Size and Shape Effects in Shrinking Submicron Magnetic Memory and Logic

Final Report

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A. Description:

This research program is based on the premise that selective area deposition of large arrays of micron and submicron scale ferromagnetic features is possible. The magnetic characterization of these features, as a function of both size and shape is a major component of this project but the ultimate goal of this program is to make magnetic device(s). In the first year and a half of this program we characterized the chemistry of magnetic feature fabrication and provided clear demonstrations that the fabrication of large arrays of ferromagnetic features is indeed possible.

The dependence of magnetic properties of a small magnetic feature on both its size and shape is of considerable fundamental interest. Several approaches to fabricating such micron and submicron scale metal features have been undertaken by us, including organometallic chemical vapor deposition (OMCVD) "writing" using scanning transmission electron microscopy (STEM), and U.V. photolysis. We have been able to develop the photolysis of organometallic compounds beyond the simple fabrication of magnetic multilayers to deposit micron-scale *magnetic* patterns on semiconductor substrates. The photo-assisted selective area OMCVD method has advantages not shared by many other techniques. The deposition rate is a few orders of magnitude faster than the STM techniques. The deposition can be performed in ultrahigh vacuum (UHV); thus, with an appropriate choice of source molecules, chemical contamination can be minimized not only within the growing film but at the surface as well. This technique is undertaken at relatively low temperatures so that unusual magnetic multilayers potentially can be fabricated. This method can yield deposition over a large area in a single-step deposition process. Since there is now enough material for an appreciable signal, magnetic properties can be studied by most magnetometry techniques including in-situ measurements, such as magneto-optical Kerr effect. Utilizing a range of masks, diffraction and relatively short wave length light (light in the U.V.), a variety of magnetic features can be directly deposited over a wide range of size and shape.

B. Significant Research Results:

The molecular adsorption and desorption of ferrocene, $Fe(C_5H_5)_2$ [1,2], and nickelocene, $Ni(C_5H_5)_2$ [3,4], on Ag(100) was studied by both photoemission and thermal desorption, while ferrocene adsorption was also studied on Mo(112) [5]. Photoemission results indicate that the initially adsorbed surface species closely resemble that of molecular ferrocene and nickelocene, respectively. The ferrocene molecule is adsorbed with the cyclopentadienyl (C_5H_5) ring ligands parallel to the surface as determined by electron energy loss spectroscopy [1-2]. In the case of nickelocene, the bonding configuration has the molecular axis is also along the surface normal but becomes canted away from the surface normal for bonding configuration phase that develops with increasing coverage [4]. The shift in photoemission binding energies relative to the gas phase is largely independent of the molecular orbital for both metallocenes [5]. The ultraviolet light does lead to partial fragmentation of the ferrocene and nickelocene but fragmentation appears to occur only in the presence of incident radiation for ferrocene [6,7] at low temperatures. The energetics of molecular desorption are influenced by lateral interactions within the molecularly adsorbed film. This is important because this is one of a family of molecules from which we believe ferromagnetic features can be fabricated.

Since fragmentation occurs only in the presence of incident radiation, selective area deposition from this class of molecules is possible. Using a focused electron beam in a scanning transmission electron microscope, we have been able to show that selective area deposition of features with resolution of a few hundred Ångstroms is readily achieved on silicon oxide substrates [6, 7]. We have now been able to improve the uniformity and feature resolution in the deposits quite substantially. Highly uniform rectangular and needle-shaped deposits have now been formed on carbon and silicon nitride substrates with edge acuity and needle width, respectively, of 40 and 80 Ångstroms [18, 19]. We believe that this nanofabrication approach is capable of still further improvement.

Nickelocene decomposition proves to have some thermal decomposition products but the photolytic decomposition process is clean and very similar to that of ferrocene [6]. Large arrays of magnetic features can be fabricated from the photolysis of nickelocene [6-8]. We have been also able to demonstrate that it is possible to deposit a wide range of sizes and shapes of magnetic features in large arrays of identical features, using this photoassisted selective area organometallic chemical vapor deposition [6-11]. Large arrays of identical micron-scale Ni features [6-10], ferrocene [11], cobalt/palladium multilayers [12,13] and cobalt [13] were deposited on a Si(111) wafers, gold, polyimide, and GaAs(110) by this method. Their magnetic properties were studied by alternating gradient force magnetometry as well as magnetic force microscopy and MOKE. 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. Most recently, we have fabricated ferromagnetic CrO_2 by this technique [14].

The experimental results for micron scale nickel features can be modeled [10]. In small spherical magnets, the coercivity is given by H_0, whereas deviations from the spherical shape give rise to shape anisotropy. According to the Brown-Morrish theorem, the magnetostatic energy of a uniformly magnetized body can bee written as $E_{ms} = \mu_0 M.\underline{D}.MV/2$, where $\underline{D}$ is the demagnetizing tensor [15]. Using the in-plane coordinate frame where $M = M_S (\cos\theta\, \mathbf{e}_Z + \sin\theta \cos\phi\, \mathbf{e}_X + \sin\theta \sin\phi\, \mathbf{e}_y)$, we obtain

$$\frac{E_{ms}}{V} = \frac{\mu_o M_S^2}{2}\left(1 - D_X - D_y + \sin^2\theta\left(\frac{3(D_X + D_y)}{2} - 1 - \frac{D_y - D_X}{2}\cos 2\phi\right)\right) \quad (1)$$

where D_X and $D_y > D_X$ are the 'in-plane' eigenvalues of $\underline{D}$. Note that the third eigenvalue is given by $D_Z = 1 - D_X - D_y$. Since we focus on in-plane magnetization processes, we can put $\theta = \pi/2$, so that aside from a physically unimportant zero-point energy

$$\frac{E_{ms}}{V} = -\frac{\mu_o M_S^2}{4}(D_y - D_X)\ \cos 2\phi$$

(2)

Since $D_y > D_X$, the preferential magnetization directions are parallel to the x-axis.

Although Eqs. (1) and (2) apply to any shape, the calculation of the eigenvalues of $\underline{D}$ tends to be very difficult. For general ellipsoids of three different axes, the problem has been solved by Osborn [16]. Using the axes of the ellipsoid as given by $a_X = a/2$, $a_y = b/2$, and $a_Z = t/2$, for $a \gg b \gg t$ one obtains $D_X = 0$ and $D_y = t/b$, whereas $a = b \gg t$ yields $D_X = D_y = \pi t/4b$. The intermediate region involves complete elliptic integrals and is more difficult to treat.

We have shown that the in-plane magnetization depends on the size and shape of the individual magnetic features [6-13] and we have now fit the magnetization curves with simple micromagnetic models, as just noted [10]. Our nickel features have thicknesses of order 500 nm and lateral dimensions of order 20 μm. A part of the features exhibit a four-fold in-plane symmetry or a nearly spherical symmetry, so that their uniform demagnetizing behavior is quasi-uniaxial ($D_X = D_y$). Since Eq. (2) gives rise to a coercivity contribution $\delta H_o = (D_y - D_X) M_S$, we expect $\delta H_o = 0$ and $H_c = H_o$. for Ni, this is 14 mT (140 Oe). On the other hand, some features exhibit a bar-shaped structure, where δH_o is of order $tM_s/b \approx 100$ mT (1 kOe). The coercivity of the bar shaped features is indeed higher than that of the circles and squares, but the difference is much smaller than expected from δH_o.

Our Ni features in question have a *multidomain* ground state, and the low remanence indicates that the actual zero-field state is close to the ground state. An applied external field leads to domain-wall motion. Since the Zeeman energy has to compete against the magnetostatic self energy, saturation is achieved in fields of order tM_S/b, that is about 100 mT. This is indeed observed [10]. By comparison, the bulk anisotropies of order 14 mT play a secondary role.

In films free of defects the domain walls are highly mobile, so that the magnetization follows the field instantaneously and $H_C \approx 0$. However, defects and film inhomogeneities lead to domain-wall pinning and yield a nonzero coercivity. Physically, the wall prefers to stay in regions where the wall energy is lowest. The coercivity is obtained the comparing the magnetostatic and wall energies [17]. The coercivity is estimated from the energy expression

$$E = - 2 \mu_0 M_S H b x t(x) + \gamma b t(x) \qquad (3)$$

where x is a real-space parameter denoting the wall position. Assuming that x = 0 for H = 0 the stability analysis of the wall position can be restricted to x « b. By putting $\partial E/\partial x = 0$ we obtain

$$H_C = \frac{\gamma}{2\mu_0 M_S} \frac{d\ln(t)}{dx} \qquad (4)$$

The logarithmic derivative exhibits a weak dependence on the film's microstructure but is of order $1/\langle t \rangle$, so that we obtain pinning coercivities of order 1 mT (10 Oe). This is smaller than the observed H_c values and indicates that simple domain-wall pinning yields only a minor coercivity contribution. One possible explanation is the involvement of small-scale peculiarities such as comparatively sharp edges, but more detailed calculations require more sophisticated model calculations.

Growth conditions are seen to substantially affect the microstructure and should affect the coercivity but surprisingly this effect is not nearly as great as the influence of patterning a film, even on the micron scale. Forming arrays of dots, with each feature as large as 20 microns, is seen to alter the magnetic anisotropy for both cobalt thin films [13] and cobalt-palladium multilayers [12-13]. On this size scale it is difficult to implicate shape anisotropy and microstructure does not seem to be a great actor – the phenomena are observed for a range of different microstructures obtained by growing on different substrates [12-13].

We are currently modeling the arrays of Co/Pd multilayer structures by our micromagnetic calculations, and characterizing the magnetization reversal dynamics of these features. We are also trying to correlate structural characterization and magnetic mapping of the smaller individual features by transmission electron microscope methods, including differential phase contrast techniques.

It should be noted that other research efforts have adopted our techniques for selective transition metal deposition (Franz Himpsel's group in Wisconsin, W.W. Pai at Oak Ridge National Laboratory, Guenter Reiss at the University of Bielefeld, Richard Palmer at

Birmingham, Marjorie Langell here at UNL, to name a few). There is, perhaps, no higher recognition of our successes.

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1. Dulip Welipitiya, P.A. Dowben, Jiandi Zhang, W.W. Pai and J.F. Wendelken, "The Adsorption and Desorption of Ferrocene on Ag(100)", *Surface Science* **367** (1996) 20-32

2. C. Waldfried, D. Welipitiya, C.W. Hutchings, H.S.V. de Silva, G.A. Gallup, P.A. Dowben, W.W. Pai, Jiandi Zhang, J.F. Wendelken and N.M. Boag, "The Preferential Bonding Orientations of Ferrocene on Surfaces", *J. Physical Chemistry* **B101** (1997) 9782-9789

3. D. Welipitiya, C.N. Borca, C. Waldfried, C. Hutchings, L. Sage, C.M. Woodbridge, and P.A. Dowben, "The Adsorption of Nickelocene I: Molecular Bonding on Ag(100)", *Surface Science* **393** (1997) 34

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5. P.A. Dowben, C. Waldfried, Takashi Komesu, D. Welipitiya, T. McAvoy, and E. Vescovo, "The Occupied and Unoccupied Electronic Structure of adsorbed Ferrocene", *Chem. Phys. Lett.* **283** (1998) 44-50

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7. D. Welipitiya, C.N. Borca, P.A. Dowben, I. Gobulukoglu, Hong Jiang, B.W. Robertson, and Jiandi Zhang, "Fabrication of Micron Scale Magnetic Nickel Features by Selective Organometallic Chemical Vapor Deposition", in Magnetic Ultrathin Films, Multilayers and Surfaces, Edited by J. Tobin, D. Chambliss, D. Kubinski, K. Barmak, P. Dederichs, W. de Jonge, T. Katayama, A. Schuhl, *MRS Symposium Proceedings* **475** (1997) 257-262

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13. C.N. Borca, Rui-Hua Cheng, and P.A. Dowben, "The Influence of Patterning in Co and Co/Pd Multilayers Structures", Mat. Res. Soc. Symp. Proc. (1999)

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18. H. Jiang, J. Swarney II, and B.W. Robertson, "2-D and 3-D Nanostructures Fabricated by Electron Beam-Induced Organometallic Chemical Vapor Deposition", subm. to Thin Solid Films.

19. B.W. Robertson, Hong Jiang, I. Gobulukoglu, and T.L. Benninger, "Versatile Single-Step Fabrication of Submicron Structures", Technical Papers of the North American Manufacturing Research Institution of SME 1997, SME, 1997, pp 155-160.

D. List of Publications:

1) Papers published or "in-press" are indicated:

1. D. Welipitiya, C.N. Borca, C. Waldfried, C. Hutchings, L. Sage, C.M. Woodbridge, and P.A. Dowben, "The Adsorption of Nickelocene I: Molecular Bonding on Ag(100)", *Surface Science* **393** (1997) 34-46

2. C.N. Borca, D. Welipitiya, S. Adenwalla and P.A. Dowben, "The Influence of Topology on Magnetism", *Phys. Low Dim. Struct.* **11/12** (1997) 173-178

3. D. Welipitiya, C.N. Borca, P.A. Dowben, I. Gobulukoglu, Hong Jiang, B.W. Robertson, and Jiandi Zhang, "Fabrication of Micron Scale Magnetic Nickel Features by Selective Organometallic Chemical Vapor Deposition", in Magnetic Ultrathin Films, Multilayers and Surfaces, Edited by J. Tobin, D. Chambliss, D. Kubinski, K. Barmak, P. Dederichs, W. de Jonge, T. Katayama, A. Schuhl, *MRS Symposium Proceedings* **475** (1997) 257-262

4. B.W. Robertson and P.A. Dowben, "Boron-Carbon Alloy Development for Use in High Temperature Electronics and Sensors", The Second European Conference on High Temperature Electronics, HITEN'97 Proceedings, (1998) 219-224

5. C.N. Borca, D. Welipitiya, S. Adenwalla and P.A. Dowben, "The Influence of Topology on Magnetism", *Phys. Low Dim. Struct.* **11/12** (1997) 173-178

6. B.W. Robertson, Hong Jiang, I. Gobulukoglu, and T.L. Benninger, "Versatile Single-Step Fabrication of Submicron Structures", Technical Papers of the North American Manufacturing Research Institution of SME 1997, SME, 1997, pp 155-160.

7. P.A. Dowben, C. Waldfried, Takashi Komesu, D. Welipitiya, T. McAvoy, and E. Vescovo, "The Occupied and Unoccupied Electronic Structure of adsorbed Ferrocene", *Chem. Phys. Lett.* **283** (1998) 44-50

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11. I. Gobulukoglu and B.W. Robertson, "In Situ STEM Technique for Characterization of Nanoscale Interconnects during Electromigration Testing", in Materials Reliability in Microelectronics IX, edited by C. A. Volkert, A. H. Verbruggen and D. D. Brown, *MRS Symposium Proceedings* **563** (1999) 181-6

12. C.N. Borca, Rui-Hua Cheng, and P.A. Dowben, "The Influence of Patterning in Co and Co/Pd Multilayers Structures", Mat. Res. Soc. Symp. Proc. (1999), in press

13. C.N. Borca, D. Welipitiya, P.A. Dowben and N.M. Boag, "Bonding Configurations for Nickelocene on Ag(100) and Steric Effects in Thermal Desorption", *J. Physical Chemistry*, in press.

14. H. Jiang, J. Swarney II, and B.W. Robertson, "2-D and 3-D Nanostructures Fabricated by Electron Beam-Induced Organometallic Chemical Vapor Deposition", subm. to Thin Solid Films.

15. Rui-Hua Cheng, C.N. Borca, and P.A. Dowben, "Photoassisted Organometallic Chemical Vapor Deposition of Ferromagnetic CrO_2", in preparation.

2) Presentations:
a) invited

1. "Stacking Sequences in Co-Sm Films", MSC Presidential Symposium at the joint Microscopy Society of America, Microscopical Society of Canada and Microbeam Analysis Society Meeting, Minneapolis, August 1996

2. "Microstructural Studies of Magnetic Materials", 1996, International Metallographic Society Conference, Pittsburgh, July 1996

3. "The CVD of Micron and Ferromagnetic Structures" Salford University Chemistry Colloquium, March 3, 1997

4. "Nanometer Scale Magnetic Patterning with Novel CVD Techniques", paper K22-1, March Meeting of the American Physical Society, Kansas City, Missouri, March 19, 1997, published abstract: P.A. Dowben, Bull. Am. Phys. Soc. 42 (1997) 505

5. "Metallocenes on Ordered Metal Surfaces", Condensed Matter Seminar, Department of Physics, University of Osnabrück, Sept. 30, 1997 [presented by David Pugmire]

6. "Die Bevorzugte Bindungsorientierung von Metallocenen an Oberflächen", Universität Heidelberg, Institut für Angewadte Physikalische Chemie, D-69120, Heidelberg, Germany (November 4, 1997) [presented by C. Waldfried]

7. "The Preferential Bonding Orientation of Metallocenes on Surfaces", Department of Chemistry, Salford University, United Kingdom, (Nov. 26, 1997) [presented by C. Waldfried]

b) Contributed

1. "The Vibrational Loss Spectra of Adsorbed Ferrocene on Ag(100)", paper F17-12, March Meeting of the American Physical Society, Kansas City, Missouri, March 18, 1997, [presented by C.Walfried], published abstract: Handunnetti de Silva, G. Gallup, W. Pai, Jiandi Zhang, J. Wendelken and E.W. Plummer, Bull. Am. Phys. Soc. 42 (1997) 253

2. "Applications of Selective Area Deposition: Magnetic Micron Scale Array of Dots", paper K22-2, March Meeting of the American Physical Society, Kansas City, Missouri, March 19, 1997, [presented by Dulip Welipitiya]

3. "The Surface Chemistry of Metallocenes and Fabrication of Micron Scale Magnetic Nickel Features", 57th Annual Conference on Physical Electronics, June 19, 1997, University of Oregon, Eugene, OR [presented by Dulip Welipitiya]

4. "Fabrication of Micron Scale Magnetic Nickel Features by Selective Area Organometallic Chemical Vapor Deposition", C.N. Borca, D. Welipitiya, Shireen Adenwalla and P.A. Dowben, 10th International Conference on Superlattices, Microstructures and Microdevices, July 11, 1997, Lincoln, Nebraska [presented by Camelia Borca]

5. "The Surface Chemistry of Metallocenes and Fabrication of Micron Scale Magnetic Nickel Features", 57th Annual Conference on Physical Electronics, June 19, 1997, University of Oregon, Eugene, OR [presented by Dulip Welipitiya]

6. "Boron-Carbon Alloy Development for Use in High Temperature Devices and Sensors", 2nd European High Temperature Electronics Conference (HITEN 97), September 1997, Manchester, England

7. "Fabrication of Micron Scale Magnetic Nickel Features by Selective Area Organometallic Chemical Vapor Deposition", C.N. Borca, D. Welipitiya, Shireen Adenwalla and P.A. Dowben, 45th Midwest Solid state Conference, Oct. 4, 1997, Kansas State University, Manhattan, Kansas [presented by Camelia Borca]

8. "The Occupied and Unoccupied Molecular Orbitals of Ferrocene", Takashi Komesu, C. Waldfried, T. McAvoy and P.A. Dowben, 45th Midwest Solid state Conference, Oct. 4, 1997, Kansas State University, Manhattan, Kansas [presented by Takashi Komesu]

9. "The Occupied and Unoccupied Molecular Orbitals of Ferrocene", Paper SS-TuP7, T.McAvoy, C. Waldfried, and P.A. Dowben, 44th National Symposium of the AVS, Oct. 21, 1997, San Jose, CA [presented by C. Waldfried]

10. "Orientation and Bonding on Solid Surfaces", paper I28-4, March Meeting of the American Physical Society, Los Angesles, California, March 17, 1998, [presented by Carlo Waldfried], published abstract: P.A. Dowben, Carlo Waldfried, T. McAvoy, Dulip Welipitiya, C.N. Borca, J. Wendelken, W.W. Pai, J. Zhang and E. Vescovo, Bull. Am. Phys. Soc. 43 (1998) 307

11. "The Occupied and Unoccupied Molecular Orbitals of Ferrocene and Cyanoferrocene on Mo(112)", paper I28-8, March Meeting of the American Physical Society, Los Angesles, California, March 17, 1998, [presented by Takaski Komesu], published abstract: Takashi Koemsu, Carlo Waldfried, P.A. Dowben and E. Vescovo, Bull. Am. Phys. Soc. 43 (1998) 308

12. "Fabrication and Characterization of Micron Scale Magnetic Features", paper S22-9, March Meeting of the American Physical Society, Los Angesles, California, March 19, 1998, [presented by C, Borca], published abstract: C.N. Borca, Shireen Adenwalla and P.A. Dowben, Bull. Am. Phys. Soc. 43 (1998) 716

13. "The Occupied and Unoccupied Molecular Orbitals of Ferrocene and Cyanoferrocene on Mo(112)", 1998 Meeting of the Nebraska Academy of Science, Nebraska Wesleyan University, April 24, 1998 [presented by Takashi Komesu]

14. "Fabrication and Characterization of Micron Scale Magnetic Features", 3rd International Symposium of Metallic Multilayers/European MRS Symposium on Magnetic Ultrathin Films and Ultrathin Film Nanostructures, Simon Frazer University, Vancouver, Canada, June 15, 1998 [presented by Camelia Borca]

15. "Occupied and Unoccupied Molecular Orbitals of Ferrocene and Cyanoferrocene on Mo(112)", 33rd Midwest Regional Meeting of the American Chemical Society", Wichita, KS, November 6, 1998, paper 51 [presented by Takashi Komesu]

16. “Boron-Carbon Semiconductor High-Temperature Devices and Sensors”, 1999 NASA / JPL Conference on Electronics for Extreme Environments, Pasadena, California, February 1999

17. "Fabrication of nanowire arrays by selective adsorption of metallocene on striped $CaF_2/CaF_1/Si(111)$", 1999 Centennial March Meeting of the APS, Atlanta GA, March 24, 1999 [presented by J.-L. Lin]; published abstract VC21-8, J.-L. Lin, H. Rauscher, A. Kirakosian, D.Y. Petrovykh, F.J. Himpsel, Bulletin of the American Physical Society, 44, 1582 (1999)

18. "Micromagnetic Model of Patterned Soft Magnetic Structures", 1999 Spring Meeting of the MRS, San Francisco, April 6, 1999, [presented by C.N. Borca] abstract J3.3

19. “Characterization of Nanoscale Interconnects by In Situ STEM Analysis during Electromigration Testing”, MRS 1999 Spring Meeting, San Francisco, April 1999, [presented by Ismail Gobulukoglu] abstract M3.1.

20. “Magnetic Nanostructures Fabricated by Electron Beam-Induced Organometallic CVD”, MRS 1999 Spring Meeting, San Francisco, April 1999, [presented by Hong Jiang] abstract J3.2.

<u>List of Honors and Awards:</u>

Fall 1996 Dulip Welipitiya	University of Nebraska	Sigma Xi Graduate Student Award
Spring 1997 Peter Dowben	University of Nebraska	College of Engineering and Technology Multidisciplinary Research Award

Brian Robertson	University of Nebraska	College of Engineering and Technology Faculty Research Award

Graduate students (1999):

Camelia Borca (female)
Rui-Hua Cheng (female)
Hong Jiang (female)
Ismail Gobulukoglu (male)

Graduates:

Dulip Welipitiya, Ph.D., Department of Physics and Astronomy, University of Nebraska, 1997, now with Applied Magnetics, Santa Barbara, California
Thesis: "Fabrication of Micron Scale Ferromagnetic Nickel Features by Selective Area Organometallic Chemical Vapor Deposition"
Student prizes: Sigma Xi Graduate Student Award (1997)

Laurence Sage, Department of Chemistry, University of Franche-Compté, Maitrise de Chimie, 1997
Thesis: "The Adsorption and Desorption of Nickelocene on Ag(100)"

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13. SUPPLEMENTARY NOTES

14. ABSTRACT The research is based on radiation-induced selective area fabrication (using metallocenes) of large arrays of µm and sub-µm scale ferromagnetic features and on magnetic characterization as a function of size and shape. With 100keV electrons we fabricated highly uniform 8nm features. With light we fabricated many sizes and shapes of identical µm-scale magnetic features (Ni, Fe, Co, CrO_2, and Co/Pd multilayers) in large arrays, quickly, cleanly and at ambient temperatures. We used alternating gradient force magnetometry, MFM and MOKE and showed that in-plane magnetization depends on feature size and shape. Coercivities are higher for bar-shaped Ni features than for 4-fold or nearly circularly symmetric ones, but less than predicted. Pinning contributes little to coercivity in multidomain Ni features with low remanence. Growth conditions affect microstructure substantially but influence coercivity much less than patterning does, even on the µm-scale. We are now modeling Co/Pd multilayer arrays, characterizing reversal dynamics, and mapping magnetic features.

15. SUBJECT TERMS
submicron magnetic features; micron-scale magnetic features; large ferromagnetic arrays; size and shape effects; photoassisted OMCVD; electron beam-induced OMCVD; selective area fabrication

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