Alignment and stretching of compliant nanomembranes by embedded nanomagnets

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We present a method to distort, stretch, and align nanomembranes by forces between nanomagnets. As shown in Figure 1, an array of magnets embedded within the membrane is brought into proximity of a matching array of magnets patterned on a rigid substrate. The attraction between substrate magnets and their corresponding membrane-embedded magnets can be sufficiently strong to overcome the membranes' stiffness and result in stretching and bending. Thus, pattern distortions on the membrane may be reduced and repeatable, accurate overlay achieved. The technique is most promising for ultra-compliant proximity lithography masks that would otherwise distort (e.g. x-ray lithography masks) and for 3D nanomembrane stacking [1] where layer-to-layer overlay alignment is critical. Previous work showed the folding and self-alignment of rigid silicon nitride membrane segments with nanomagnets [2]. In this work, we present the theoretical framework for predicting maximum membrane distortion from geometry and material properties, and apply it in experiment to the special case of cobalt nanomagnet disks embedded in PMMA nanomembranes.

Numerical and analytical models show a near-linear response for both the membrane distortion and inter-magnet forces at displacements smaller than the magnet diameters. Therefore, the effective spring constants of an array of magnets and the membrane can be compared to calculate the reduction in alignment error that the magnets provide. Figure 2 shows the results for disk nanomagnets covering 20 μm^2 in the middle of a 2mm×2mm membrane of 200nm thick PMMA and 100nm thick PDMS. A range of magnet diameters and initial spacing between membrane and substrates is shown. For example, 150nm diameter magnets patterned on the 200nm PMMA membrane can reduce alignment error from 50nm to 5nm. Optimization is achieved by maximizing the membrane compliance without making it prone to breakage, and then minimizing the amount magnets needed for alignment.

The fabrication process for embedding nanomagnets in the polymer membranes is shown in Figure 3. Nanomagnet pillars and disks 200nm thick were patterned on 200nm SiN_x that are 1.6mm squares using e-beam lithography and lift-off. Next 200nm of PMMA was spun onto the membrane and the underlying SiN_x was removed with a backside reactive ion etch. Numerous membrane and magnet sizes were explored; the stress of the deposited magnetic material and the lift-off process were the critical processing points. Figure 4 shows 200nm diameter nanomagnet pillars embedded in the suspended PMMA membrane.

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[1] K. Aoki et. Al. Microassembly of semiconductor three-dimensional photonic crystals. *Nature Materials* **2**, 117 (2003)
[2] A. Nichol et. al, "Two-step magnetic self-alignment of folded membranes for 3D nanomanufacturing," Microelectronic Engineering, vol. 84, no. 5-8, pp. 1168-1171, Feb. 2007.

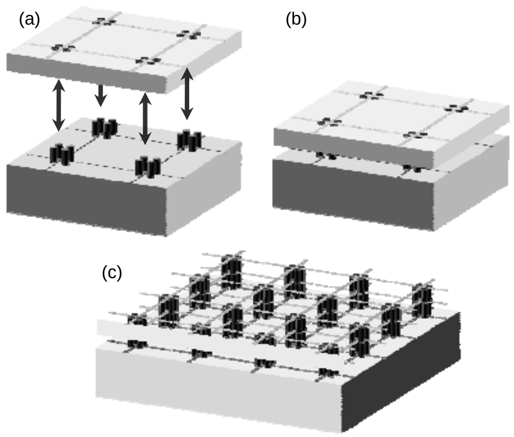

Figure 1: Schematic of the membrane alignment method. (a-b) Nanomagnets embedded within the polymer membrane attract and align to a matching array on the substrate. (c) A large grid allows for local alignment over wide areas.

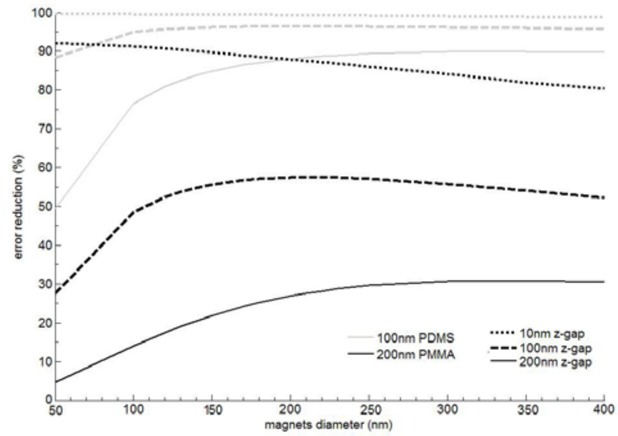

Figure 2: Percentage error reduction that a 20μm^2 array of nanomagnets on a 2mm×2mm can provide for a given magnet diameter, z-gap between membrane and substrate, and membrane thickness and material.

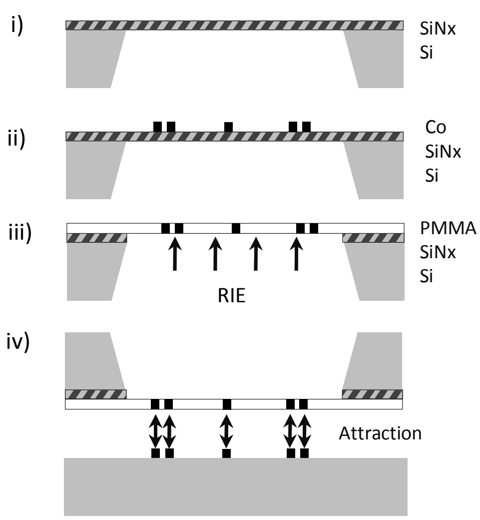

Figure 3: Process for embedding and aligning a polymer membrane. A 200nm thick silicon nitride membrane is patterned with 200nm thick cobalt nanomagnet. Next PMMA is spun onto the membrane and the nitride is removed with a backside RIE.

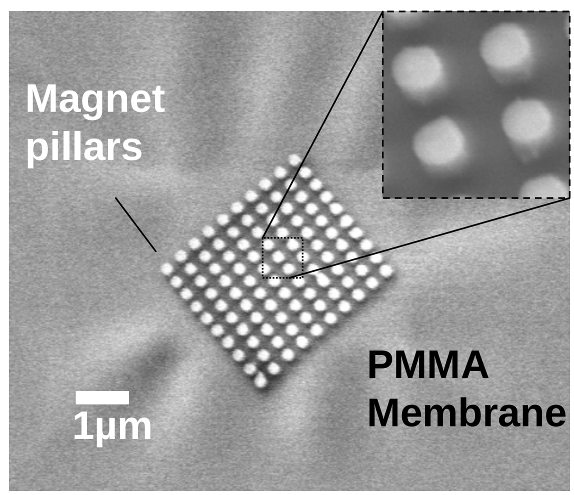

Figure 4: SEM micrograph of the 200nm diameter, 200nm tall cobalt nanomagnet pillars embedded in a PMMA membrane. The membrane distorted with electron exposure in the SEM.