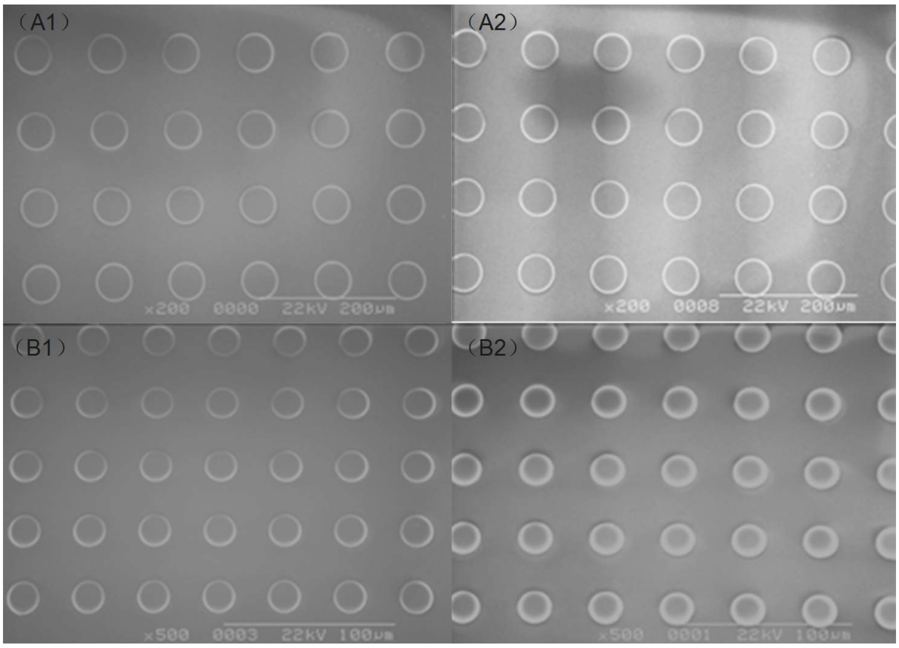
Electronic Supplementary Material (ESI) for Lab on a Chip

Supplementary information

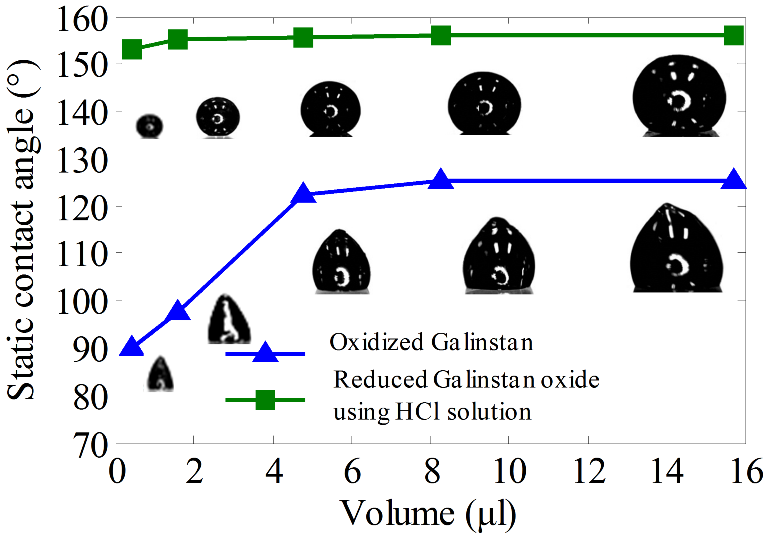
1. Effect of 37 wt% HCl on PDMS

In order to study the effect of 37 wt% HCl solution on PDMS, we have made PDMS pillar-based device and dipped it in 37 wt% HCl. After predetermined time period, 60 hours in our study, we have analyzed the PDMS pillars under SEM. As can be observed from the SEM images, 37 wt% HCl solution do not have any noticeable effect on the PDMS pillars. Therefore, our use of 37 wt% HCl to remove Galinstan oxide initially and later reduction of HCl solution concentration for oxide removal is quite plausible solution.



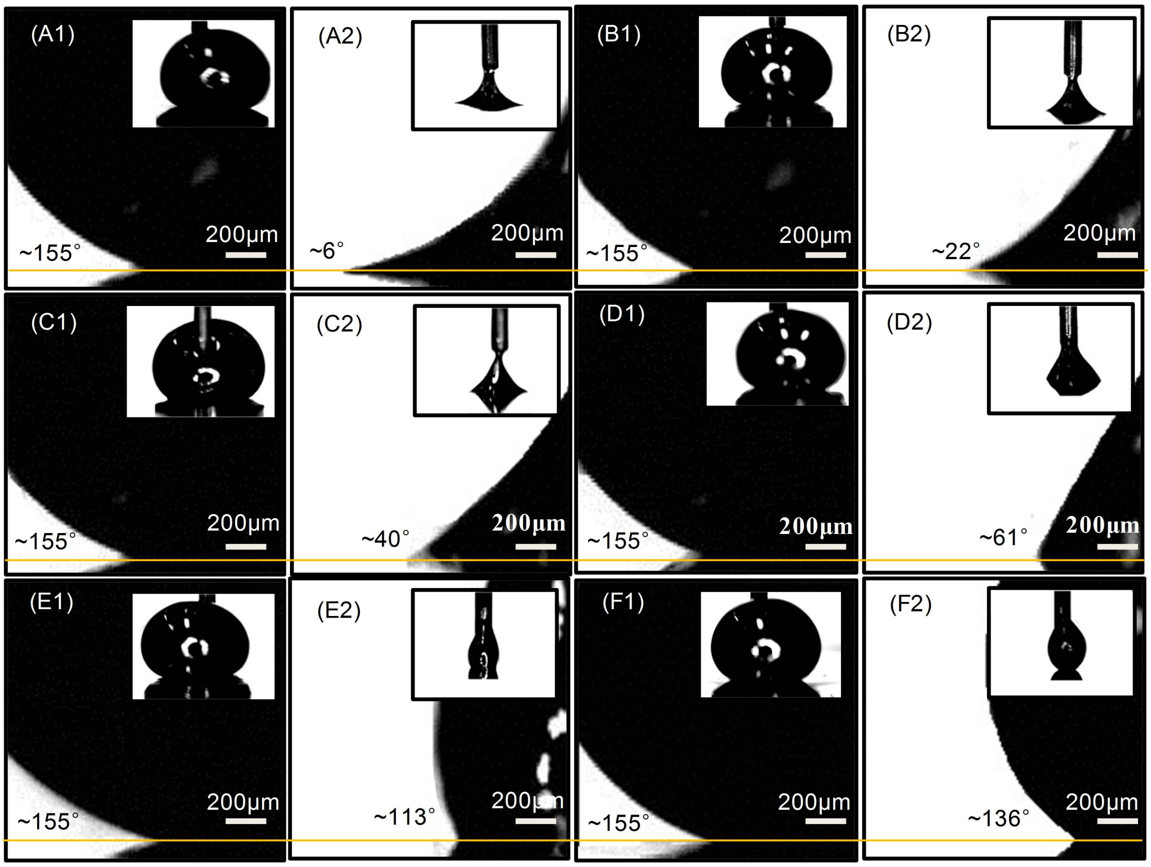
Supplementary Fig. S1. Scanning electron microscope (SEM) images showing the condition of PDMS after 37 wt% HCl immersion for 60 hours; (A1, B1) SEM images of PDMS with 50 μm, 20 μm diameter pillars before HCl treated; **(B1, B2)** SEM images of PDMS with 50 μm, 20 μm diameter pillars after 37 wt% HCl immersion for 60 hours.

2. Variation of static contact angle of oxidized and HCl-treated Galinstan (reduced Galinstan oxide) droplets with varying volumes:



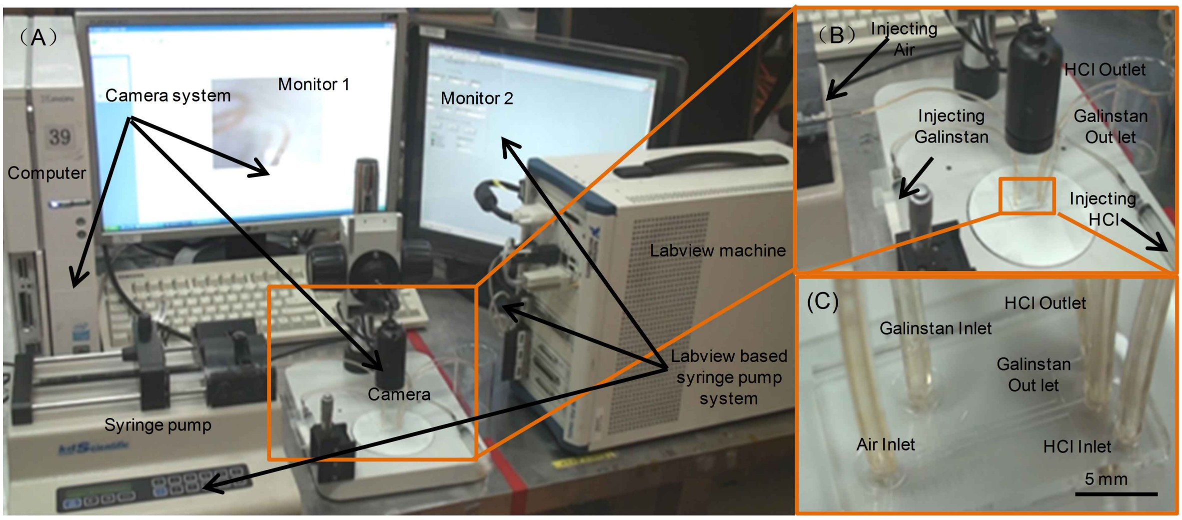
Supplementary Fig. S2. Comparison of contact angles between oxidized Galinstan droplets and 37wt% HCl treated Galinstan droplets with various volumes.

3. Dynamic contact angle (advancing and receding angle) of oxidized and reduced Galinstan oxide droplets with varying HCl concentrations:



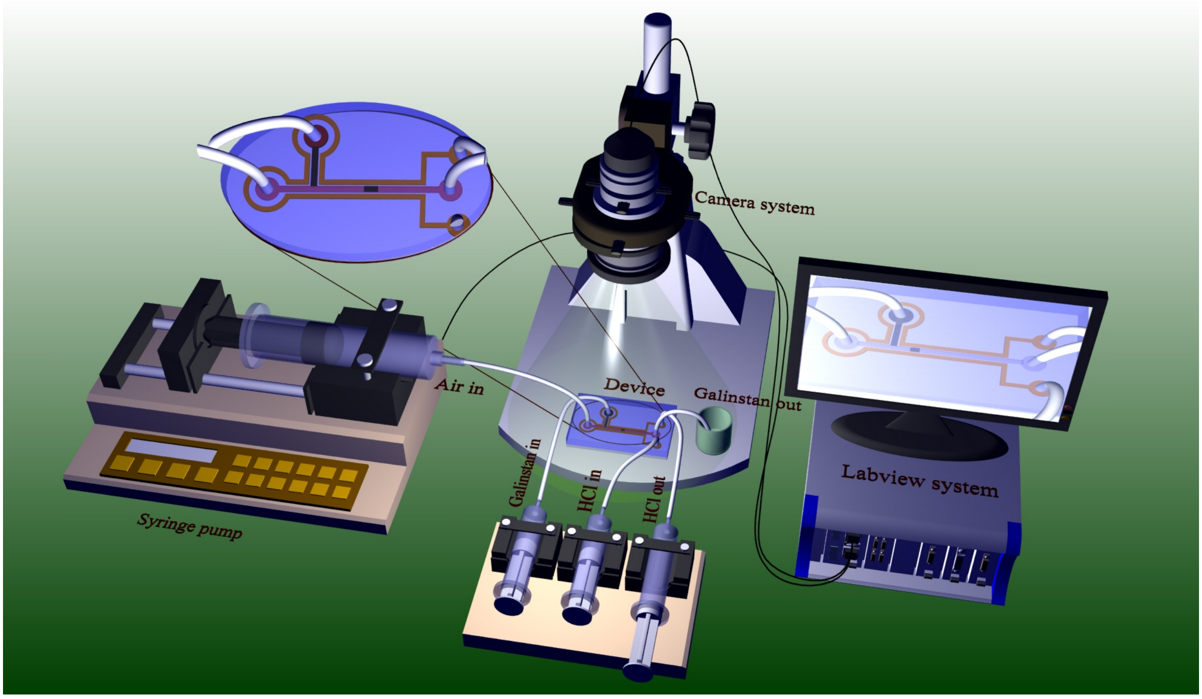
Supplementary Fig. S3. Photograph of advancing angle and receding angle for witout HCl treated Galinstan (A1, A2), 16 wt% HCl treated Galinstan (B1, B2), 23 wt% HCl treated Galinstan (C1, C2), 26 wt% HCl treated Galinstan (D1, D2), 30 wt% HCl treated Galinstan (E1, E2) and 37 wt% HCl treated Galinstan (F1, F2) respectively.

4. Experimental setup used for the analysis of Galinstan behavior in a microfluidic channel:



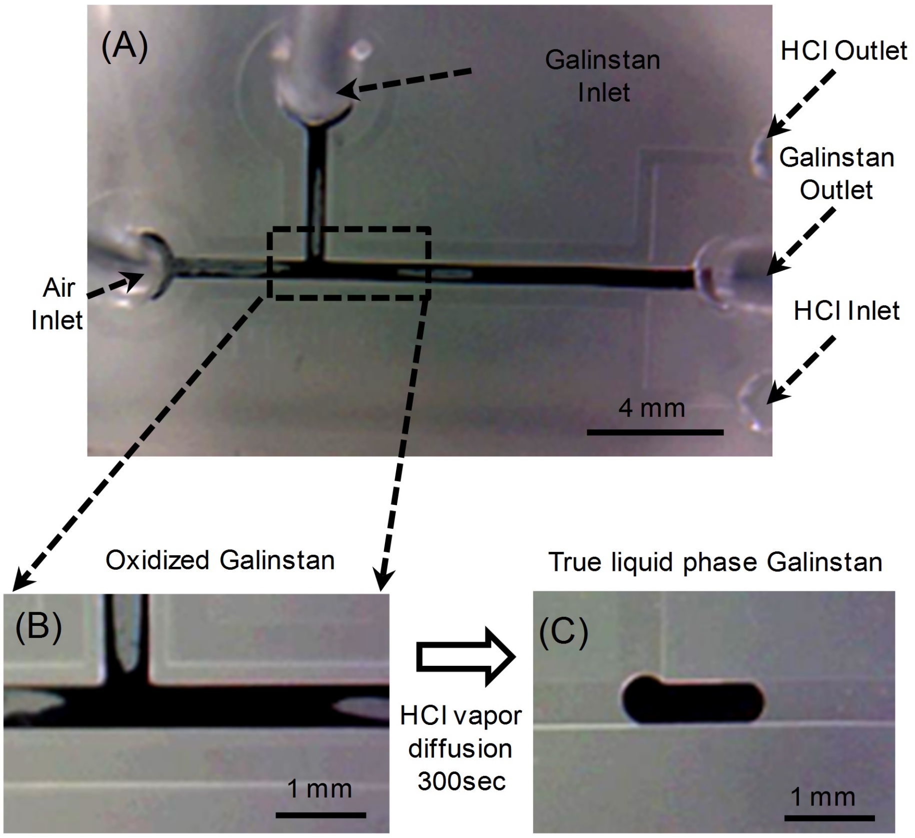
Supplementary Fig. S4. Experimental setup used for controlling reduced Galinstan oxide. (A) The experimental setup is comprised of CCD camera system and Lab-view controlled syringe pump system. (B) The CCD camera system is used to record the movement of reduced Galinstan oxide in microfluidic channel. (C) The coplanar microfluidic channel is applied to measure the behavior of reduced Galinstan oxide in microfluidic channel.

5. Experimental setup system Sketch



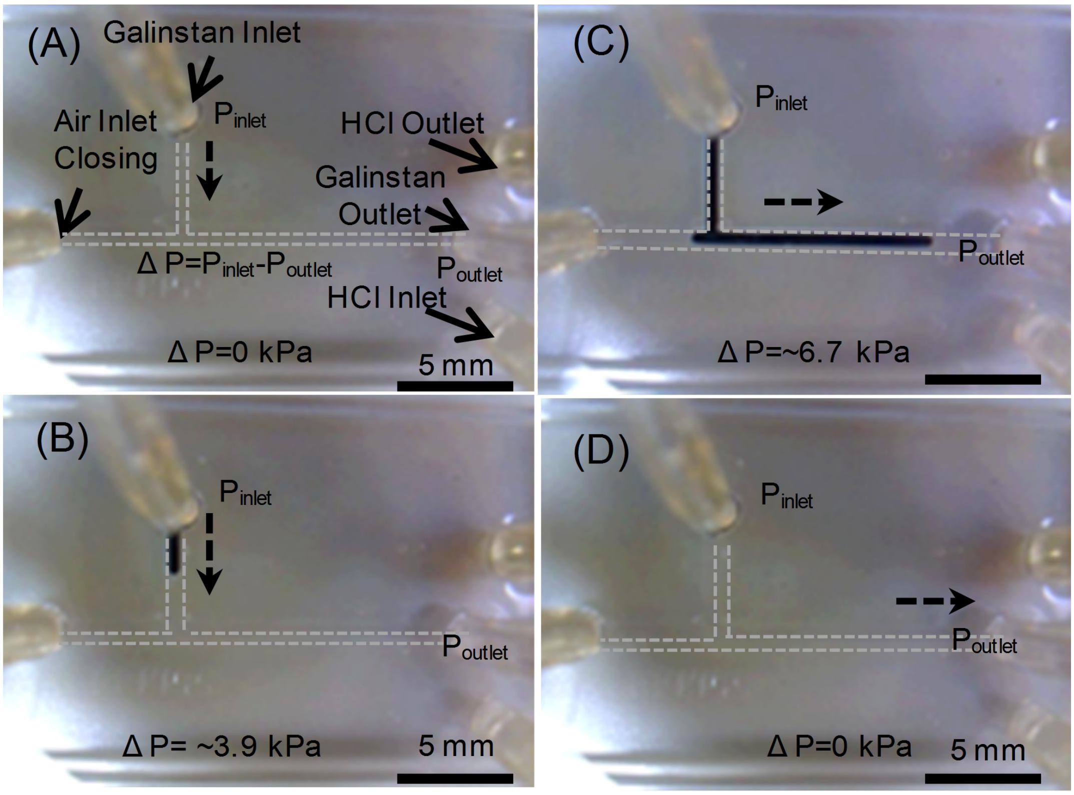
Supplementary Fig. S5. Experimental setup system sketch

6. Shape shifting of oxidized Galinstan and reduced Galinstan oxide in a microfluidic channel (before and after the HCl treatment):



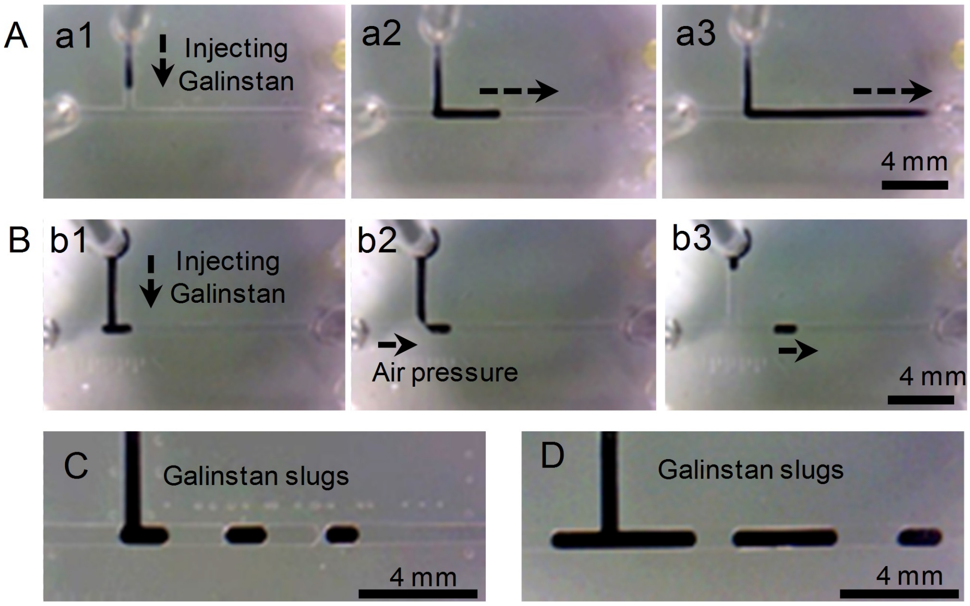
Supplementary Fig. S6. The shape changing of Galinstan before and after the treatement with 37 wt% HCl solution (A) Top view of the coplanar microfluidic channel. (B) Naturally oxidized Galinstan in the channel. (C) True liquid phase Galinstan after HCl vapor diffusion.

7. Injection of Galinstan into microfluidic channel and its dependence on pressure:



Supplementary Fig. S7. Injecting Galinstan into microfluidic channel and its dependence on pressure. (A-B) Only a part of ~ 1 μl Galinstan droplet is filled in the narrow channel until the difference of pressure reached to ~ 3.9 kPa. (C) Galinstan is filled in the channel slowly before the difference of pressure to ~ 6.7 kPa. (D) When the pressure ecceeding to 6.7 kPa, Galinstan passes through the chanel rapidly (< 1s) and the system is returned to ambient pressure.

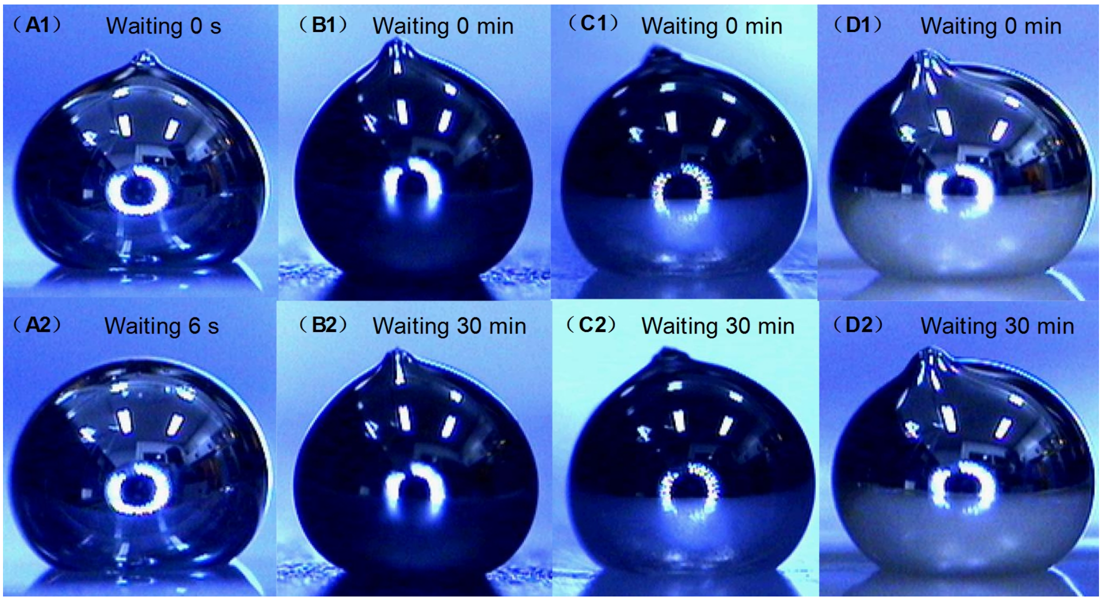
8. Injection of Galinstan into microfluidic channel and its separation into droplets of different volumes:



Supplementary Fig. S8. Injecting(A) and separating(B) of HCl treated Galinstan in microfluidic channel; (C) Same volume Galinstan droplet; (D) different volume Galinstan droplet.

9. Inherent volatilization of HCl and ways to reduce the volatilization:

HCl is a high-vapor pressure liquid. Due to its high vapor pressure, it is quite volatile in ambient condition and escapes in the ambience. One of the ways to reduce the vaporization of HCl is either to cover the ports and surface with glass (Fig. 7 in the manuscript) or coat the complete device with a transparent acid-resistant material such as Wax, Parafilm® or Teflon. In the present study, we have performed initial study in this regard. Following figure shows the effect of different material coated over the PDMS surfaces and efficiency of oxide removal. As oxide removal is due to HCl interaction with the Galinstan oxide surface, the inefficiency of oxide removal also shows the ability of the material to reduce the loss of HCl due to volatilization. The materials being analyzed are wax film, Parafilm® and the melted solution of Parafilm®. The intention of using melted solution of Parafilm® is to overrule adhesion problem if any. As can be observed in the figure (A1-A2), the PDMS film without any coating material removes the oxide layer within 6 sec and there is a noticeable shape change due to the oxide removal. However, in case of wax film, Parafilm® and the melted solution of Parafilm® there is no shape change even after 30 min (figure (B-D)). This also indicates the presence of oxide layer and the efficiency of the coated material to stop the permeation of HCl solution and thereby reducing the volatilization of HCl. The film thickness for these materials is around 100 μm.



Supplementary Fig. S9. Oxide removal efficiency and ability to reduce volatilization of HCl during the coating of different material over PDMS (A) Without any coating on PDMS (B) Wax solution coating (100 μm thick) (C) PDMS coated over Parafilm® (110 μm thick) (D) Melted Parafilm® solution coating (100 μm thick).

Once HCl is vaporized completely, it will not further remove oxide layer of Galinstan oxide and the precise control of the oxide position will be difficult. In order to ensure continuous removal of oxide layer, the device can be further modified by providing additional detachable HCl reservoir.

Supporting Video SV1. The video depicts experiment system and the reduced Galinstan oxide droplet reciprocating movement.

Supporting Video SV2. The video depicts that the reduced Galinstan oxide is separated into small droplet at the "T" junction by providing air pressure from the other side.

Supporting Video SV3. The video depicts the reduced Galinstan oxide droplet linear movement with various air flow rate (0.6, 1.2, 1.8, 2.4 and 3.0 ml/min) controlled by the syringe pump.

Supporting Video SV4. The video depicts the reduced Galinstan oxide droplet reciprocating movement with various air flow rate (3.6, 4.2, 4.8, and 5.4 ml/min) controlled by the syringe pump.