ISSN 2005-8446

# 한국정밀공학회 2013년도 추계학술대회 논문집

## Proceedings of KSPE 2013 Autumn Conference

**상** 정밀가공, 로봇 제어 자동화, 생산시스템, 공작기계, 나노마이크로기술, 임의형상제조시스템, 특별세션

- 일 자 : 2013년 10월 30일(수) ~ 11월 1일(금)
- 장 소 : 부산 BEXCO
- 주 최 : 사단법인 한국정밀공학회

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2013 한국정밀공학회 추계학술대회 논문집 상

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## ◐ 논문발표목차



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### 나노마이크로기술-3



### 나노마이크로기술-4

# 산화된 액체금속 마이크로유체를 이용한 조정이 가능한 콘덴서 응용에 관한 연구

# Oxidized Liquid Metal Based Microfluidic Platform for Adjustable Capacitor Applications

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Key words : Liquid Metal, Galinstan, Microfluidic Platform, Adjustable Capacitor

## 1. INTRODUCTION

Galinstan is a low-toxic liquid metal eutectic GaInSn. Owing to the outstanding properties such as higher boiling point, low electrical resistivity and low toxicity, it is suitable for replacement of mercury in many applications such as tunable frequency selective surface (FSS) [1]. However, the surface of Galinstan is instantly oxidized in ambient conditions and behaves more like gel rather than true liquid; adhering to almost any solid surface. In recent years, some methods have been developed to solve this problem. Liu *et al.* present Galinstan behaves like true liquid metal in sub-ppm oxygen environment [2]. Kim *et al.* proposed surface modification of Galinstan by hydrochloric acid treatment [3]. In this paper, physical (paper texture based PDMS coated micro/nano particles) and chemical (reaction between PDMS and acid) methods are proposed to modify PDMS surface for enhancing the non-wetting characteristic of oxidized Galinstan.

## 2. PHYSICAL AND CHEMICAL METHOD

Fig.1 shows static contact angle (CA), advancing and receding angle and residual state of ~ 8 μl oxidized Galinstan droplet on different substrates; pure PDMS, normal A4 paper, PDMS with paper texture(transferring normal the paper texture to PDMS surface by soft lithography), PDMS (with paper texture) immersed in 10 μg/ml acetone solution with graphite particles. For the last condition, higher advancing and receding angle are achieved and there is no residual on PDMS. The reason is the PDMS with paper texture (coated graphite particle) has a structure similarly to lotus leaf with super-lyophobic surface. The concentration of micro/nano particles and particle type are optimized in order to further enhance the non-wetting characteristic. For this condition of PDMS with paper texture (immersed in 15 μg/ml acetone solution of graphite particles), smaller CA hysteresis (difference value ~16° of advancing angle ~163° and receding angle ~147°) is obtained.

Meanwhile, the chemical method (reaction between PDMS and concentrated acid) is also used to enhance non-wetting characteristic of oxidized Galinstan. Fig. 2 shows static CA, advancing and receding angle, and residual state of ~ 8 μl oxidized Galinstan droplet on different PDMS surface (pure PDMS, PDMS immersed in 49% hydrofluoric acid (HF), 69% nitric acid ($HNO_3$) and 89% sulfuric acid ($H_2SO_4$) for 1 min, respectively). For the last condition, advancing and receding angle are larger than other condition and no residual was observed on PDMS surface. PDMS immersed in $H_2SO_4$ also shows multi-scale structures similarly to the physical method. After optimization of reaction time, the smallest CA hysteresis (difference value ~14° of advancing angle ~167° and receding angle ~153°) is achieved for this condition (PDMS reacting with 89% $H_2SO_4$ for 1.5 min).

## 3. APPLICATION AND CONCLUSION

After fundamental experiments, two micro-channels with multi-scale structures are fabricated by physical method (injecting 15 μg/ml acetone solution of graphite particle into micro-tunnel with paper texture inwall and drying) and chemical method (injecting 89% $H_2SO_4$ into micro-tunnel for 1.5 min, cleaning and drying). Fig. 3 shows a series of images of moving oxidized Galinstan required minimum air pressure 6.29 kPa (physical method) and 5.87 kPa (chemical method), respectively. Finally, the oxidized Galinstan based microfluidic platform is applied to adjustable capacitor shown in Fig. 4. The results demonstrate that the two methods can work very well for enhancing anti-wetting effect of oxidized Galinstan.

## ACKNOWLEDGMENT

This work was supported by National Research Foundation of Korea (NRF) grant through the Korean government (MEST) (No. 2012R1A2A2A01014711).

## Reference


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2. T. Y. Liu, P. Sen and C.J.Kim, J.MEMS, **21**, 443-450, 2012.
3. D. Kim, P. Thissen, and J.B. Lee, Appl. Mater. Interfaces, **5**, 179–185, 2013.


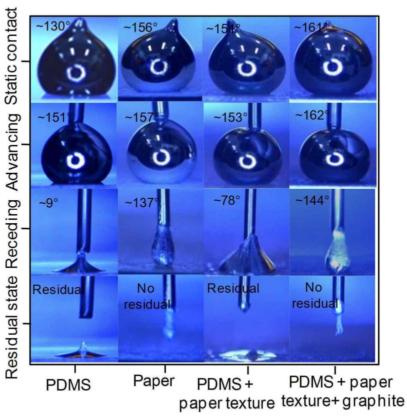


Fig. 1 Static contact angle, advancing angle, receding angle and residual state on different substrates for ~ 8 μl oxidized Galinstan droplet.

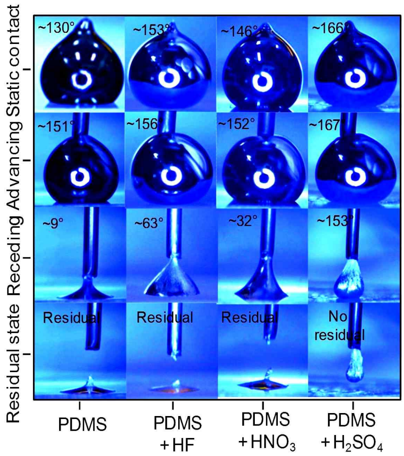


Fig. 2 Static contact angle, advancing angle, receding angle and residual state on different PDMS surface for ~ 8 μl oxidized Galinstan droplet.

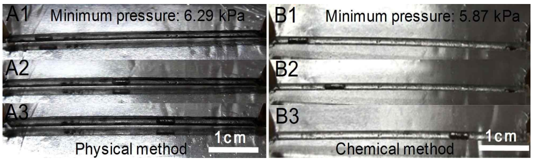


Fig.3 A series images of oxidized Galinstan droplet moving in the PDMS micro-tunnel fabricated by (A) physical and (B) chemical method.

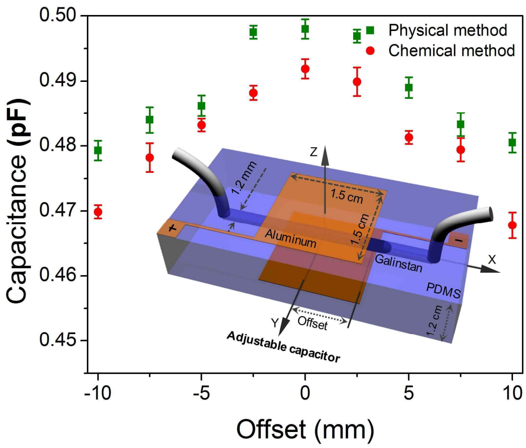


Fig.4 Galinstan based adjustable capacitor fabricated by physical and chemical method and its capacitances.

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# Oxidized liquid metal based microfluidic platform for adjustable capacitor applications

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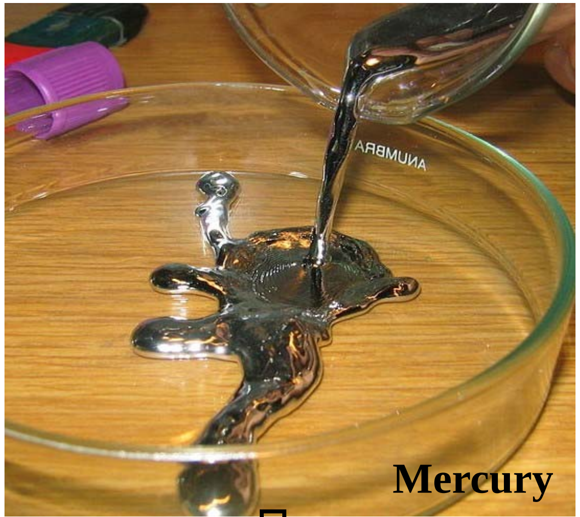
# Outline

1. Introduction
2. Physical method
3. Chemical method
4. Demonstration of oxidized Galinstan movement
5. Adjustable capacitor application
6. Next step

# 1. Introduction

## What is Liquid Metal?

**Liquid metal is a metal is a metal that is in liquid phase at room temperature.**




**Non-toxic gallium-based liquid metal alloy**

**Liquid** + **Metal**

**Liquid** → **Continuous deformation** → **Continuous deformation**

**Metal** → **High thermal and electrical conductivity** → **Antenna**, **Heat transfer**

**Tunable antenna, filter, frequency selective surface (FSS) metamaterials, heat sink ……**

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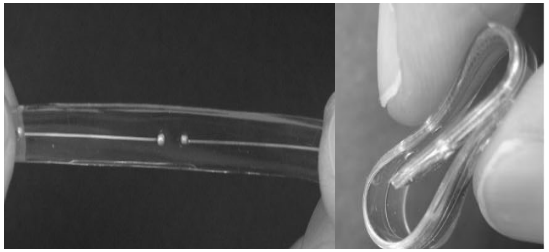
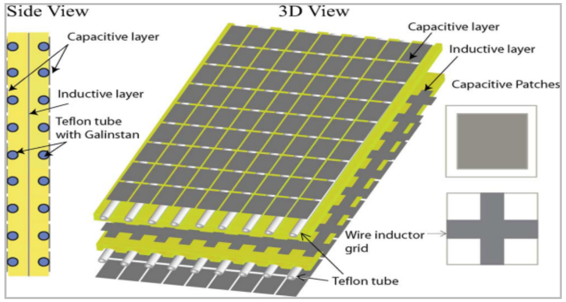
## Application area of liquid metal

### Mechanically Tunable Fluidic Antennas



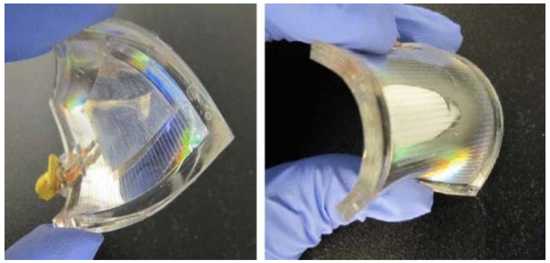
J.-H. So *et al*, *AFM*, 2009

### Liquid Tunable Frequency Selective Surfaces



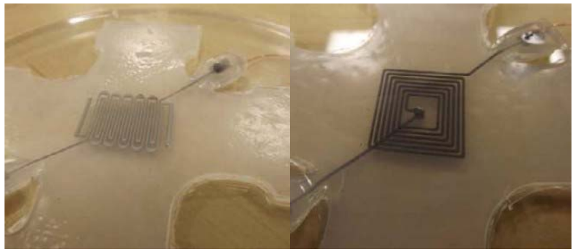

M. Li *et al*, *IEEE microwave and Wireless Component Letters*,2010

### Flexible Liquid Metal alloy Microstrip Path Antenna



G. Hayes *et al*, *IEEE Trans. On Antenna and propagation*,2012

### Soft-matter capacitors and inductors



A Fassler *et al*, *Smart materials and structures*, 2012

# 1. Introduction

## Introduction of Galinstan

### ◻ Definition

➢A family of eutectic alloys mainly consisting of gallium, indium, and tin, which are liquids at room temperature

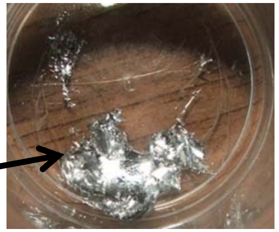
➢Typical composition:68.5% Ga,21.5% In, and 10% Sn

### ◻Material properties (Galinstan Vs Mercury)

| Property | Galinstan | Mercury |
|---|---|---|
| Toxicity | Non-toxic | Toxic |
| Boiling point( ℃) | >1300 | 356.62 |
| Thermal Conductivity($W \cdot m^{-1} \cdot K^{-1}$) | 16.5 | 8.541 |
| Electrical conductivity | $2.3 \times 10^{6}$ | $1.04 \times 10^{6}$ |

Challenge: the surface oxidation

*"The oxide layer adheres to almost any surfaces."*



Wetted Galinstan

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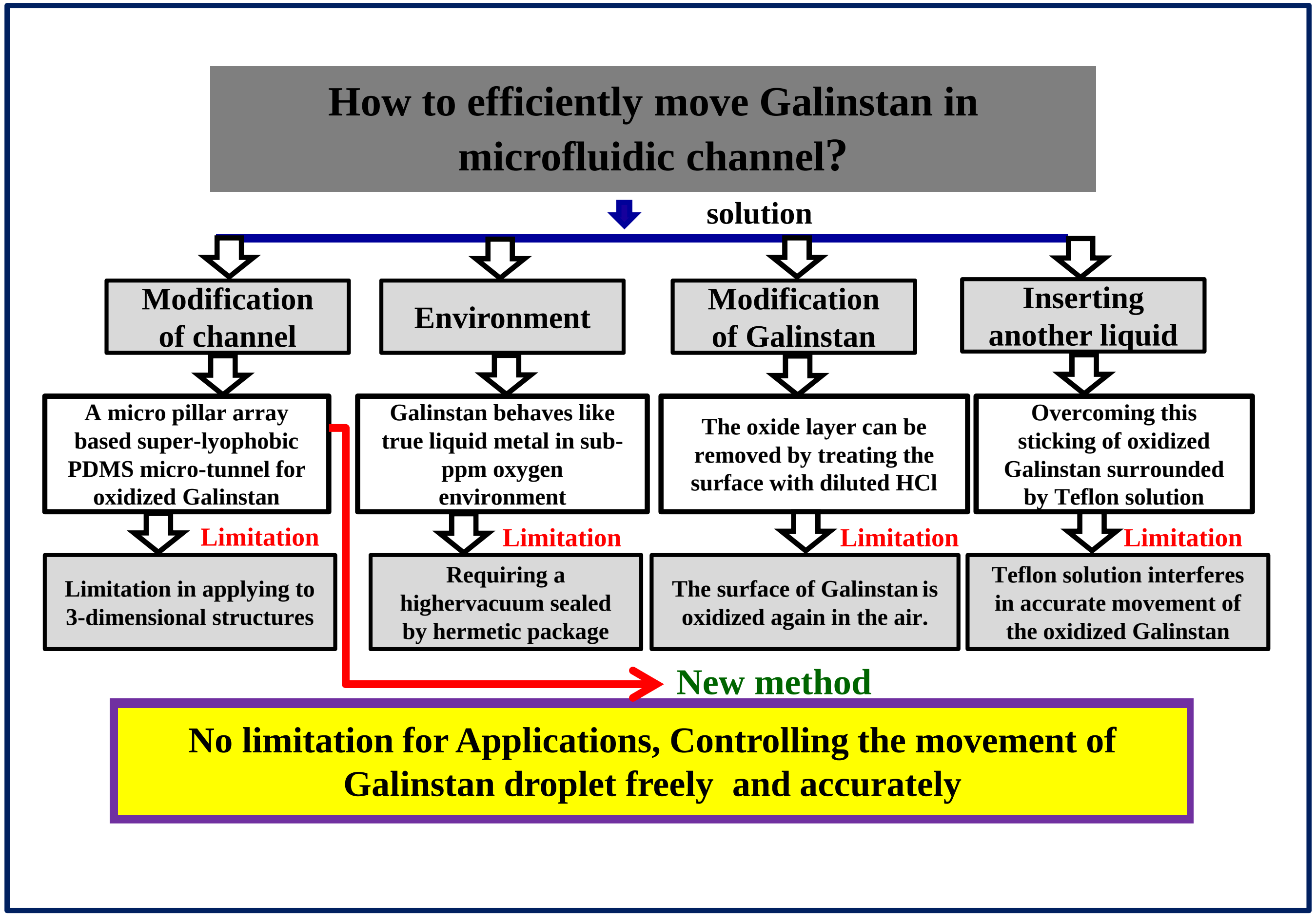
# 1. Introduction

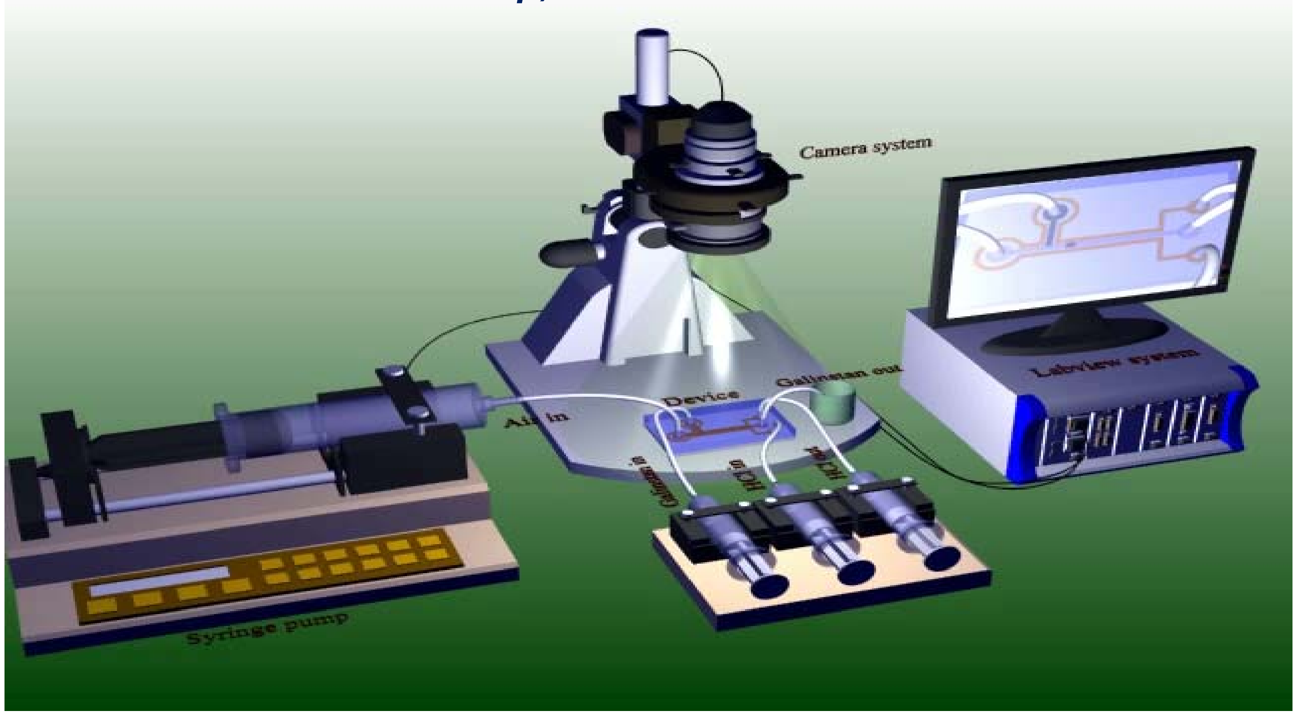
## Motivation



# 1. Introduction

## Previous works

"Coplanar microfluidic channel device for reduction of oxidized Galinstan" On *Lab on a Chip*, 2013.




However, HCl is quite volatile in ambient condition and escapes in the ambience which can corrode the metal.

# 1. Introduction

## Lotus effects

**Engineering approaches to mimic nature**

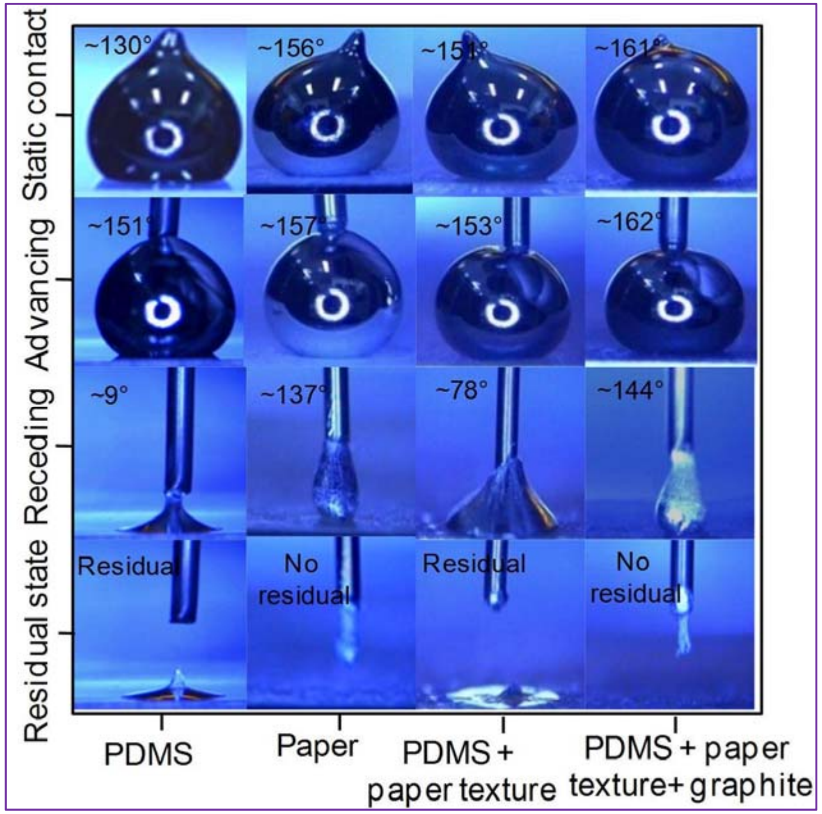
**We approach two different ways:**

**The use of oxidized liquid metal**

- **Physical method**
- **Chemical method**

# 2. Physical approach

## Surface textures with various morphologies




For the last condition, **higher advancing and receding angle** are achieved and there is no residual on PDMS.
The reason is the PDMS with paper texture (coated graphite particle) has a structure similarly to **lotus leaf with super-lyophobic surface**.

# 2. Physical approach

## SEM images of surface texture modified by physical methods

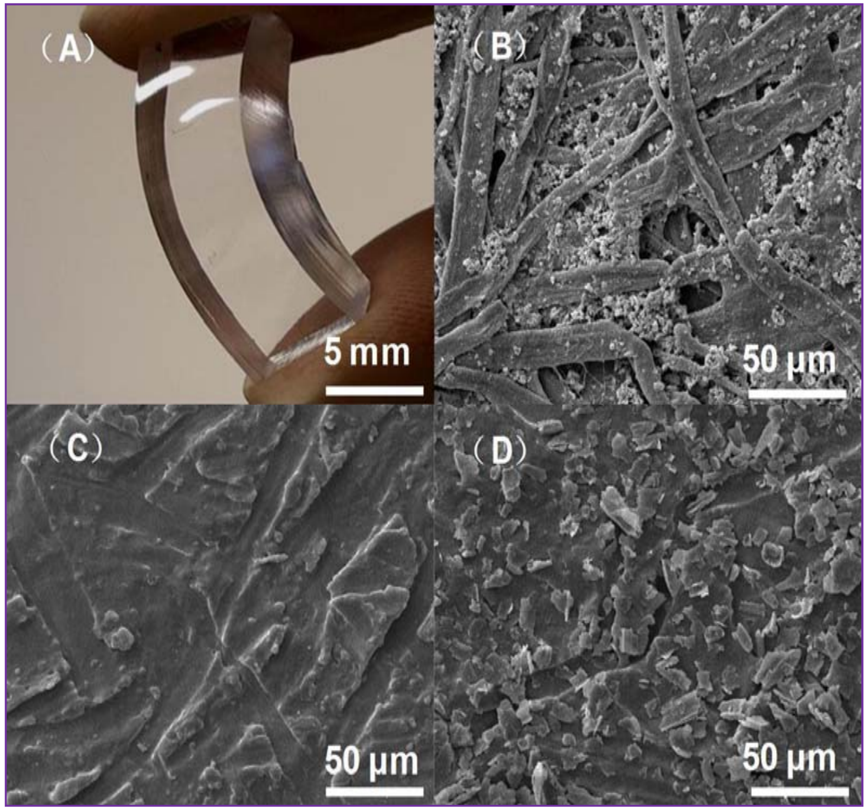



Figure shows (A) optical image of PDMS; surface SEM images of (B) normal paper, (B) PDMS with paper texture and (D) PDMS with paper texture after immerging in 4 mg/ml graphite acetone solution particles.

# 2. Physical approach

## Optimization of particle concentration and type

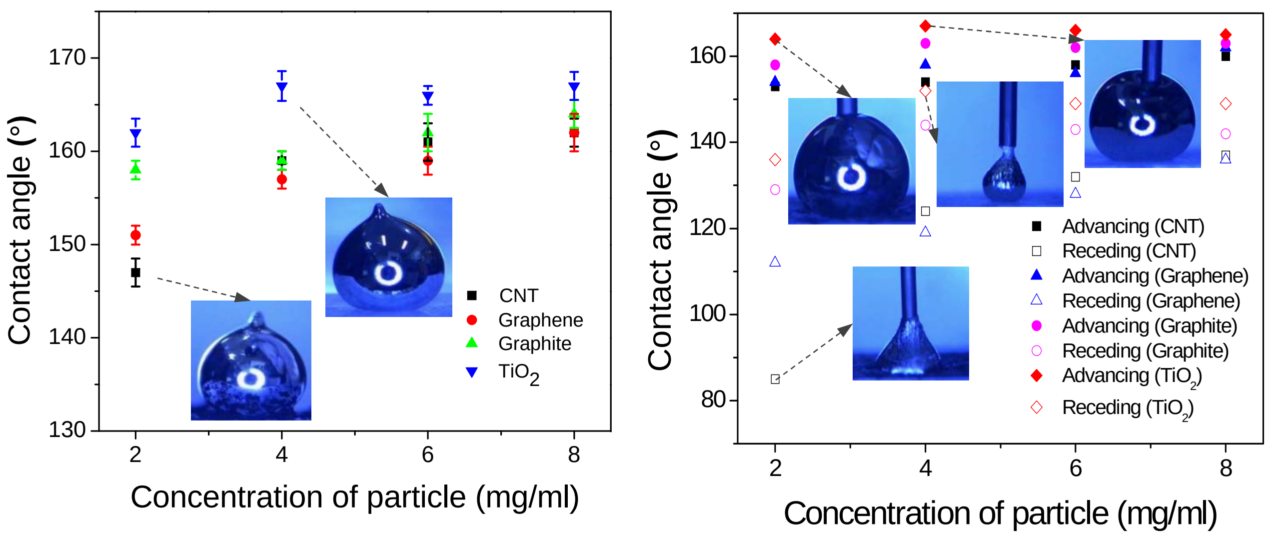



**Figure shows static and advancing-receding angle on the paper texture based PDMS surface after immerging different concentration solution of CNT, graphene, graphite and $TiO_2$.**

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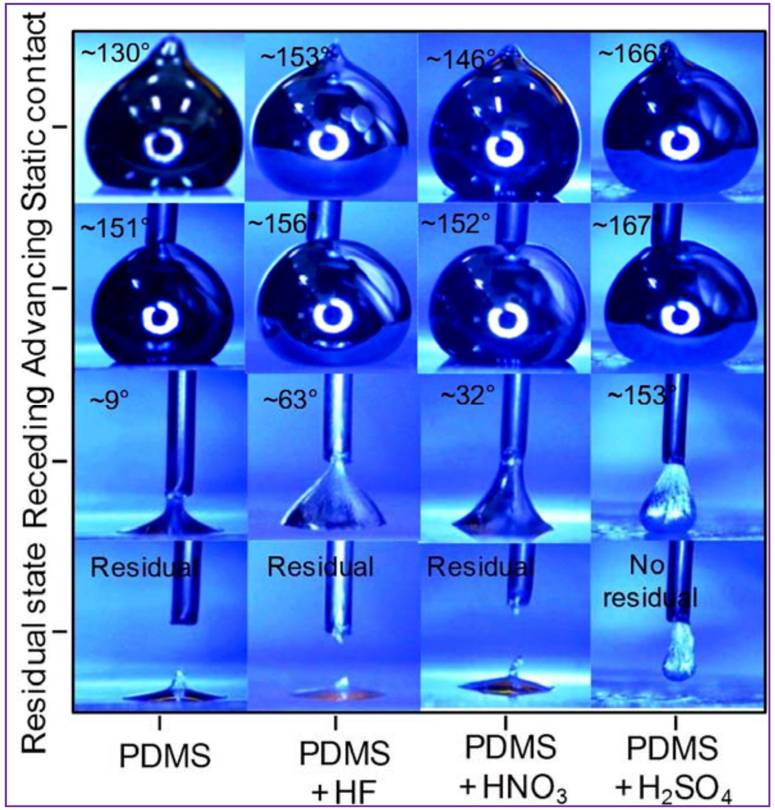
# 3. Chemical approach

## Chemical method




**Left figure shows static CA, advancing and receding angle, and residual state of ~ 8 μl oxidized Galinstan droplet on different PDMS surface (pure PDMS, PDMS immersed in 49% hydrofluoric acid (HF), 69% nitric acid ($HNO_3$) and 89% sulfuric acid ($H_2SO_4$) for 1 min, respectively).**

# 3. Chemical approach

## Structure of different substrate surfaces

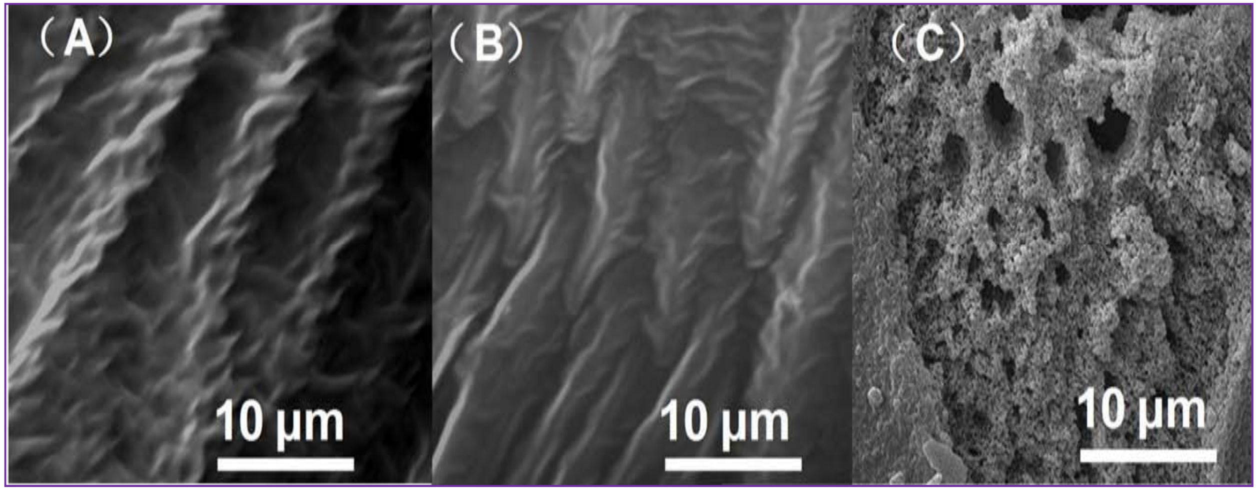



**Figure shows surface SEM images of PDMS after immerging (A) 49% HF, (B) 69%$HNO_3$ and (C) 89% $H_2SO_4$ solution for 1min respectively. PDMS immersed in H2SO4 also shows multi-scale structures similarly to the physical method.**

# 3. Chemical approach

## Optimization of reaction time

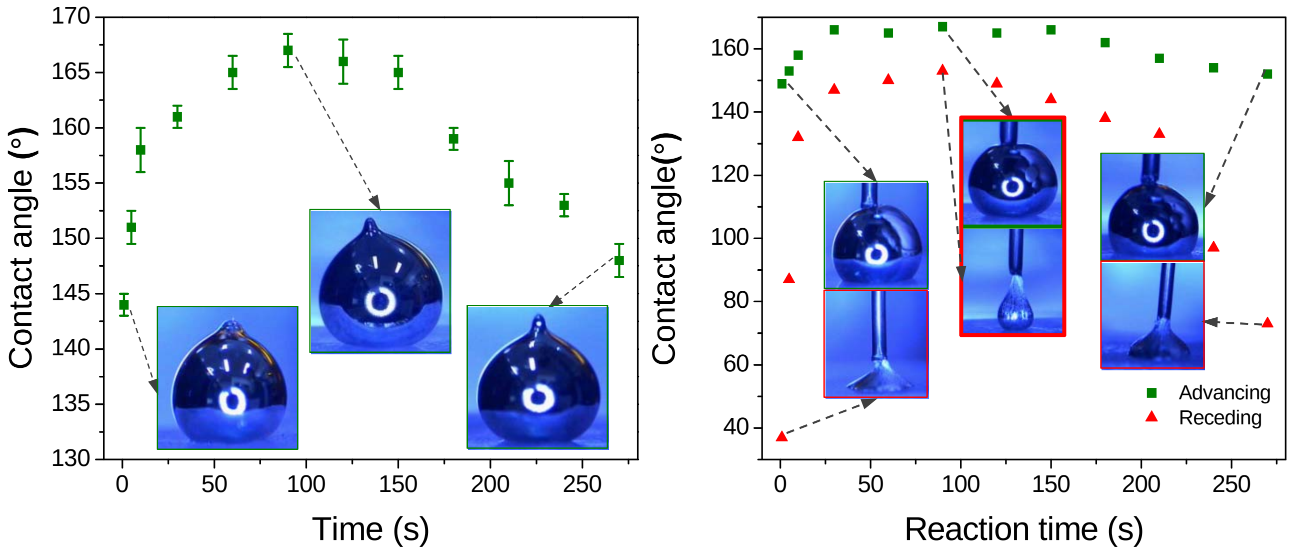



**Figure shows static and advancing-receding angle on PDMS immersed 89% $H_2SO_4$ solution for different time.**

# 4. Demonstrate of movement of oxidized Galinstan

## Demonstrate of movement of oxidized Galinstan

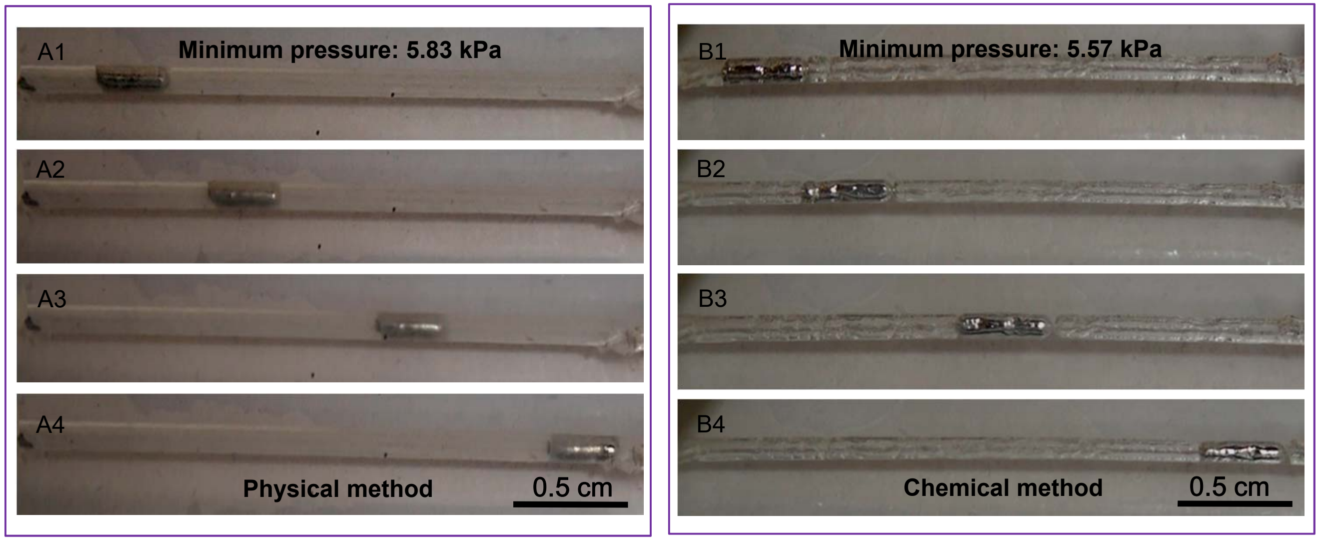
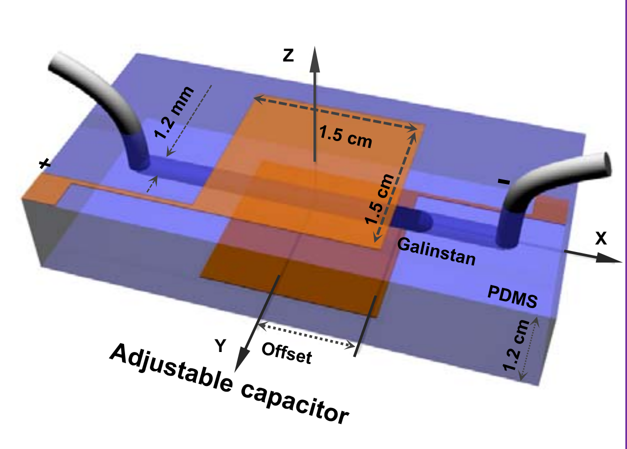



**Figure shows a series images of oxidized Galinstan droplet moving in the super-lyophobic PDMS micro-tunnel fabricated by (A) physical and (B) chemical method.**

# 5. Adjustable capacitor application

## Adjustable Capacitor



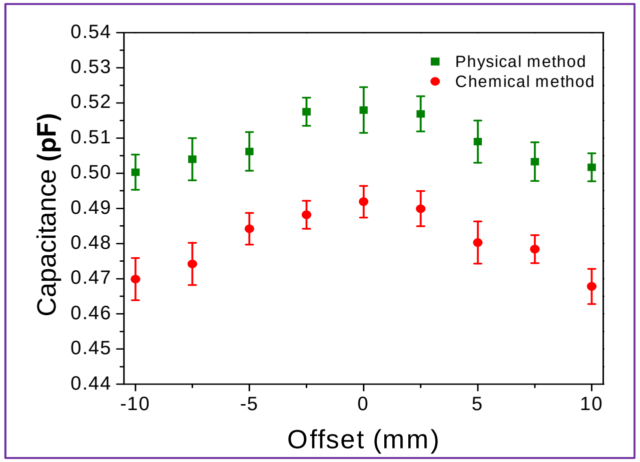
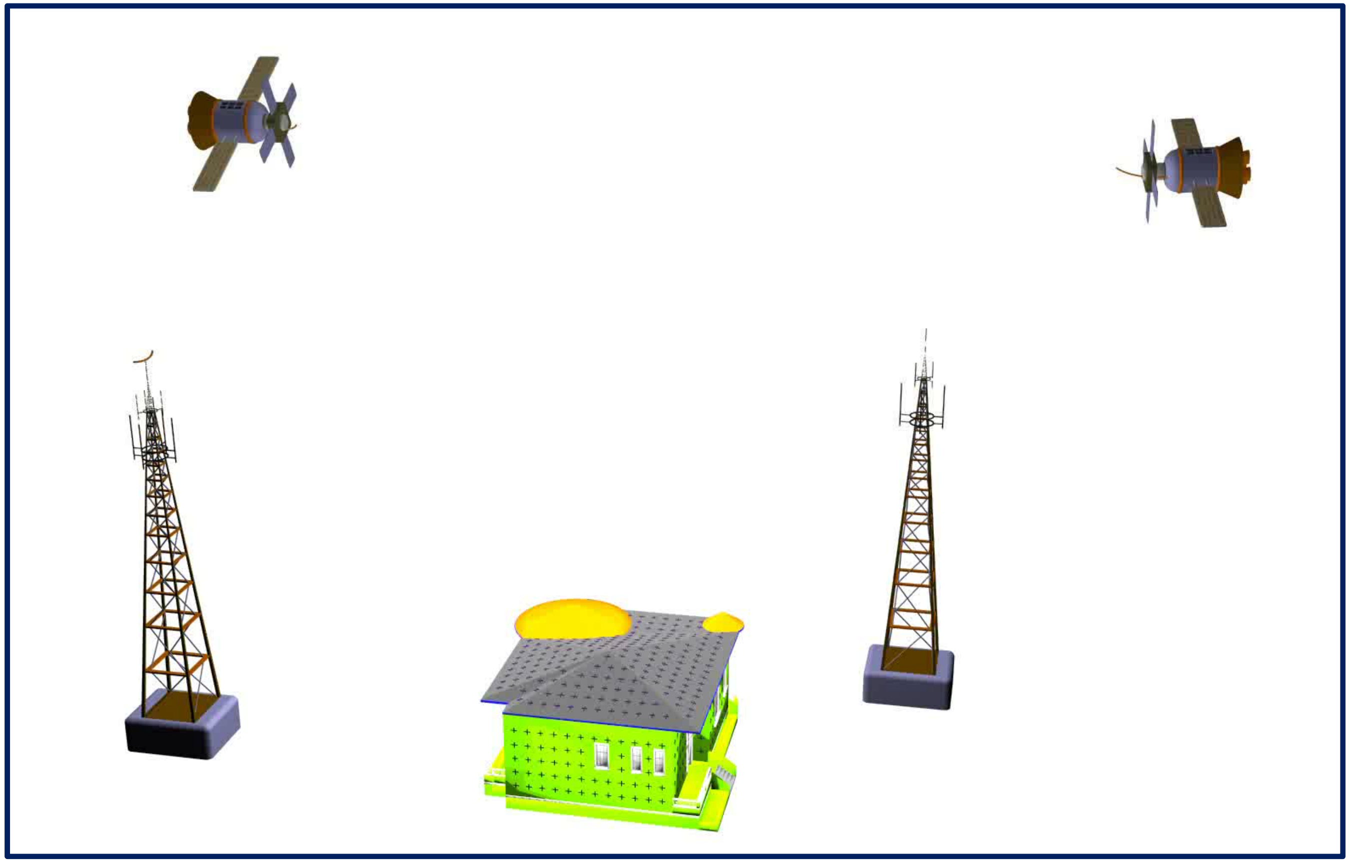




**Figure shows the oxidized Galinstan based microfluidic platform is applied to adjustable capacitor. The change range of the adjustable capacitors capacitance is 0.021 pF (physical method) and 0.024 pF (chemical method). The idea is very useful for realization of the flexible frequency selective surface applications**

# 5. Adjustable capacitor application

## Video demonstration of frequency selective surface (FSS) application



# 6.Next step

◆Further enhance the effect of the physical and chemical method.

◆ Analyze the characteristic of oxidized liquid metal movement in mircrofluidic channel.

◆Improve the properties of adjustable capacitor.

◆Apply oxidized liquid metal based microfluidic platform frequency selective surface application.

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# Thank your attention！

LI GUANGYONG

10.31 2013

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