Anti-fouling surfaces

Removal and exclusion 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 from the human body, transport of microscopic particles, etc. Here, for the first time, we experimentally prove that **magnetic artificial cilia (MAC)** are able to remove and exclude micro-particles from the ciliated area.

EXPERIMENTS

I Micro-moulding Process of MAC

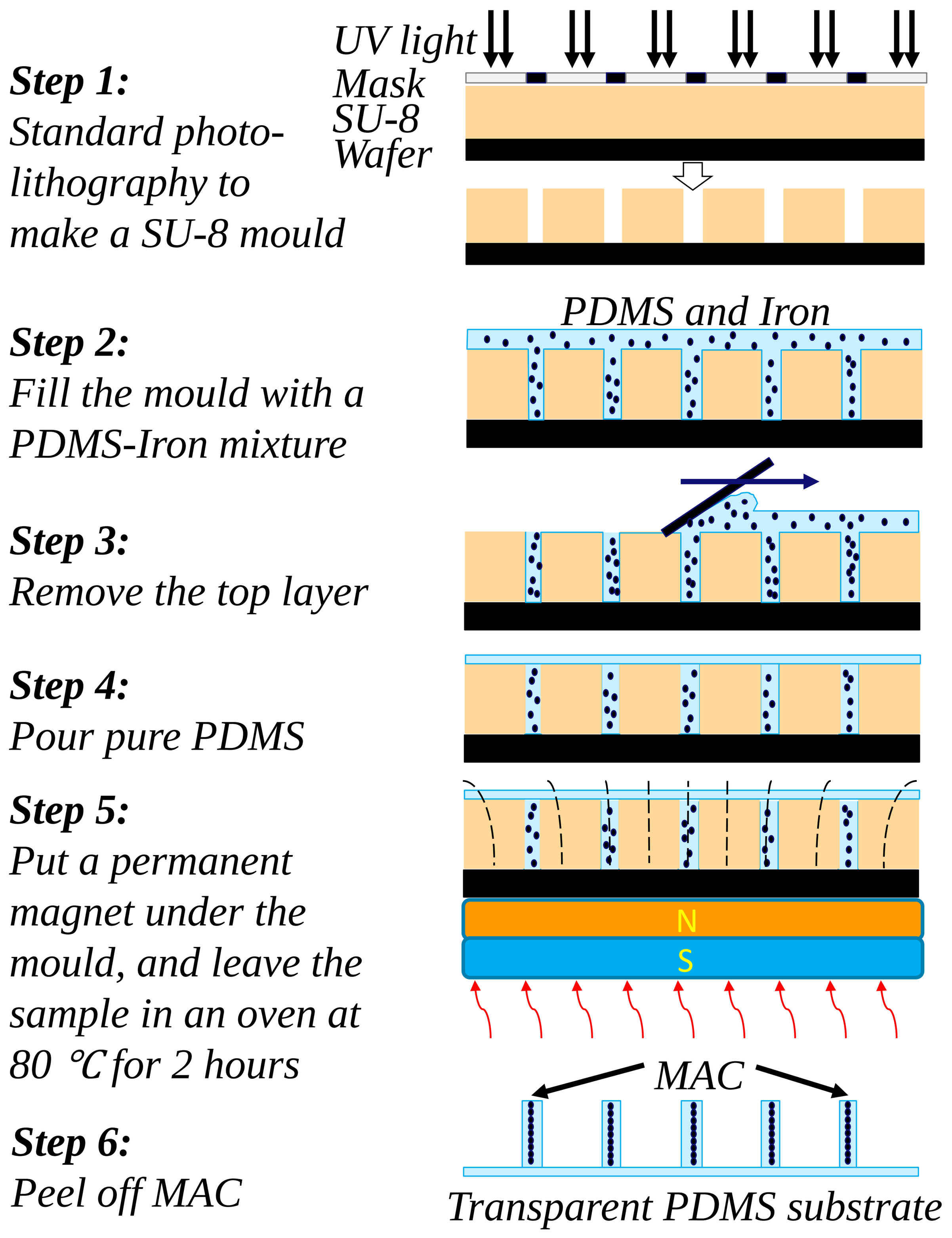

Fig. 1 Schematic diagram of the moulding process to fabricate MAC which have a strong magnetic response. [1]

II Actuation scheme

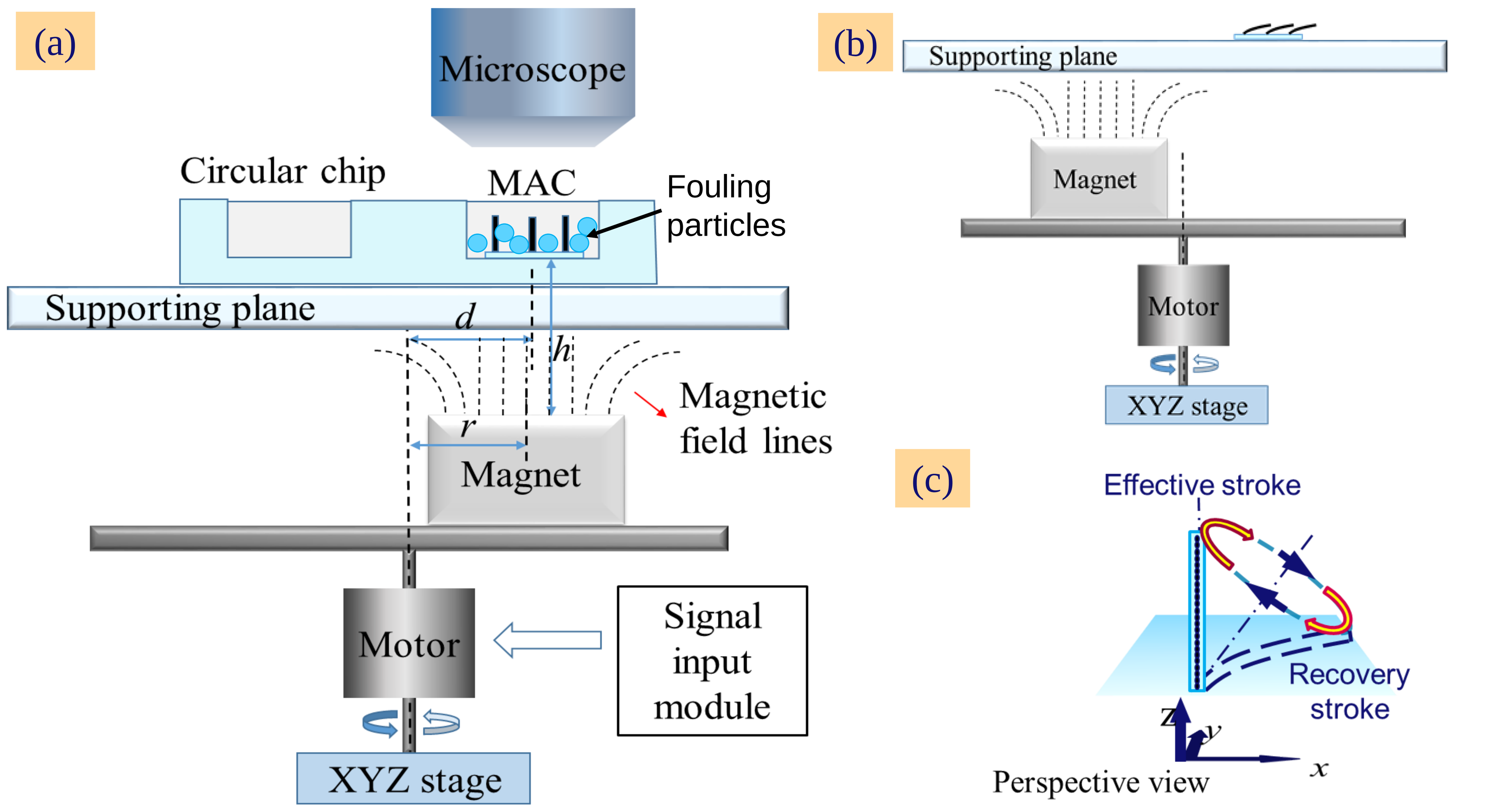

Fig. 2 Actuation scheme of the fabricated MAC. (a) Schematics of the actuation setup with MAC integrated in an open-top circular chip with a rectangular cross section with a channel width of 5 mm and channel height of 4 mm, placed on a supporting plate and underneath a microscope. The fouling representative particles (blue polylactic acid 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. In the shown position, the cilia orientation is perpendicular to the substrate (effective stroke). (b) Schematic drawing of the bending cilia when the magnet rotates 180°. In this position, the cilia are bent (recovery stroke). (c) Schematic drawing of the rotating cilium performing a tilted conical motion in perspective view. Illustrations are not to scale.

RESULTS

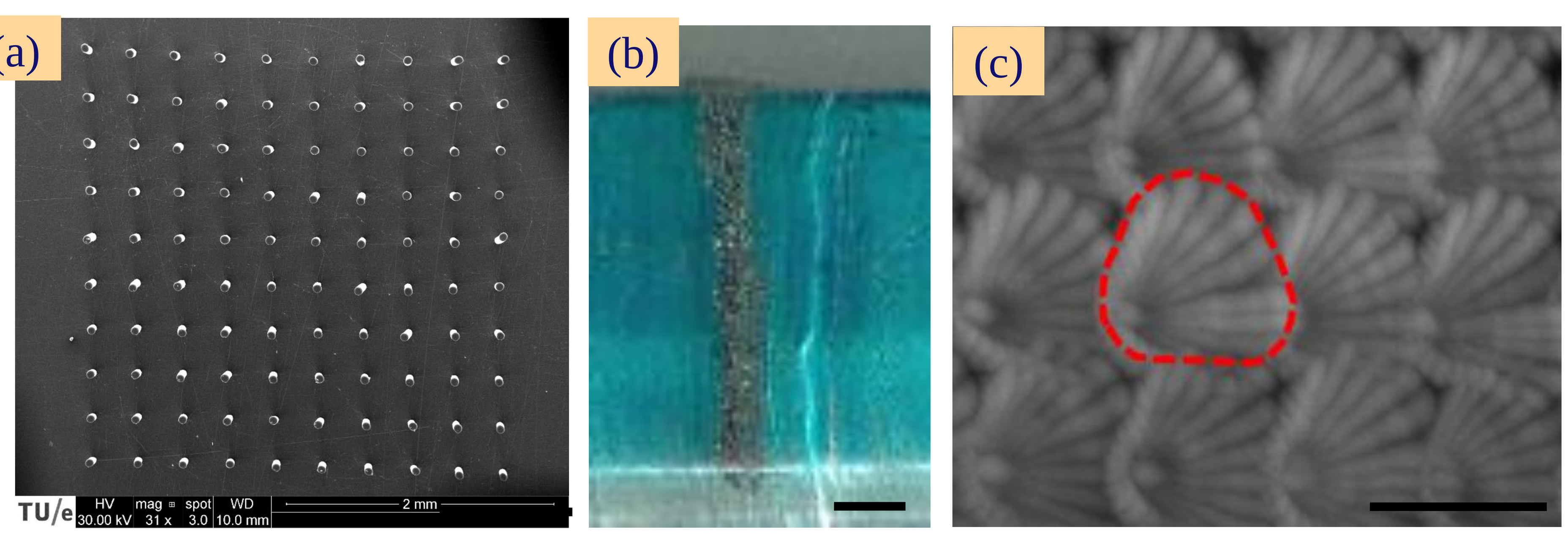

Fig. 3 (a) A top-view SEM image of the MAC with a diameter, length and pitch of 50, 350, and 250 μm, respectively. (b) Cross sectional view of the MAC. The scale bar is 50 μm. (c) A top-view image of the motion of the rotating MAC at 40 Hz in water. The image is composed of 25 overlapping frames in one actuation cycle. The red dashed line indicates the cilia tip trajectories. The scale bar is 250 μm.

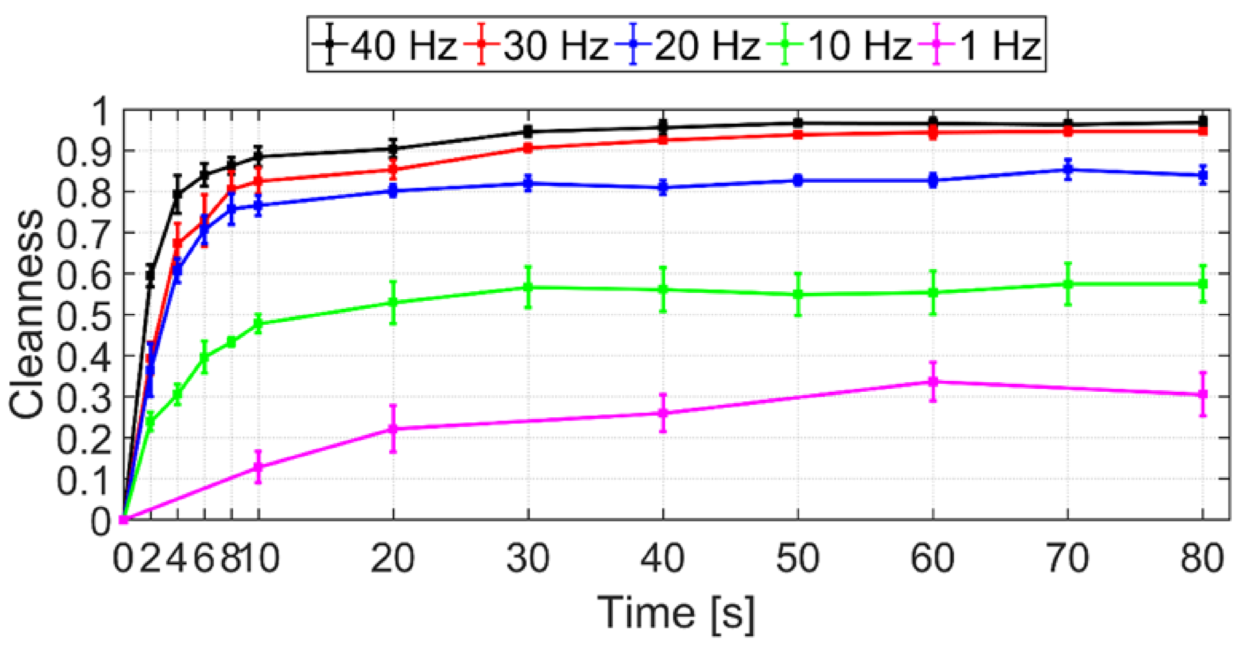

Fig. 4. Calculated cleanness as a function of the working time at different revolution frequencies of the MAC. The cleanness is defined as $C=(N_0-N_t)/N_0$, where N_0 is the number of particles at time 0, and N_t is the number of particles at time t. When the cleanness equals 1, no particles are present within the ciliated area.

CONCLUSION

Micro-moulded magnetic artificial cilia are able to remove and exclude the vast majority 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.

[1] S. Zhang, Y. Wang, R. Lavrijsen, P.R. Onck and J. den Toonder, *Versatile microfluidic flow generated by moulded magnetic artificial cilia*, Sensors & Actuators B, vol 263, pp. 614-624, 2018.