Electronic Supplementary Information (ESI)

Switchable Smart Porous Surface for Controllable Liquid Transportation

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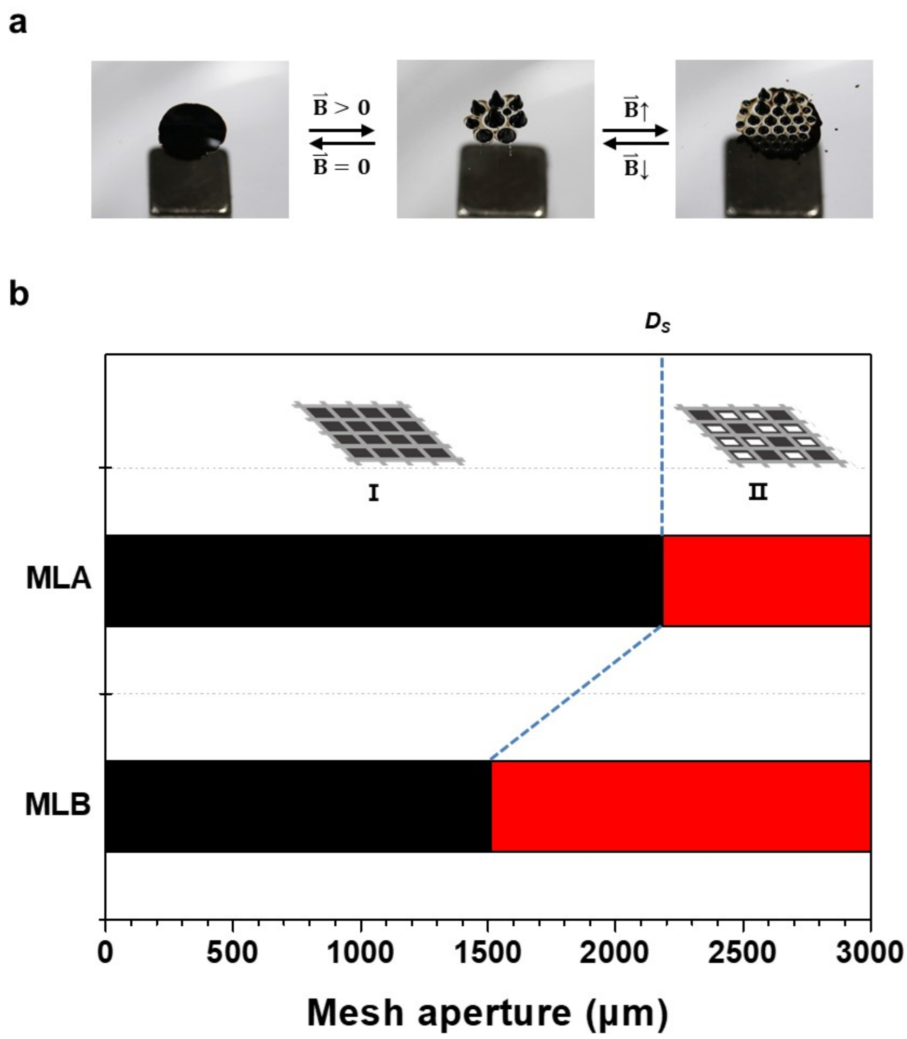

Fig. S1. The magnetic liquid reconfiguration with magnetic field and the stability of the composite film. (a) The magnetic liquid morphology responds to the magnetic field. (b) The stability of the magnetic liquid/micro-nanostructured porous mesh composite film varies with the mesh aperture and magnetic liquid. According to the critical mesh aperture (D_s) for formation of the composite film in air, the mesh aperture can be divided into two regions. In region I, stable composite film can be formed. In region II, composite film cannot be formed stably.

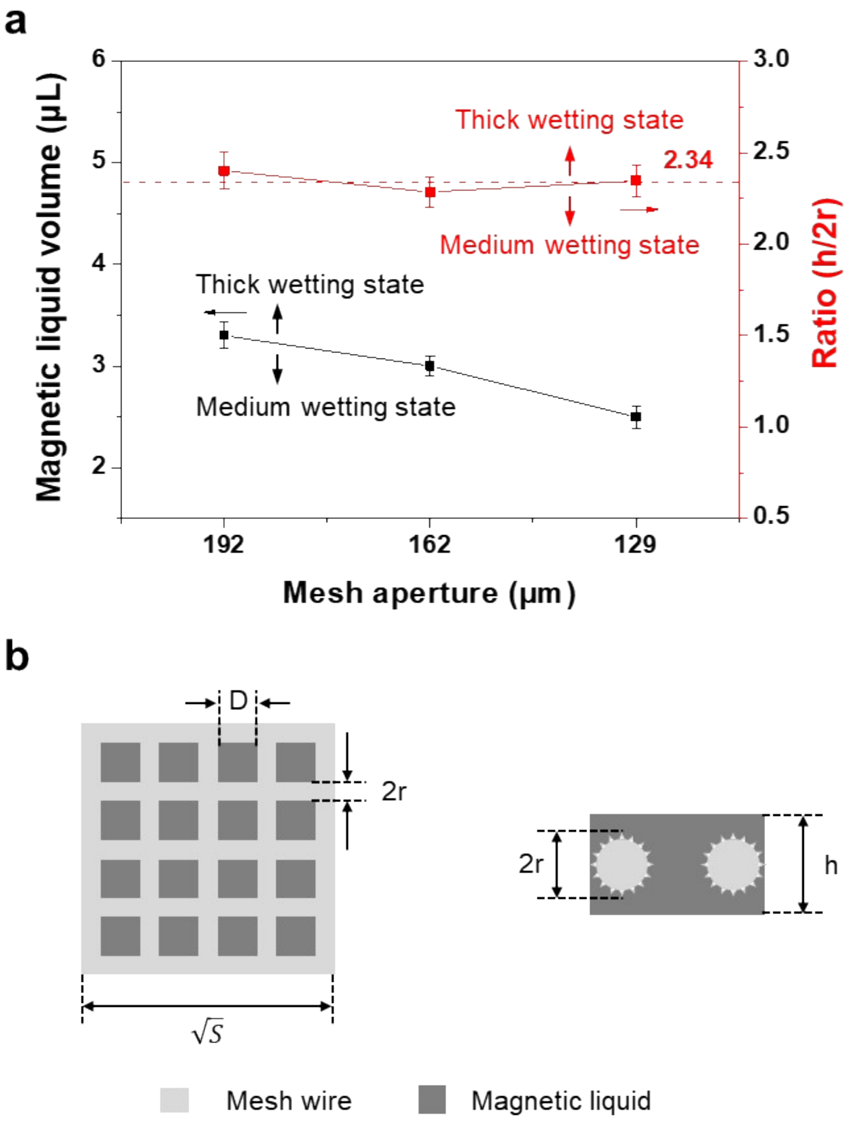

Fig. S2. The critical transition between thick wetting state and medium wetting state change with the volume of magnetic liquid and mesh aperture. (a) The volume of magnetic liquid and the ratio of film thickness to wire diameter (*h*/2*r*) in the critical state when the composite film is converted from medium wetting state to thick wetting state. The critical volume and the corresponding thickness of magnetic liquid decreases as the aperture decreases, while the critical ratio is stable within a certain range, and the average of *h*/2*r* is ~234%, which is basically consistent with the results in Fig 2a. (b) A simplified model for calculating the critical thickness of the composite film as it transitions from thick wetting state to medium state.

because

$$V_{ML} + V_w = Sh$$

for

$$V_w = \pi r^2 \times a \times 2\sqrt{S}$$

$$a = \left[\frac{\sqrt{S} - 2r}{2r + D}\right]$$

where *r* is the radius of the wire, *D* is the aperture of the mesh, h is the thickness of the composite film, *S* is the area of the composite film, *a* is the number of wires on one side of *S*, and V_{ML} and V_w are the volumes of the magnetic liquid and the wire, respectively.

Thus *h* can be given as

$$h = \frac{V_{ML}}{S} + 2\pi r^2 \times \left[\frac{\sqrt{S} - 2r}{2r + D}\right]$$

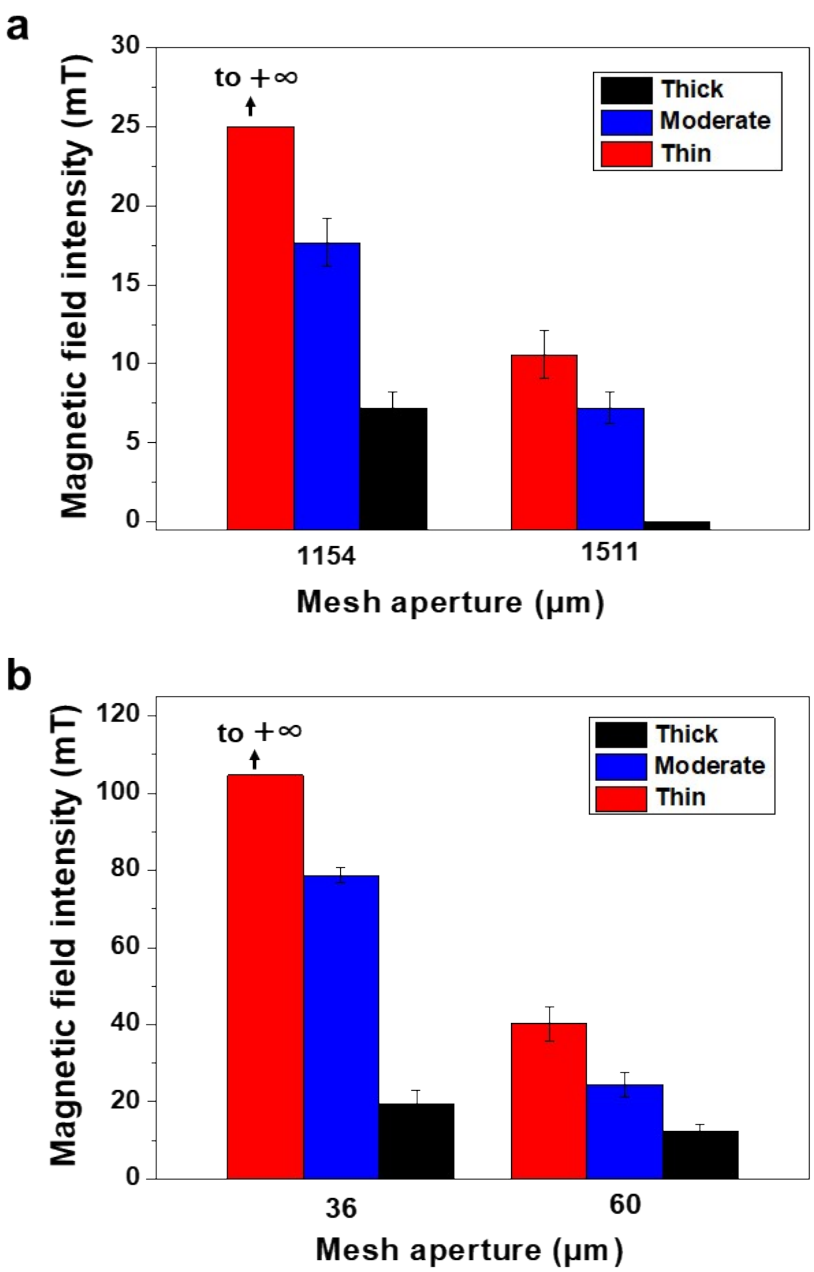

Fig. S3. The magnetic field intensity required for water droplet permeation changes with the mesh aperture and different wetting state of the composite film. (a) For the MLA-composite film, as the mesh aperture increases, the magnetic field intensity required for droplet permeation decreases. For the same mesh aperture, the magnetic field intensity required for water droplet permeation decreases with the magnetic liquid thickness of composite film increases. (b) The law of magnetic field intensity variation of the MLB-composite film is consistent with (a).

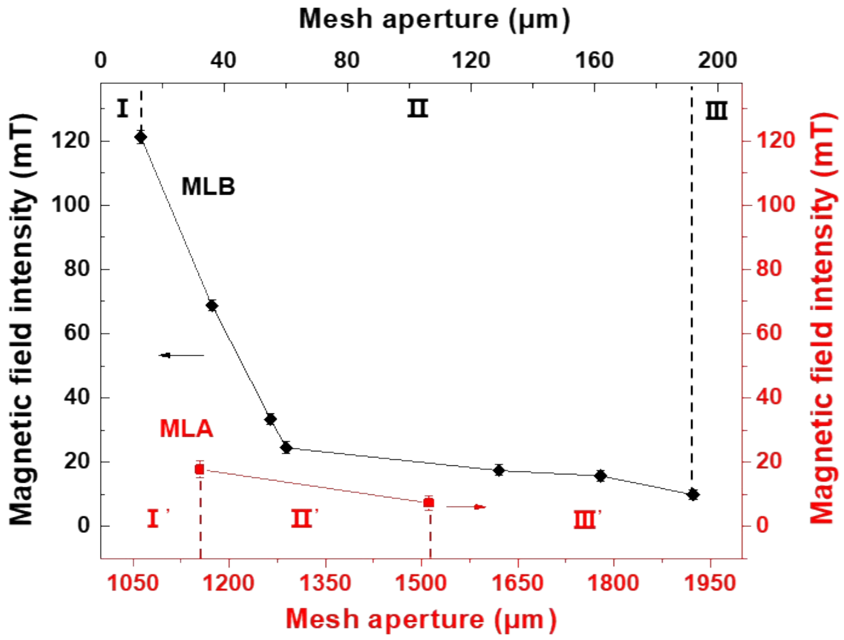

Fig. S4. The magnetic field intensity for water droplet permeation on the composite film, at medium wetting state with MLA and MLB, changes as a function of the mesh aperture. As the aperture of the mesh increases, the magnetic field intensity for water droplet permeation tends to decrease, which can be divided to three regions. In the aperture range of I or I', water droplet cannot permeate the composite film. In the aperture range of II or II', water droplet can permeate the composite film controlled by the magnetic field. For the same aperture of the mesh, the MLA-composite film needs higher magnetic field intensity than that of MLB. In the aperture range of III or III', water droplet permeates the composite film without magnetic field.

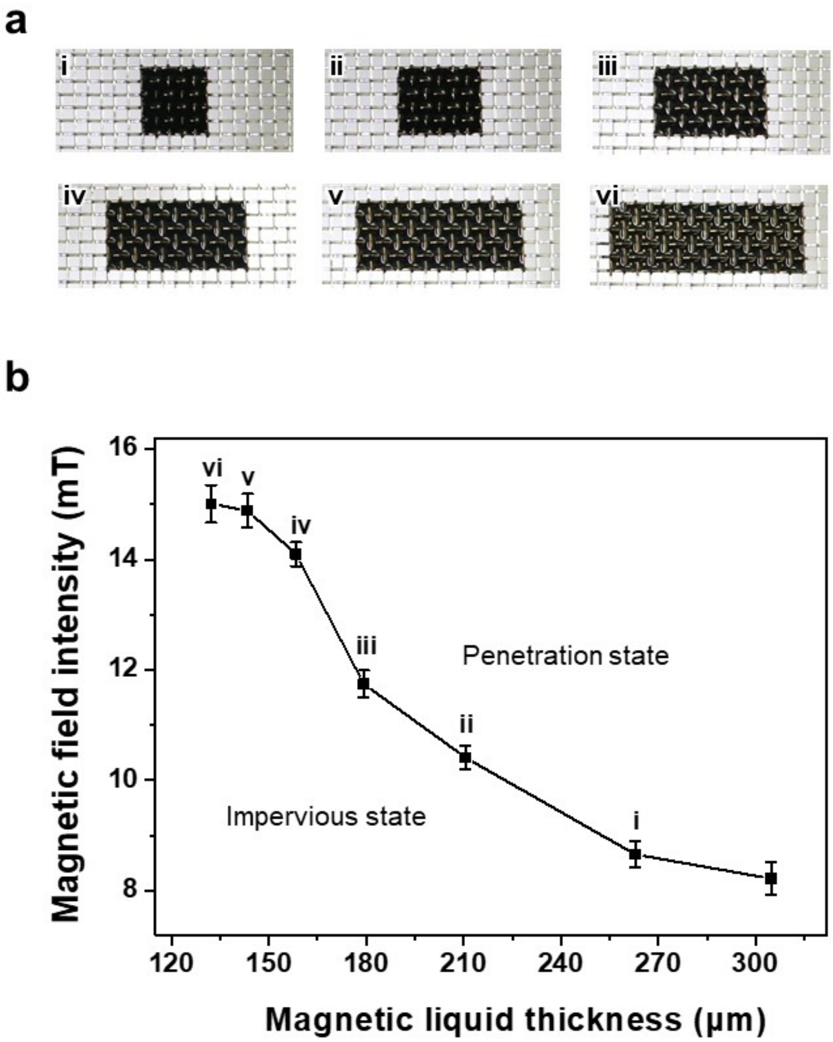

Fig. S5. The influence of magnetic liquid thickness of composite film on the magnetic field intensity required for water droplets permeation. (a) The shape of the composite film with varying spreading area of mixed magnetic liquid of MLA and MLB (MLA: MLB=25:1, 5 μL) on a mesh with the aperture of 71 μm. (b) The magnetic field intensity needed for water droplet permeation changes with the composite film thickness corresponding to the (a). The thicker the composite film, the smaller the intensity required for water permeation.

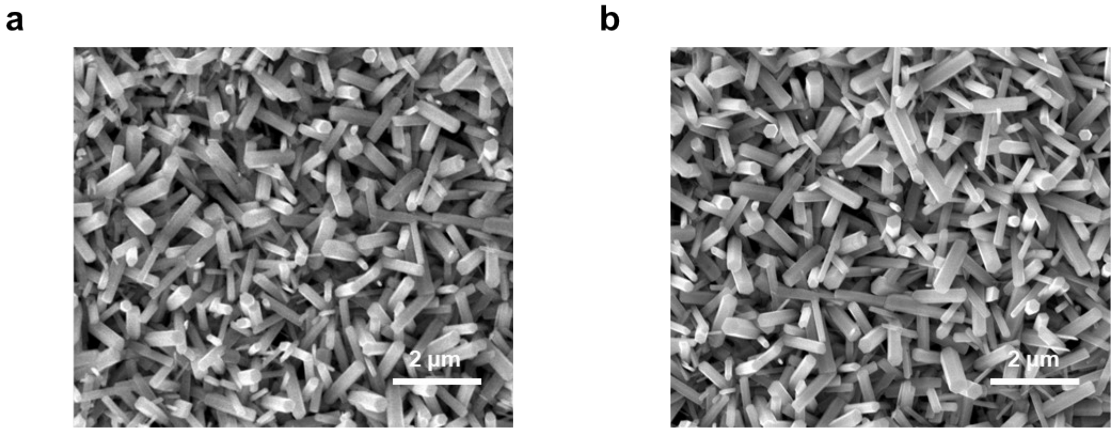

Fig. S6. The SEM images of the ZnO nanoarray on the mesh before (a) and after (b) friction damage. Physical friction was applied to the ZnO nanoarray on the mesh. Comparing the SEM images before and after rubbing, it can be seen that the ZnO nanoarray has almost no obvious shedding and damage. The ZnO nanoarray on the mesh is robust and can be reused for a long time.

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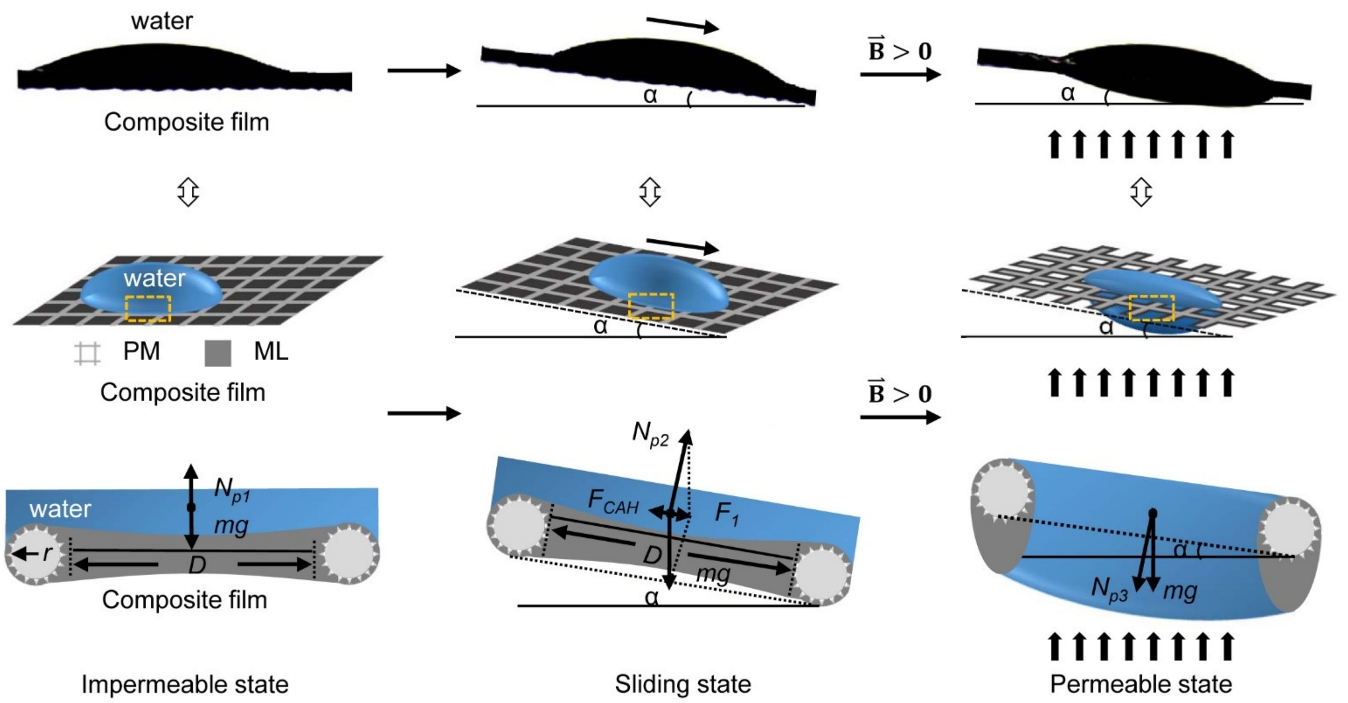

Fig. S7. Schematic mechanism of magnetic responsive liquid sliding and penetration process of water droplet on the composite film. A water droplet can stay stable on the horizontal composite film, and will slide on the inclined composite film with a certain angle. While the water droplet can penetrate the composite film as long as the external magnetic field is strong enough to open the pores of the composite film. The image below is a enlarging view of the area with the yellow boxes in the image above.

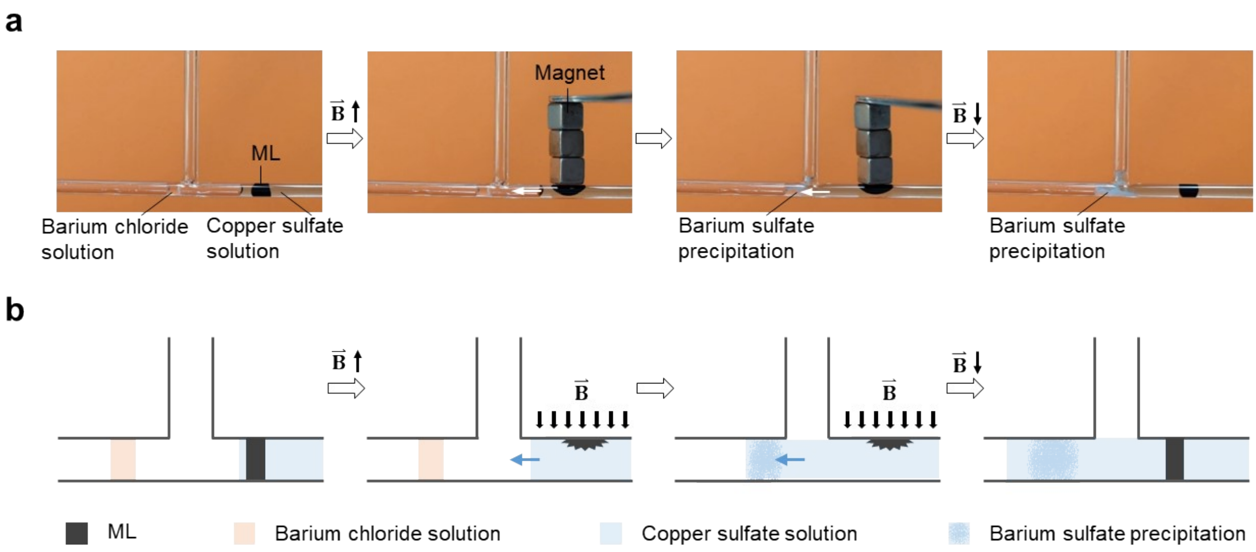

Fig. S8. Laboratory demonstration of the microfluidic device based on magnetic liquid combined with the ZnO nanoarray coated glass tube. (a) Demonstration of the actual operation process of the microfluidic device. The two solutions reacted to produce barium sulfate precipitation when the channel is open with increasing magnetic field. (b) Schematic illustration of the magnetic responsive microfluidic device. Under the manipulation of magnetic field, the magnetic fluid acted as a valve in the device. When the valve was closed, the copper sulfate solution remained stable on the right side of the channel. Moreover, the copper sulfate solution began to be transported to the left side under the action of the liquid pump, when the valve was open. Then the copper sulfate solution contacted with the barium chloride solution and reacted to form barium sulfate precipitation.

Supplemental Movies

Movie S1. Reversible conversion of the composite film. The composite film can be manipulated between the closed state and open state by varying magnetic field

Movie S2. Liquid permeation on the composite film. Water permeation can be realized when the applied external magnetic field is higher than the threshold magnetic field intensity.

Movie S3. Water droplet permeation without magnetic field. Water droplets can permeate the composite film directly even without applied magnetic field.

Movie S4. Water droplet permeation through magnetic field. Water droplets permeation can be controlled by varying magnetic field.

Movie S5. Repeated permeation of water droplet through magnetic field. Water droplet can permeate the composite film under the action of the magnetic field, but return to its original position after the magnetic field is removed

Movie S6. Water droplets cannot permeate through magnetic field. Water droplet cannot permeate the composite film even the composite film is destroyed under the action of magnetic field.

Movie S7. The switchable magnetic responsive water penetration device. Controllable water permeation switch can be achieved via the designed device.

Movie S8. The physical rubbing process of the ZnO nanorod-decorated mesh. After being subjected to physical friction, the ZnO nanoarray has basically no obvious shedding and damage.

Movie S9. Switchable moving and permeation behavior of droplet on inclined ML/PM composite film by magnetic field. A water droplet (10 μL) can stay stable on the horizontal composite film, and will slide on the inclined composite film with a certain angle. While the water droplet can penetrate the composite film as long as applied magnetic field is strong enough to open the pores of the composite film.

Movie S10. Demonstration of the actual operation process of the microfluidic device. Two reaction solutions can be selected on both sides of the device, and the progress of the reaction can be flexibly controlled by the magnetic field.