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FABRICATION OF MICRON SCALE MAGNETIC NICKEL FEATURES BY SELECTIVE AREA ORGANOMETALLIC CHEMICAL VAPOR DEPOSITION

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Abstract:

We demonstrate that it is possible to deposit a wide range of magnetic features, using photoassisted and electron radiation induced selective area organometallic chemical vapor deposition. Large arrays of identical micron to nano scale Ni features were deposited by these methods. Their magnetic properties were studied by alternating gradient force magnetometry as well as magnetic force microscopy. Our morphological and magnetic measurements show that the structures are spatially well defined, and the magnetic properties are related to the structural shapes of the features.

Introduction

Conventional magnetic media have large variations of local magnetic properties, making them extremely hard to use in ultra high density recording media. With the development of advanced photo-chemical vapor deposition techniques it is now possible to fabricate arrays of prepatterned single magnetic domain structures located uniformly on a nonmagnetic media. Each magnetic domain will then represent a bit which is spatially well defined at a specified location. This is of advantage in that the magnetic bit writing process can be vastly improved while there is a reduction in bit to bit cross-talk. The decrease in noise and error rate could ultimately result in higher density.

Different methods can be adopted to fabricate ferromagnetic structures ranging from micron to nano scale regime. Organometallic chemical vapor deposition (OMCVD) has several attractive features over the conventional techniques which require multiple step processing. OMCVD is potentially a single step selective deposition process. The study of micron scale magnetic dots made by CVD is among the more unusual and challenging tasks in the area of magnetism, but the magnetic characterization of materials fabricated by this technique is limited [1]. For the deposition of contaminant free metal features, the organometallic compound should satisfy

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several criteria as noted elsewhere [2]. Thus understanding the surface chemistry of the CVD compounds is essential, as has been done [3]

We have been able to fabricate micron scale arrays of geometrically defined ferromagnetic nickel structures by photolysis of nickelocene [$Ni(C_5H_5)_2$].

Experimental

Selective area chemical vapor deposition was carried out in an ultra high vacuum chamber which was equipped with a quadrupole mass spectrometer (Dycor) for thermal desorption studies, and a single pass CMA and a nitrogen laser, as described elsewhere [4]. The base pressure of this system was maintained at $5x10^{-10}$ torr. Fabrication of nickel containing features by photolysis was carried out on Si(111) substrates which were mounted on a load lock manipulator system that was capable of introducing multiple samples into the system. During deposition nickelocene vapor pressure was carefully monitored and kept at a pressure of $3x10^{-5}$ torr. Incident radiation for photolysis was supplied by a commercial (Molectron) N_2 laser with a wave length of 337nm which corresponds to an energy of 3.69 eV. A quartz lens was used to focus the beam onto the Si(111) substrate. A metal grid with a spacing of 20μm x 20μm was placed to restrict radiation as well to act as a grating. Arrays of Ni features with different shapes were fabricated by changing the focal position of the quartz lens. During irradiation, mass components were detected by the quadrupole mass spectrometer operated in the pulse counting mode.

Nanoscaled nickel features were drawn by a Vacuum Generators microscope model HB5 scanning transmission electron microscope (STEM) modified to admit sublimed nickelocene, as previously described elsewhere [5]. Deposition was carried out after gradually admitting nickelocene up to pressure ranges of 10^{-7} torr. To enhance the adsorption, the substrate was kept at temperatures below 150K. Decomposition rates were monitored simultaneously with a quadrupole gas analyzer.

Results and Discussion

Figure 1 shows a magnetic force microscopy (MFM) image of a sample prepared by OMCVD. A commercially available microscope with magnetized tips was utilized (Nanoscope III, Digital Instruments) as described elsewhere [4]. An area of 40x40 μm^2 scan shows parallel bars of nickel features fabricated in a larger array. The MFM images as well as kerr microscopy images clearly shows that the nickel features are ferromagnetic, as expected, and are seen to be spatially well separated. The integrated volume of the particles is in rough agreement with the magnetization measurements [4]. The hysteresis loops shown in figure 2 provide strong evidence that the magnetization is largely in-plane.

Figure 4a shows an in-plane magnetic hysteresis loop from the array of nickel squares (Fig. 3a). The loop was measured by a commercial alternating gradient force magnetometer. The

saturation field is about 1 kOe, and its coercivity is approximately 50 Oe. The ratio of the remanence to the saturation magnetization is 0.18. The hysteresis loops in both the in-plane and perpendicular configurations are nearly identical. This may be because the demagnetization effects of the film are similar in both orientations, since the size of nickel structures is rather small.

To demonstrate the influence of shape on the magnetic properties, we made arrays with differently shaped Ni features. To do this with the same mask, we changed the diffraction condition so that the laser illuminated a different pattern. Figures 3b & c show the SEM images of an array of nickel features deposited under such conditions. These patterns are very different from the square shaped figures. These films consist of spatially well separated nickel bars within the illuminated area as well as disks. The size of these features were about 3 μm x 17 μm and the diameter of the disks were about 8 μm.

The hysteresis loops for these features are shown in Fig. 4b & 4c. Besides the differences in saturation magnetization, determined by the total amount of nickel, the hysteresis loop shape is rather different from that for the array of square-like features (Fig. 4a). The ratio of remanence to saturation is much larger for the features with parallel bars, and the saturation field is slightly lower compared to the square features. The disk features on the other hand possess the lowest coercivity as well as the saturation field. These differences indicate that the hysteresis dynamics are dependent upon the shape of even small volume Ni structures. Systematic studies of different patterns are planned, and will lead to an improved fundamental understanding of magnetic dynamics. Those studies are currently underway. The saturation magnetization of the entire array of nickel dots is consistent with the magnetic properties of nickel, if the integral volume of all the nickel features is considered. It may be that the saturation magnetization is, therefore, not dominated by shape for features of these dimensions, but rather by the composition of the material.

We have proved that fabrication is possible by electron induced radiation. This was achieved by using a scanning transmission electron microscope. Initial deposition studies were undertaken on films of carbon (10 nm thick) or SiO (about 100 nm thick) supported over the openings in 200 mesh 3 μm copper grids. Depositions were performed with an electron energy of 100 keV and with electron beam diameters in the range from under 1 nm to more than 10 nm. The field emission source and optical system are well suited to stable focusing and scanning of the electron beam under electronic control. Also important, the morphology, structure and other properties of the deposits can be examined in situ with lateral spatial resolution down to about 1 or 2 nm since the substrates are so thin. Figure 5 shows two lines drawn in this manner.

Summary

Our results suggest that it may be possible to make features with a sufficiently small volume so as to limit each feature to a single domain. We have deposited micron- and nano scale Ni structures by using photoassisted and electron radiation induced selective area organometallic chemical vapor deposition. Drastically different Ni features were obtained by manipulating the

laser diffraction conditions. Their magnetic properties are correlated with the shape of the Ni features. This deposition method demonstrates a new approach for novel device fabrication.

Acknowledgments
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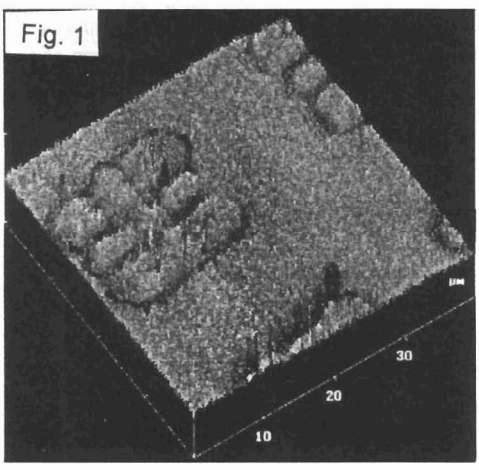

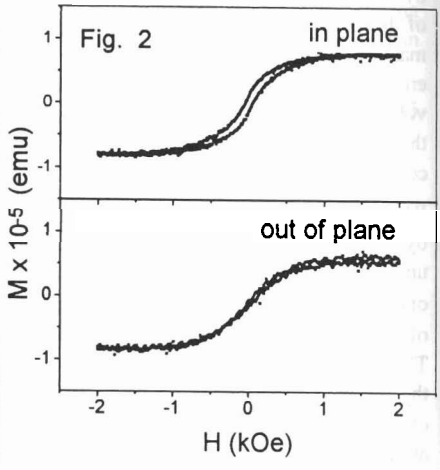

Fig. 1. A 40x40 μm^2 area showing a MFM image. The dimensions are less than 20x20 μm^2 for the arrays of bars with an average height of each Ni bars of about 300nm to 600nm.

Fig. 2. Out of plane and in-plane hysteresis loops obtained from an alternating gradient magnetometer for the same feature

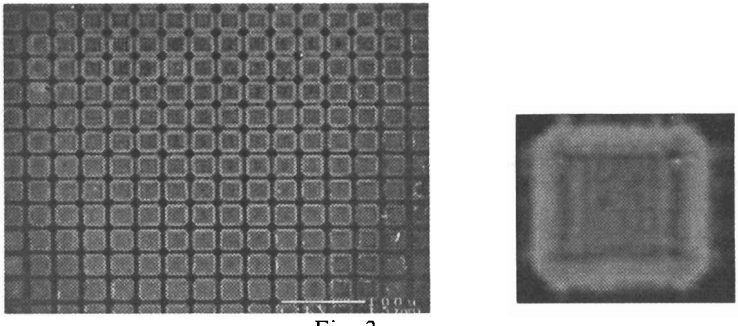

Fig. 3 a

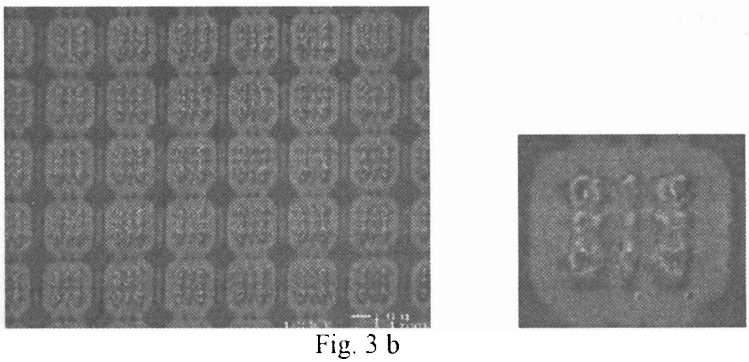

Fig. 3 b

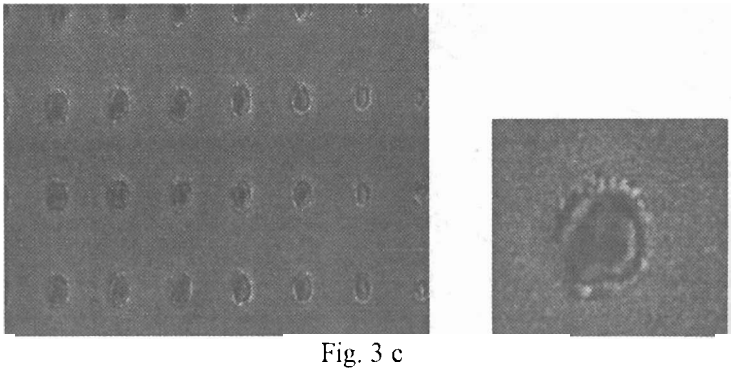

Fig. 3 c

Scanning electron microscope images of nickel features that was fabricated by changing the laser diffraction conditions. Fig. 3a is an array of squares of about 18μmx18μm in dimension, fig. 3b shows a clear diffraction pattern of the nickel features (which are 3μm x 17μm bars), fig. 3c is an array of nickel disks with a diameter of about 8μm

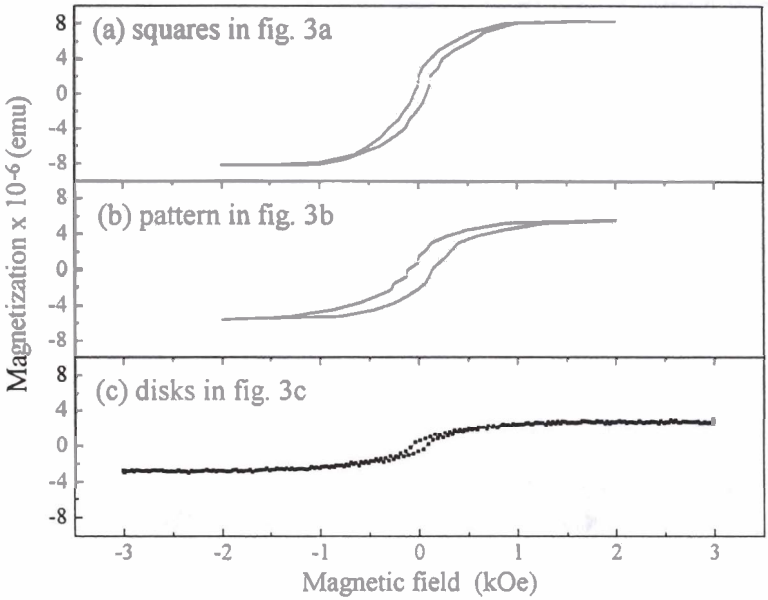

Fig. 4 Hysterisis loops measured by alternating gradient force magnetometer

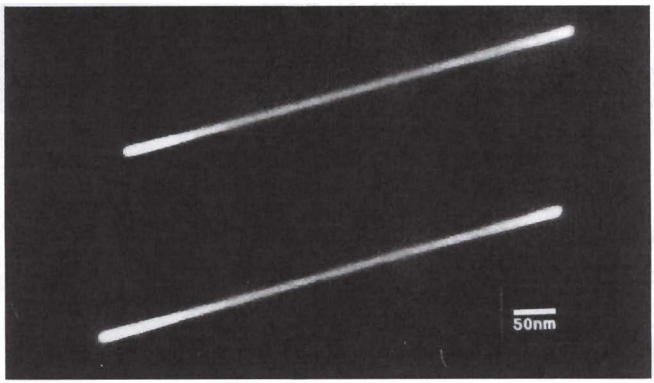

Fig. 5 An annular dark field STEM image of deposits fabricated by electron beam induced OMCVD form nickelocene. Thickness of these lines are in the range of 10-14nm.