Tunable nanoparticle self-assembly on magnetic template with dynamic optical properties

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Magnetic tunable micro-/nanostructures have attracted significant research interests recently due to the dynamic properties and the low energy consumption compared with electrical devices. Many of these structures are based on embedding magnetic particles in solid polymer materials, which can be used for various applications such as dry adhesion [1], sensors or actuators in microfluidics [2], and cell manipulation [3]. In comparison, there is less work on tunable structure in liquid carrier. We previously worked out a device which can guide the self-assembly of nanoparticles in ferrofluid to form rectangular array with 2D periodicity on magnetic template [4]. The self-assembly can be actuated to tilt and rotate, resulting in color change from green to red. Based on previous work, here we report the method to fabricate self-assembled nanoparticles with 1D periodicity on magnetic template. This structure demonstrates dynamic birefringent effects, which can potentially be used as tunable polarization element.

The fabrication procedure is shown in Fig 1. First, a 2D periodic (~ 2 μm period) photoresist mold is fabricated by laser interference lithography. Then the mixture of PDMS and iron oxide nanoparticles (~ 10 nm) is applied into the mold, cured, and then separated from the mold using soft lithography, resulting in a replica of periodic magnetic pillar array (aspect ratio ~ 1), as shown in Fig 2a. Finally, ferrofluid is applied on the magnetic template and covered by PDMS micro-fluidic channel. Fig 2b shows the assembly of magnetic nanoparticles on the pillar array when the in-plane external magnetic field is applied. The 1D self-assembly can rotate in the in-plane directions according to the external field, which results in the change of the optical anisotropy. To characterize the polarization change, the linear polarizer is introduced into the measurement, as shown in the schematic in Fig 3a. When the linear polarizer is perpendicular to the polarization of incident light, the reflected light will be blocked. However, when the 1D self-assembly is rotated by the external magnetic field, a clear enhancement of the reflectance can be observed with rotation angles of 45° and 135°, shown in Fig 3b.

The fabrication and characterization of 1D self-assembled nanoparticles on magnetic template will be reported. The structure can be manipulated in real-time, resulting in a tunable polarization structure. We will also discuss challenges and limitations in achieving uniform periodicity.

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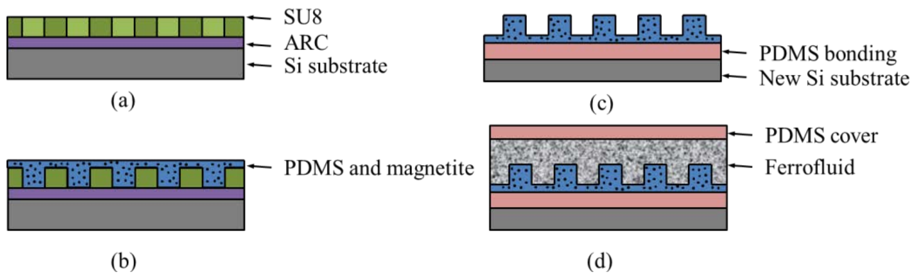

Fig 1. Fabrication procedure. (a) Interference lithography for 2D periodic template; (b) curing for the mixture of PDMS and magnetite nanoparticles; (c) demolding and bond pillar array onto new silicon substrate by PDMS; (d) apply ferrofluid onto pillar array and confined with PDMS channel.

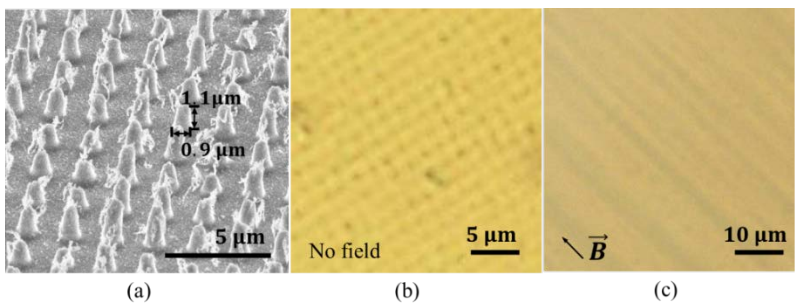

Fig 2. Microscopy imaging of magnetic template and self-assembly. (a) SEM image of magnetic template. (b) The top-view optical microscopic image of magnetic template and ferrofluid on it. (c) The top-view optical microscopic image of 1D self-assembly.

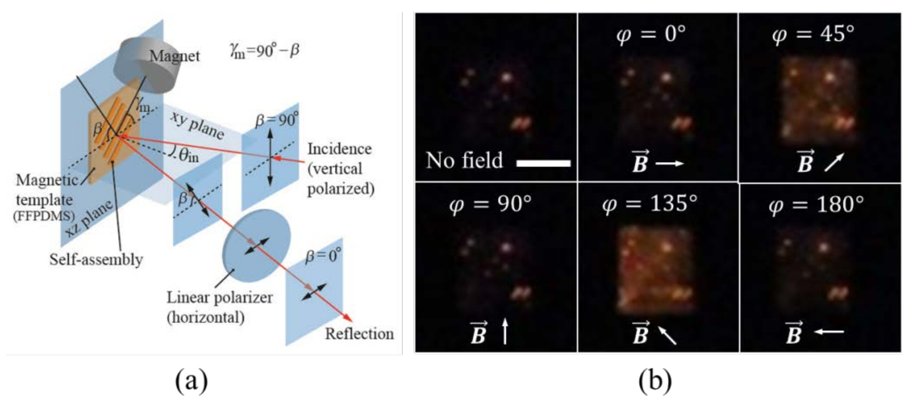

Fig 3. Characterization of dynamic polarization. (a) The schematic of measurement setup. (b) The reflection of the 0^{th} order at different rotating angles φ. The scale bar is 1 mm.

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