Fabrication of magnetic nanostructures for real-time manipulation of ferrofluid

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Magnetic tunable nanopillars have attracted significant research interests recently due to their dynamic properties and low energy consumption compared with electrical actuation. These structures can be used for various applications, such as dry adhesion [1], sensors or actuators in microfluidics [2-3], and cell manipulation [4]. Mechanical flexibility and magnetic susceptibility are both important for these structures, and can be enabled by using mixtures of polymer such as PDMS and magnetic nanoparticles (iron, iron oxide, cobalt, nickel, etc.). Using lithography, micropillars with diameter of 25 μm can be patterned in an array with low aspect ratio (AR) around 2, limited by the magnetic material's size and the demolding method [1]. At the sub-μm, random pillar array with high AR (~ 100) has been made by using magnetite nanoparticles and dissolvable template, which can be used to control fluid flow [2]. Here we introduce a simple method to fabricate a periodic pillar array with sub-micrometer features, which can be used as a tunable optical element by serving as a template for magnetic nanoparticle assembly.

The fabrication procedure is shown in Fig 1. First, a 2D periodic (~ 2 μm period) template was made by laser interference lithography. The mixture of PDMS and magnetite nano-particles (~ 10 nm diameter) was then applied into the template, which results in a periodic magnetic pillar array after curing and demolding. Structures with AR around 1-10 have been achieved, as shown in Fig 2. Finally, ferrofluid can be confined on the pillar array using PDMS micro-channels. Fig 3 demonstrates the assembly of magnetic nanoparticles on the pillar array when external fields are applied. Under a perpendicular, out-of-plane magnetic field, the nanoparticles form columns on the magnetic pillars and increase the AR of the periodic structure. Such template-directed assembly of periodic columns can also be actuated by external magnetic field such as tilting and rotating, thereby changing the optical properties. Particularly, 1D parallel lines can be formed under horizontal field for in-plane magnetization, changing the optical properties. Fig 4 illustrates the reflection efficiencies of -1^{th} and $+1^{th}$ orders measured as a function of field tilt angle, indicating tunability of up to 40%.

A fabrication method for robust magnetic periodic pillar array is reported here. The structure can be used to manipulate nanoparticle assembly in real-time, resulting in a tunable photonic structure. We will present detailed fabrication and particle assembly results, as well as characterization of optical properties under various external magnetic field conditions. We will also discuss challenges and limitations in achieving uniform periodicity.

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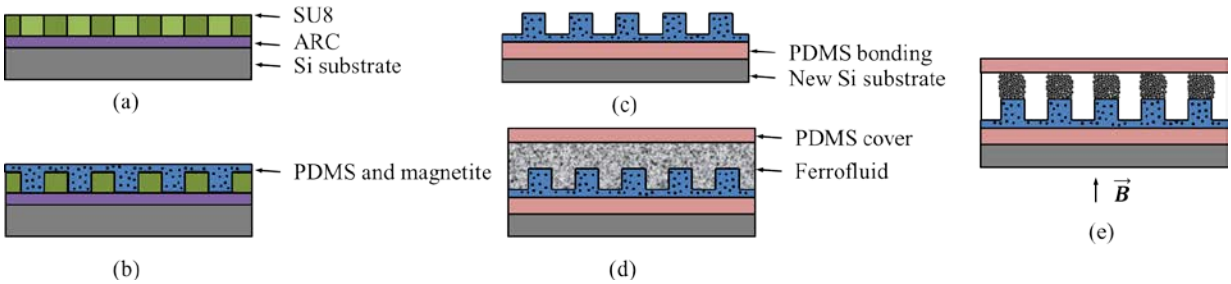

Fig 1. Fabrication procedure. (a) Interference lithography for 2D periodic template; (b) curing for the mixture of PDMS and magnetite nanoparticles; (c) demolding and bond pillar array onto new silicon substrate by PDMS; (d) confine ferrofluid onto pillar array by PDMS channel; (e) real-time manipulation by external magnetic field.

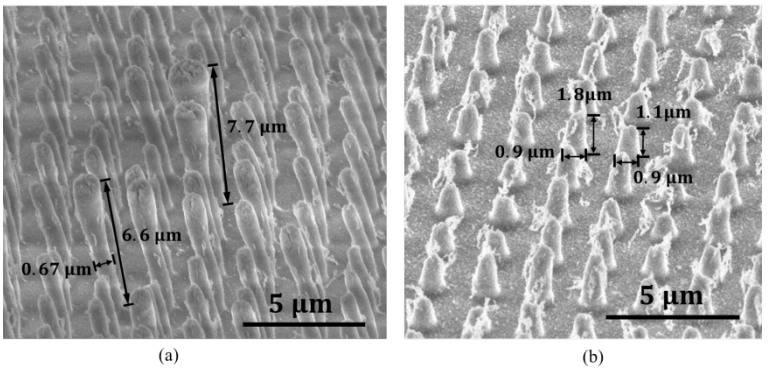

Fig 2. SEM images of the pillar array. (a) High AR around 10; (b) low AR around 1- 2.

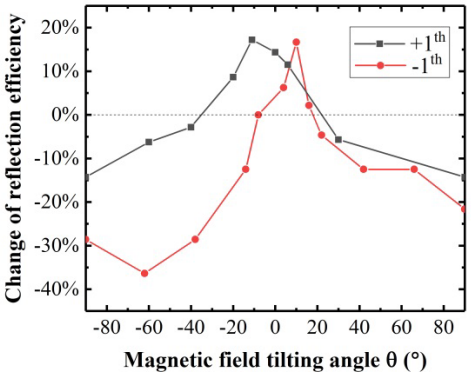

Fig 4. The reflected diffraction efficiency changes vs field angles.

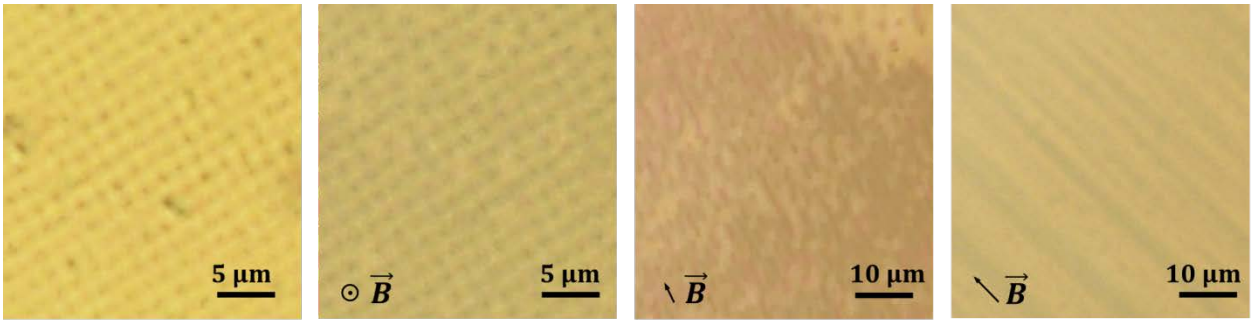

Fig 3. The optical microscope images illustrate particle assembly under external field. (a) The ferrofluid on 2D template without magnetic field; (b) periodic 2D columns are formed under perpendicular field; (c) columns tilt along field direction; (d) 1D parallel lines are formed under horizontal field.

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