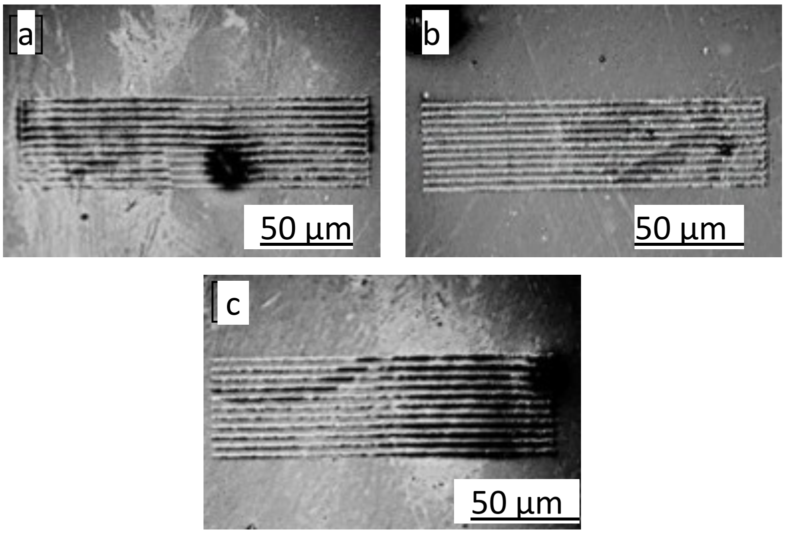

Figure 4. SEM images of magnetic wires on glass substrate with a thin film thickness of 25 nm: a) closed ends b), just one open end and c) both ends are open.

the quality of SEM images of magnetic wires on the glass carrier are affected by the non-conductive properties of glass. However, the patterned wires on the glass substrates seen in the images show that the magnetic wires exhibit similar forming difficulties at thicknesses of 75 and 100 nm, but at the thickness of 5, 10, 25 and 50 there is an indication of a better-quality definition. This phenomenon is due to the need to apply higher fluence for thicker films to achieve the ablation threshold, as the ablation threshold depends on the thin film thickness.

Further magnetic structures have been successfully fabricated of thickness of 25 nm on the glass substrates as shown in Figure 4 which illustrated the different wires investigated; non-connected with the film, one end of wire connected with the film and both ends of wire are connected with the film.

Figure 5a and b shows a comparison of the coercivities of the fabricated wires and different samples from the Focused Magneto-Optic Kerr Effect (fMOKE) (the hysteresis curves are shows in Figures 6 and 7). The coercivities of the thin films (un-patterned) vary from 0.25 Oe to 0.76 Oe for the silicon substrates and 0.26 Oe to 0.99 Oe for glass substrates without trend; That basically because of the dominant factor of the not the same dimensions of the specimens, which affects the coercivity as result of the effect of shape anisotropy[15, 16].

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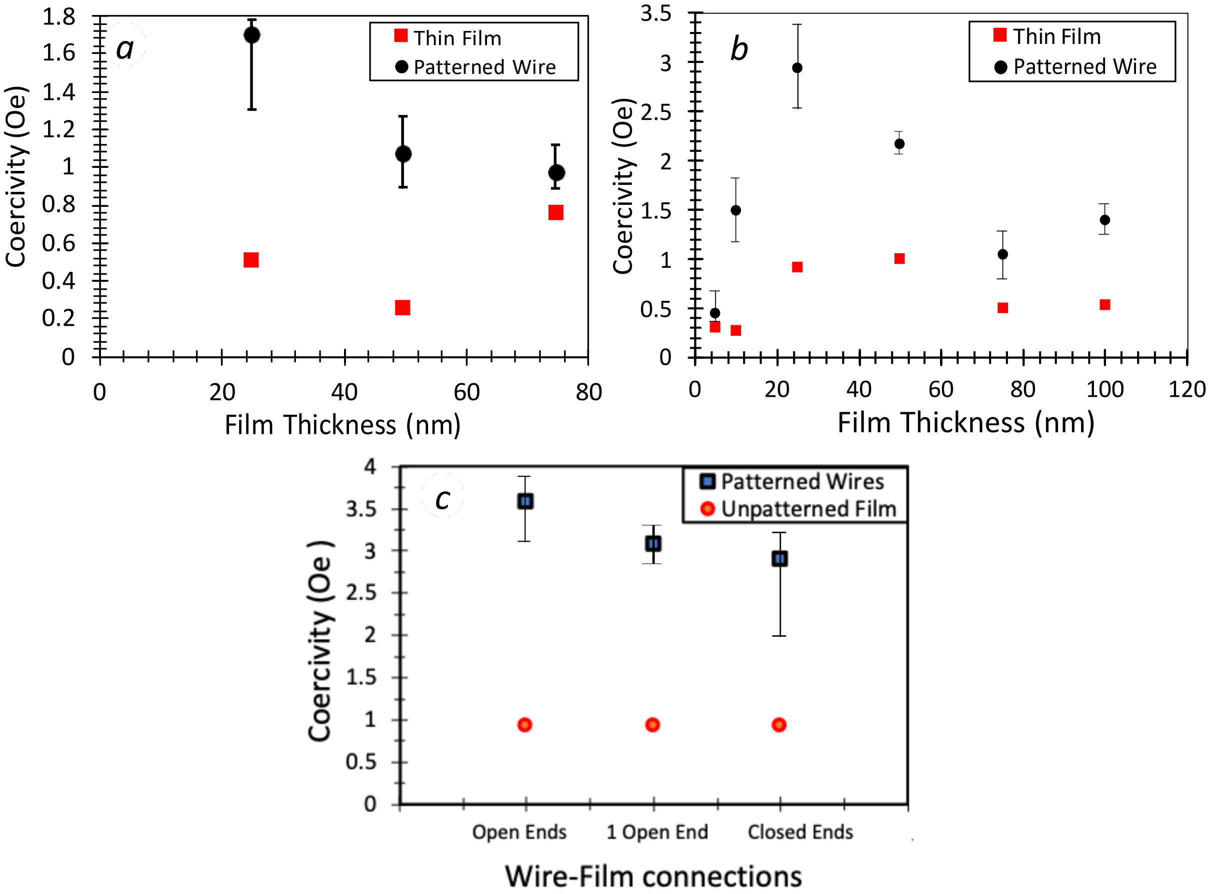

Figure 5. Coercivity of magnetic wires and un-patterned thin film on: a) silicon substrate, and b) glass substrate and c) Coercivity of 25 nm thick magnetic wires on a glass substrate with three cases of wire-film connections.

Thin film patterning leads to a marked increase in in the coercivity. The coercivity increases with reduction the widths of magnetic wires because of shape anisotropy. [16]. The coercivity varying from 0.97 Oe to 1.7 Oe and 1.0 Oe to 2.93 Oe for the silicon and glass specimens respectively. In general, the magnetic wires patterned on the glass samples exhibited a higher coercivity. That possibly due to used lower ablation threshold to remove undesired areas of the thin films on glass to produced magnetic wires with better quality. The magnetostatic energy are removed by loss the definition, that make the system easier switched to an opposite direction. However, It should be indicated that these coercivities are significantly lower than the values measured in one of our previous paper. [17]. The difference between previous and current results due to fabricate wires with larger widths in this project and consequently a weaker shape anisotropy.

The fMOKE measurements for the set of magnetic wires with thicknesses of 5, 10 and 100 nm were unable to be taken because of the limited ablation. However, the other set of magnetic wires on silicon substrates exhibited a clear decrease in the coercivity with increasing of the thicknesses of film as seen in Figure 5a.

Correspondingly, the coercivities of the wires set of the glass samples trend to drop after the thickness of 25 nm as shown in Figure 5b, which could be linked to the same previous cause. The coercivity shows a minor rise with the transition of thicknesses from 75 nm to the 100nm on the glass samples; This could possibly because of the higher coercivity of the un-patterned 100 nm film, however the partly ablated lines may represent as pinning sites for domains to successfully increase the

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coercivity relative to the un-patterned film. The coercivities of magnetic wires of the glass samples also show a considerable increase from 5 to 25 nm thin film wires. The measured coercivities of the others structures formed on the 25 nm thin film on glass substrate are shown in Fig 5c. Additionally, the measured coercivities of the connection's cases wire-film were approximately between 2.94 to 3.63 Oe for the disconnected magnetic wires and the connected magnetic wires respectively. The domain walls are induced to the system using large permalloy pads at the terminals of magnetic wires which would efficiently reduce the coercivity, however, it is possible that the wire widths were not small enough to detect that effect, therefore, the change in coercivities could be a consequence of the LDW variations that happen even under the parallel conditions.

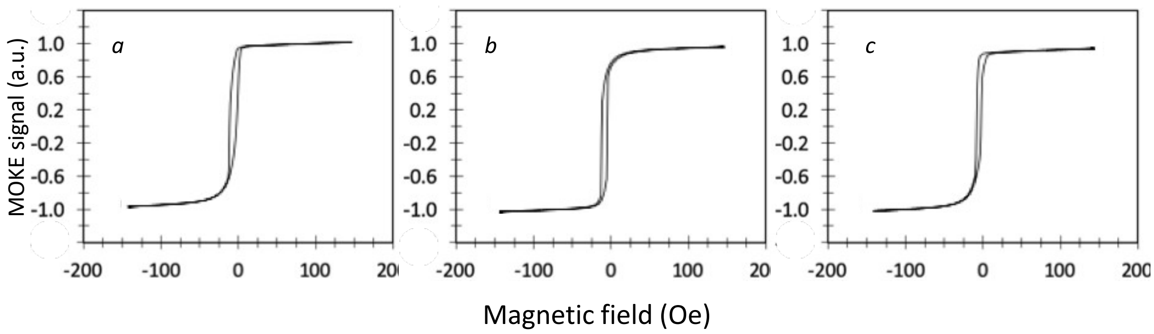

Figure 6. Example fMOKE Hysteresis loops for permalloy micromagnetic wires on a silicon substrate: a.) 25 nm b.) 50 nm and c.) 75 nm.

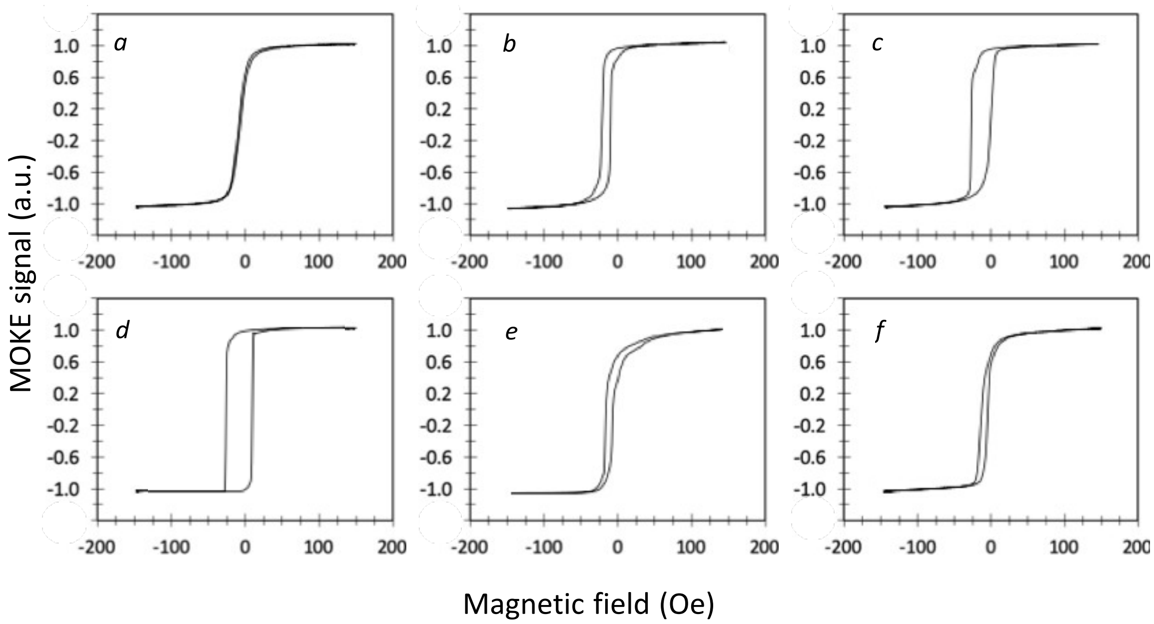

Figure 7. Example fMOKE Hysteresis loops for permalloy micromagnetic on a glass substrate: a.) 5 nm, b.) 10 nm, c.) 25 nm, d.) 50 nm, e.) 75 nm and f.) 100 nm thin films.

4. Conclusion

The LDW of permalloy was investigated for a range of thicknesses of thin films on glass and silicon substrates. Numerous film thicknesses (from 5 to 100 nm) were deposited on glass and silicon substrates then patterned and characterised by SEM and fMOKE to achieved the magnetic responses. The patterned wire showed good responses to applied magnetic field with coercivities between 0.97 Oe and 1.7 Oe of magnetic wire on silicon and between 1.0 Oe to 2.93 Oe for wire on glass depending on the shape anisotropy. Different wire-film connections were also investigated. The coercivity measured as approximately 2.94 to 3.63 Oe for the disconnected wires and the connected wires respectively because of induce of domain walls. These promising results indicate the capability of LDW for fabricating magnetic structures for possible application in devices such as sensors with low cost and in process of one step.

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