

## Antifouling surfaces

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# Antifouling Surfaces: Removal of Micro-Particles by Magnetic Artificial Cilia

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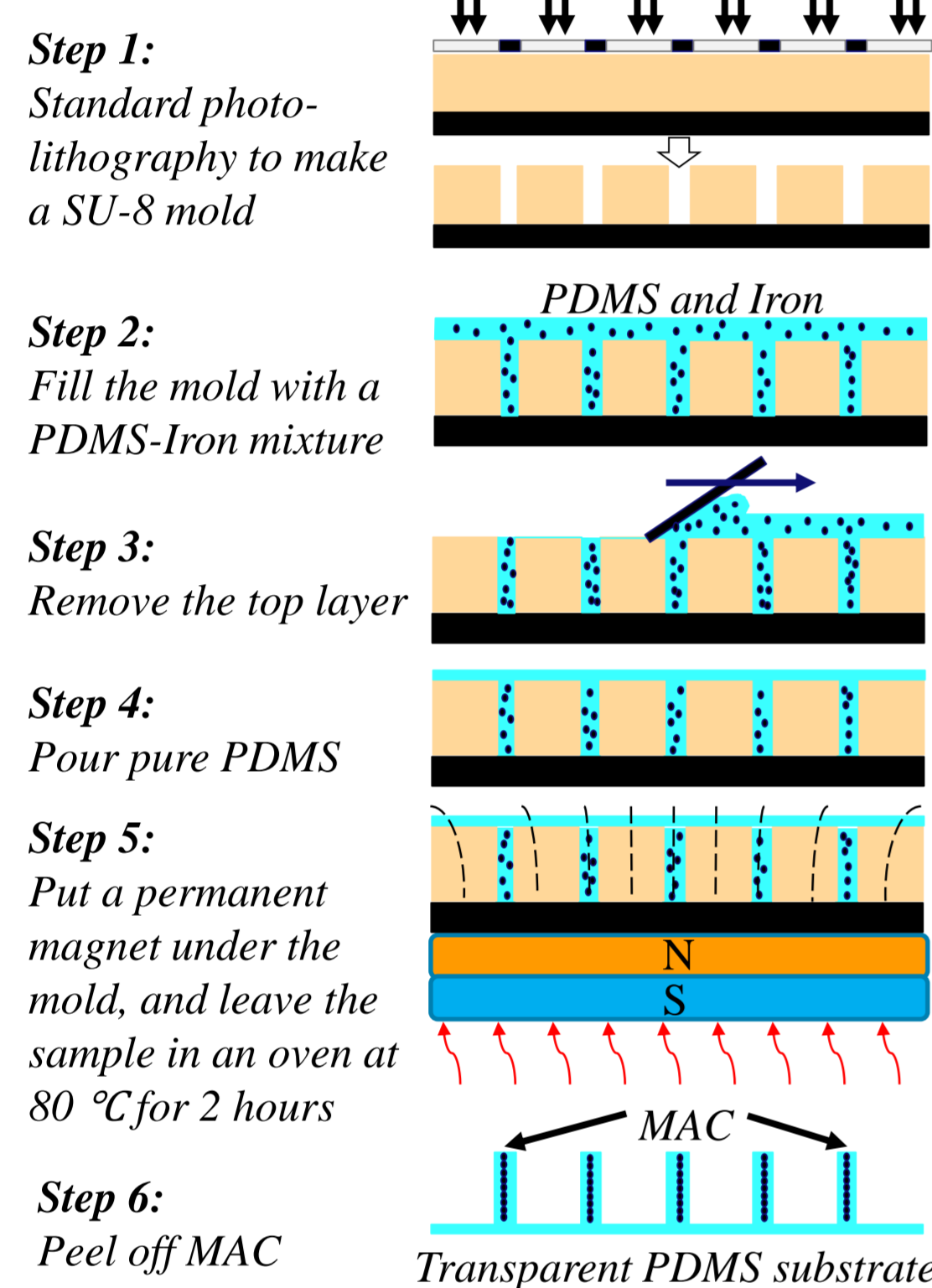


## MOTIVATION

The **fouling** of surfaces submerged in a liquid is an important problem for many applications. One biologically inspired strategy to tackle this problem is given by **cilia-induced particle transportation and cleaning**. Biological cilia are micro-hairs, which have been reported to have such functions as fluid propulsion, feeding, mucus removal out of the human airway, transport of microscopic particles, etc. Here, for the first time, we experimentally prove that **magnetic artificial cilia (MAC)** are able to remove micro-particles from the ciliated area.

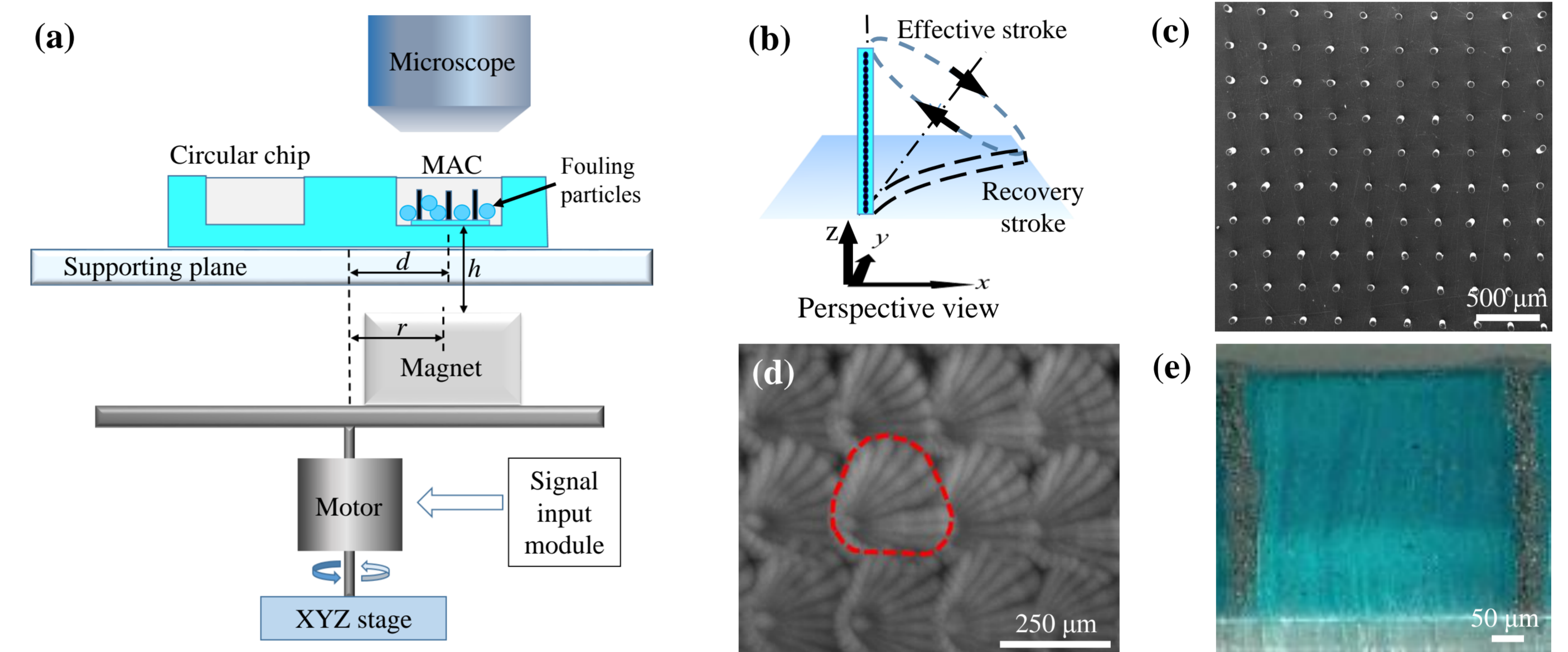
## EXPERIMENTS

### I Micro-Molding Process of MAC



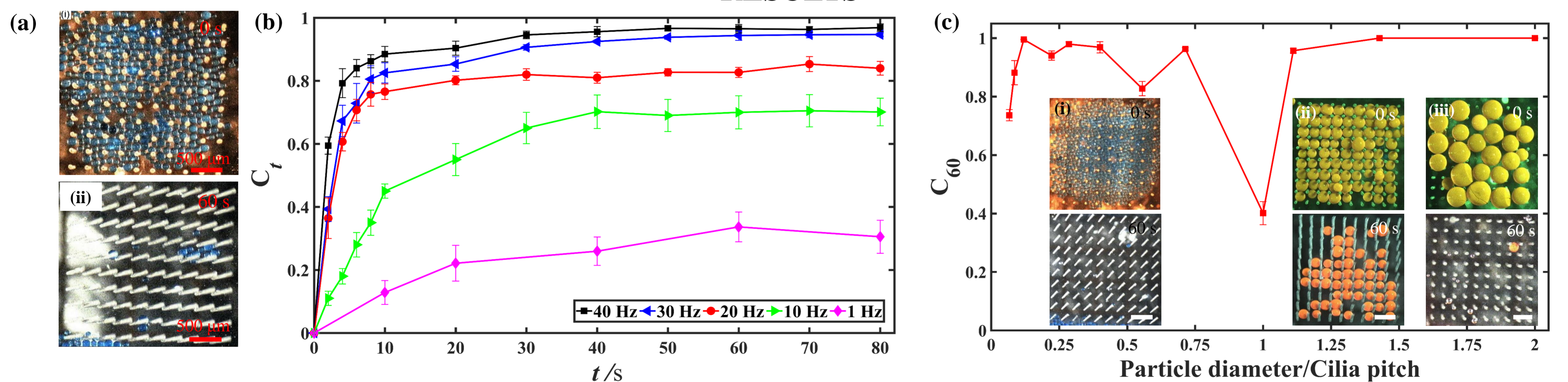
**Figure 1.** Schematics of the process to fabricate MAC which have a strong magnetic response. [1]

### II Actuation scheme



**Figure 2.** Actuation scheme of the MAC. (a) Schematics of the actuation setup with MAC integrated in an open-top circular chip with a rectangular cross section with a width of 5 mm and height of 4 mm. The fouling representative particles (blue polylactic acid (PLA) particles) are loaded in the ciliated area before actuation. The rotation axis of the magnet is offset by a distance  $d=6$  mm with respect to the center of the ciliated area, and the magnet is placed at a distance  $r=6.5$  mm from the rotation axis. The vertical distance  $h$  between the top surface of the magnet and the MAC was set to 2 mm. (b) Schematic drawing of a rotating cilium performing a tilted conical motion in perspective view. Illustrations are not to scale. (c) A top-view SEM image of the MAC with a diameter, length and pitch of 50, 350, and 250  $\mu\text{m}$ , respectively. (d) A top-view image of the motion of the rotating MAC at 40 Hz in water. The image is composed of 25 overlapping frames in one actuation cycle. The red dashed line indicates the cilia tip trajectory. (e) Cross sectional view of the MAC. [1]

## RESULTS



**Figure 3.** (a) Snapshots from one recorded experiment after the MAC operate for (i) 0 seconds, and (ii) 1 minute, showing that PLA particles (blue) are gradually removed from the ciliated area. In this experiment, the actuation frequency was 40 Hz; the MAC had a pitch of 250  $\mu\text{m}$ , and the microparticles had an average diameter of 100  $\mu\text{m}$ . (b) Calculated cleanliness as a function of the operating time at different actuation frequencies. The cleanliness is defined as  $C_t = (N_0 - N_t) / N_0$ , where  $N_0$  is the number of particles within the ciliated area at time 0, and  $N_t$  is the number of particles left after the MAC operating for  $t$  seconds. In these experiments, the MAC had a pitch of 250  $\mu\text{m}$ ; the particles used were 100  $\mu\text{m}$  PLA particles. (c) Calculated cleanliness as a function of the ratio between the particle diameter and the cilia pitch when the actuation frequency is 40 Hz. The cleanliness is  $C_{60} = (N_0 - N_{60}) / N_0$ . The insets are snapshots from the recorded experiments for particle size to cilia pitch ratio of (i) 2/7, (ii) 1 and (iii) 2. The scale bars in (i) are 700  $\mu\text{m}$ , and the scales bars in (ii) and (iii) are 500  $\mu\text{m}$ .

## CONCLUSION

Micro-molded magnetic artificial cilia are able to remove the vast majority of a large size range (30 to 500  $\mu\text{m}$ ) of micro-particles from their vicinity within a minute, creating a clean area. This finding offers a new method to manipulate micro-particles and to create a novel type of self-cleaning/antifouling surface, which can find applications in, for example, marine antifouling and lab-on-a-chip devices.