A Combined Electron-Beam and Nano-Imprint Lithography Technique for the Affordable Creation of Exchange Coupled Composite Patterned Media

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Abstract:

Electron beam lithography was used to pattern a 1 x 1 mm matrix of holes with 300 nm diameters in silicon nitride. This master stamp was used in a nano-imprint process to cast PMMA resist dots on an exchange coupled composite magnetic bilayer, which when ion-milled, produces separated islands of magnetic material (100 nm wide with a 1 μm period). This nano-imprinting process allows inexpensive production of patterned media by repeatedly and quickly casting patterns that were slowly and painstakingly created. The developed nano-imprinting technology could be applied to any other product from logic devices to quantum computing which requires large numbers of inexpensive nano-scale features.

Introduction:

In the quest for 1 terabit per inch square magnetic hard drive data densities, patterned media offers the way forward. Because the grain size of the magnetic material is effectively limited to ~ 8 nm by the superparamagnetic effect, and in continuous media the signal to noise ratio depends on the number of grains making up each bit, the data density of continuous media is limited. Patterned media allows one grain per bit by physically separating grains from each other, meaning at least a 10 fold increase in data density.

The magnetic material itself was an exchange coupled composite (ECC). Magnetic materials with a high anisotropy constant offer long data life, but are called 'hard' because it takes an enormously strong field to initially write data. 'Soft' materials are easy to write, but data degrades quickly. ECC media couples a soft material to a hard material to gain the benefits of both.

The fabrication process was aimed at mass production. Inexpensive PMMA was used throughout the process instead of a more expensive negative resist. A stamp was made via costly and slow electron-beam lithography, but was then repeatedly used to pattern casts in a nano-lithography process. This process combines the precise features offered by electron-beam lithography with the high throughput of nano-lithography.

Experimental Procedure:

A 110 ± 15 nm thick layer of silicon nitride was deposited on a wafer, then spin coated with PMMA. Electron-beam lithography created patterned holes in the PMMA. This pattern was transferred to the silicon nitride layer by reactive ion etching with CF_4. After cleaning off the rest of the PMMA with O_2 etching the stamp was finished.

The cast was made by sputtering magnetic material onto a wafer, then spin coating with PMMA. The PMMA was hardened by baking at 180ºC for four hours. The PMMA was hardened so that it would not flow away or stick to the stamp during nano-imprinting.

When the stamp was pressed into the cast at 250 psi the stamp's patterned holes were converted to patterned pillars on the cast. After pressing, the stamp was cleaned for reuse in an ultrasonic bath for 10 minutes, then under O_2 etching for one minute.

The cast was then ion milled for 17 minutes. The PMMA pillars served as a resist such that only the islands of magnetic material protected by them remained afterwards.

Results and Conclusions:

As shown in Figure 1, the smallest dots patterned on the stamp were 50 nm in diameter. These smallest dots did not transfer well during nano-lithography, so 300 nm in diameter dots with 500 nm periods were used instead.

The depth of the holes in the stamp remains unknown. The maximum depth given by the AFM was 50 nm, with larger holes having larger depths. Whether this depth is accurate is an open question. Because the diameters were so small, the sides of the AFM probe might have physically kept the actual tip from touching the hole's bottom.

Figure 2 shows minimal degradation to the stamp after five pressings. Some of the holes are filled in with PMMA, and dark smudges of PMMA cling to the sidewalls of other holes. This could be remedied by further O_2 reactive ion etching. The primary method of damage to the stamp came from dust causing cracks to form in the silicon during the pressing process.

The final patterned media is shown in Figure 3. On the macroscale, pattern uniformity was low with many dots missing from their intended spots. This was due to an overly long ion milling time. A shorter time would yield more uniform pattern, but larger dots.

Within the pattern, dot placement lacks uniformity as shown in Figure 4. This results from differences in the physical strength of the material under the PMMA resist pillars. The PMMA pillars protected many grains. During the ion milling process the weaker grains were blasted away and mere chance determined which of the grains survive. Thus the remaining grains were not in neat rows.

Because the nano-lithography was not done under clean room conditions, dust contamination was a major problem. If a piece of dust got between the stamp and cast, the pattern would not transfer because the stamp and cast were not in contact. Worse, because 250 psi was concentrated on one small dust particle, it would crack the silicon of the stamp and cast, which often lead to shattering.

Future Work:

The density of dots in the patterned media will be increased. The nano-lithography press will be brought into the clean room. This will allow smaller PMMA resist dots to transfer during nano-lithography which will improve the placement uniformity within the pattern. The ion milling time will have to be adjusted to the dot diameter and period for improved macroscale pattern uniformity.

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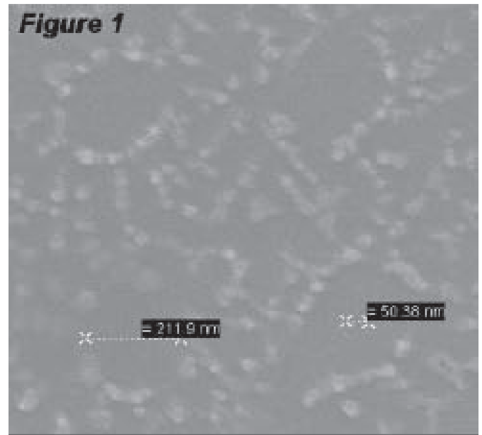

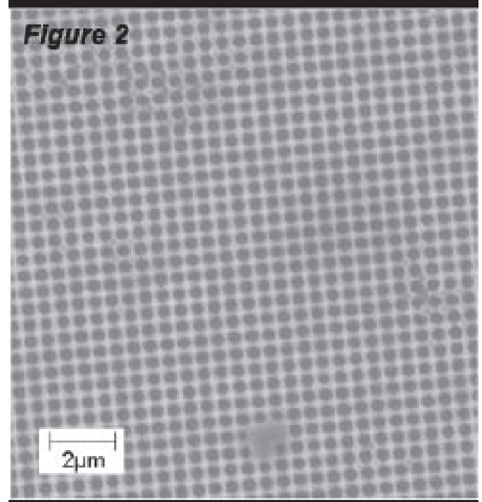

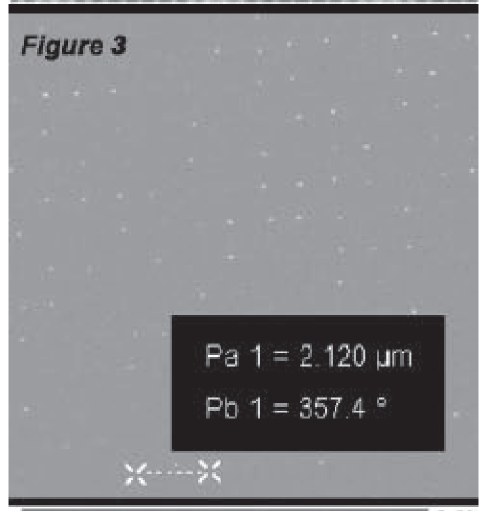

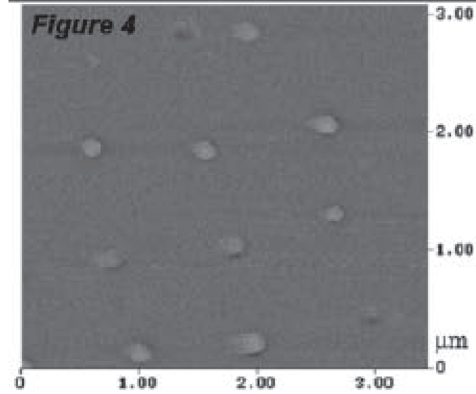

Figure 1: The smallest patterned features on the stamp were 50 nm across.

Figure 2: An SEM of a stamp used 5 times showing minimal degradation.

Figure 3: Total pattern uniformity is low.

Figure 4: MFM showing uniformity of dot placement within the pattern is low.