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A PMUT Integrated Microfluidic System for Volumetric Flow Rate Sensing

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Outline

1. Introduction
2. Fabrication
3. Working Principle
4. Experimental Setup
5. Results
6. Conclusion

1. INTRODUCTION

Introduction

- Volume flow rate is one of the ways to quantitatively characterize fluid flow
- It is the volume of a fluid that passes a known spatial coordinate per unit time
- Fluid density-dependent resonant frequency shift is the method for measuring volume flow rate described in the paper

2. FABRICATION

Fabrication

- The PMUT uses PZT as the piezoelectric material (deposited using sol-gel method)
- Contains one driving and one sensing electrode
- Fabricated on an SOI substrate
- Made in a circular shape

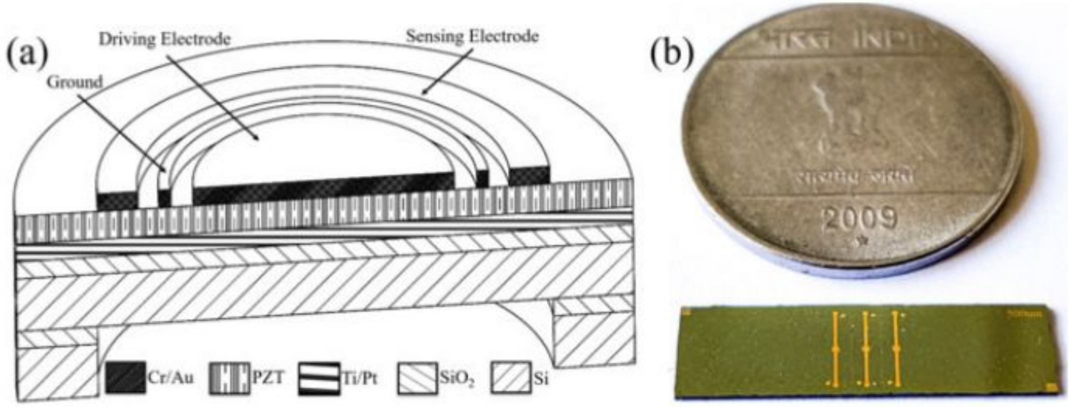


Figure 1: A cross-sectioned 3D schematic of single cell dual-electrode PMUT showing consisting layers

Integration with Microfluidics

1. Silicon wafer patterned using photoresist then etched using DRIE
2. The structure obtained is used as a mold
3. PDMS and curing compound mixture (10:1) poured over the mold, cured for 1 hour (120°C)
4. PDMS stripped off and 1mm diameter holes punched for inlet and outlet
5. Microfluidic channel and PMUT cell array aligned and bonded

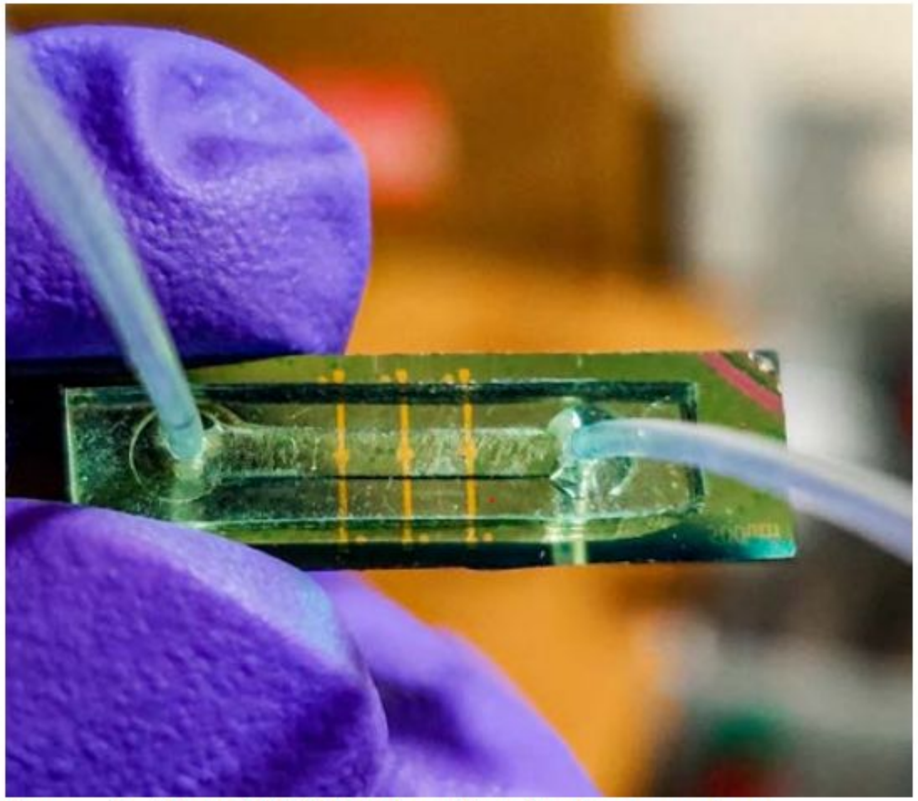
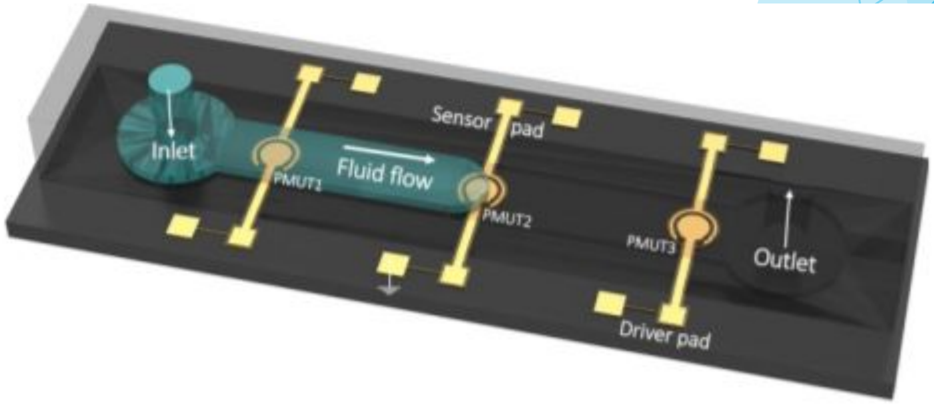


Figure 2: The PMUT-Microfluidic-Integration



3. WORKING PRINCIPLE

Working Principle

- Works by virtual added mass effect
- Fluid pushed into inlet via a syringe pump (constant flow rate)
- Air-fluid interface created inside microfluid channel
- Virtual added mass created as air-fluid interface touches and moves on PMUT surface
- The RF value lowers, then reaches a constant value once the PMUT is fully covered
- Time taken for the RF to reach this value is the Resonant Switch Time (RST)

$$\text{Flow rate (Q)} = \frac{\varphi * s}{RST}$$

where,

φ is the diameter of the PMUT, and
s is the microfluidic channel cross-section

4. EXPERIMENTAL SETUP

Experimental Setup

- Device die bonded to custom made PCB
- Electrical isolation of the PMUT from the fluid achieved by using a Teflon solution (cured at 60°C, 2 hours)
- Connected to syringe pump
- LDV used to observe the frequency response of the PMUT

Figure 3: A PMUT-Microfluidic-Integration wirebonded to a custom-made printed circuit board

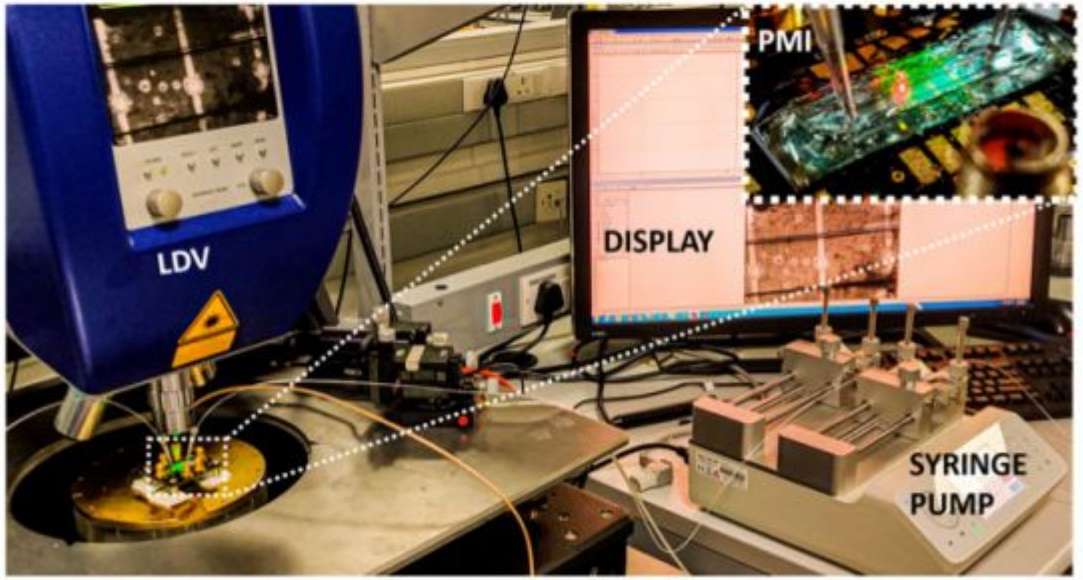


Figure 4: The experimental arrangement used for microfluidic flow sensing

5. RESULTS

Results

- Deionized water used for testing (syringe pump rate of 50 μl/hr)
- Air-fluid interface forms a nearly vertical line
- Resonant freq of single cell in PMUT array tracked and recorded using LDV
- Frequency of the device shifts relative to the air-fluid interface
- Time taken from in-air frequency value to in-fluid value is directly proportional to interface crossing time

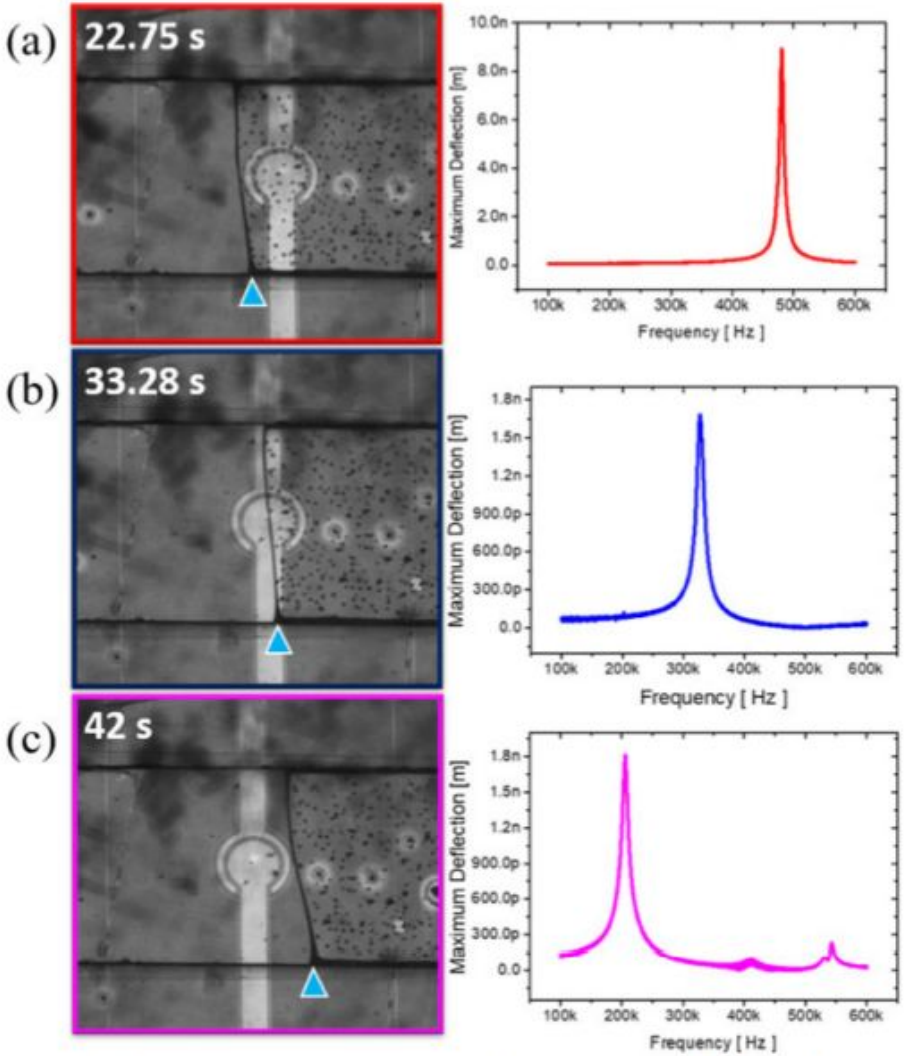


Figure 5: Frequency response function obtained using the MSA 500, Laser Doppler Vibrometer (LDV), as the air-fluid interface flows along the PMUT in (a) 22.75 s (b) 33.28 s (c) 42 s

Actual vs Sensed Rate

- Varied flow rates from 30 µl/hr to 50 µl/hr
- time taken for the frequency to switch was recorded
- Flow rate calculated using previous equation
- Data plotted
- Slope value of 1.04 confirms negligible difference in actual and sensed values

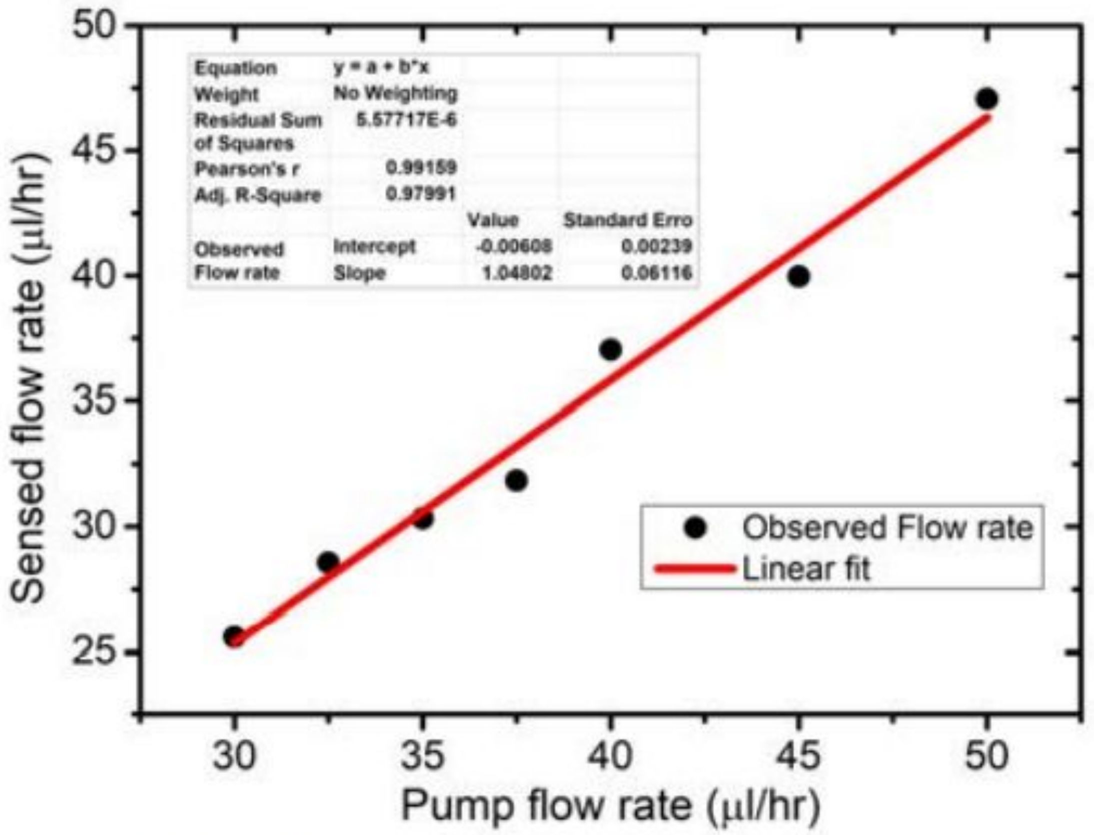


Figure 6: Graph comparing sensed flow rate value with the original pump flow rate value

Flow Sensitivity

- RST recorded for same range of flow rates
- Plot of RST vs flow rate
- Slope of line gives the sensitivity of the device
- Sensitivity found to be 537 ms/µl/hr

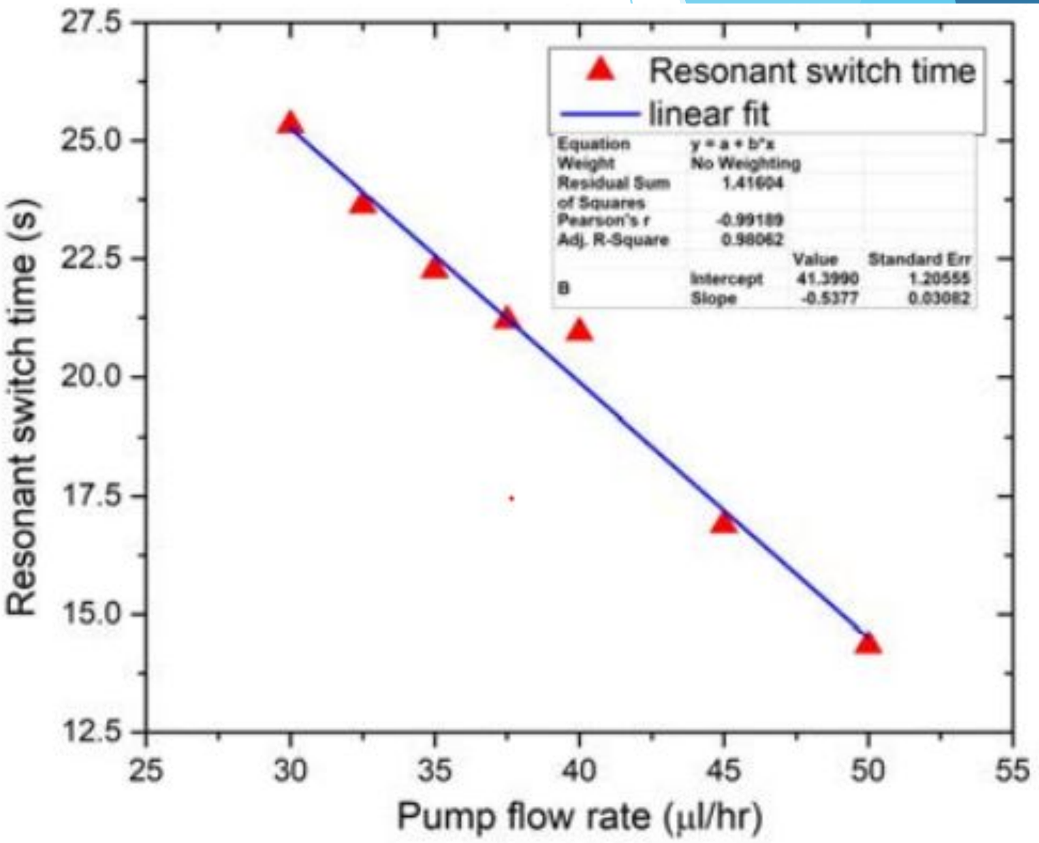


Figure 7: Graph showing the variation in the resonant shift time with respect to varying flow rates

6. CONCLUSION

Conclusion

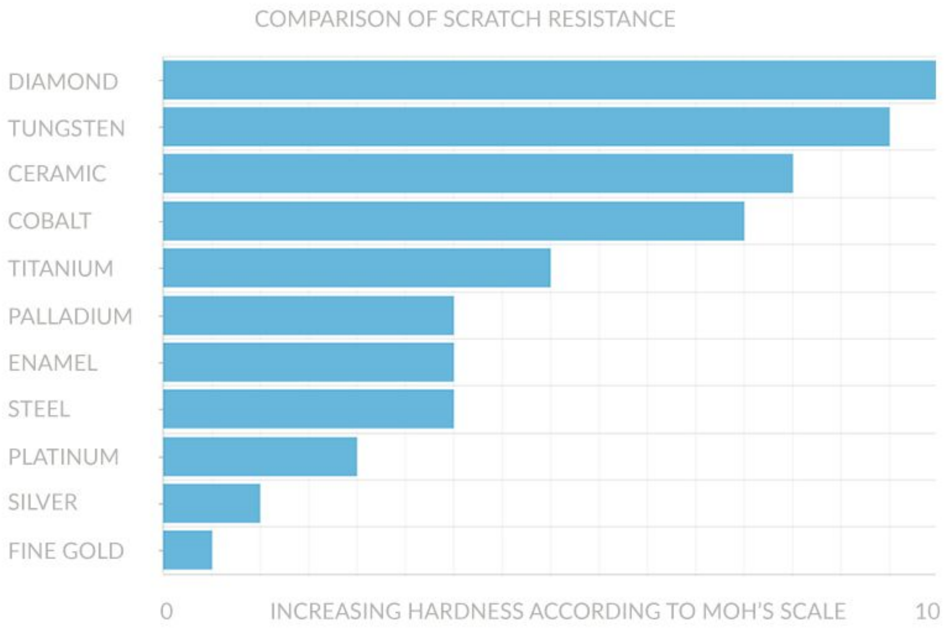
- Dual-electrode PMUTs were developed for flow rate sensing
- The module was used along with a novel technique for measuring volumetric flow rate
- The technique was based on resonant frequency shift

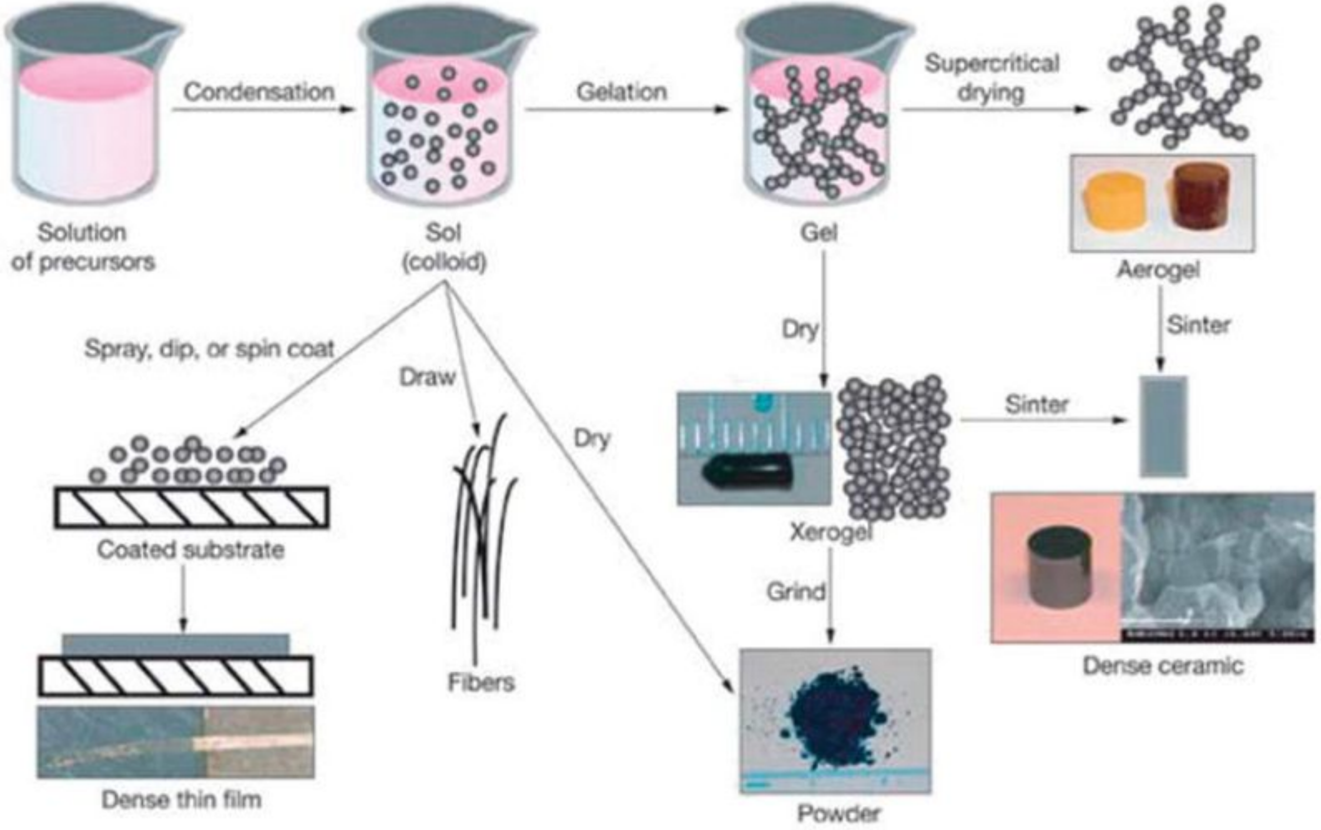
Thank You!

Q&A

Additional Info

MATERIAL	ELECTRICAL CONDUCTIVITY Sm^{1}
Silver	66.7×10^6
Copper	64.1×10^6
Gold	49.0×10^6
Aluminium	40.8×10^6
Rhodium	23.3×10^6
Zinc	18.2×10^6
Nickel	16.4×10^6
Cadmium	14.7×10^6
Iron	11.2×10^6
Platinum	10.2×10^6
Palladium	9.3×10^6
Tin	8.7×10^6
Chromium	7.9×10^6
Lead	5.3×10^6
Titanium	2.3×10^6
Mercury	1.0×10^6




Condensation
Gelation
Supercritical drying
Solution of precursors
Sol (colloid)
Gel
Aerogel
Dry
Sinter
Spray, dip, or spin coat
Draw
Dry
Sinter
Xerogel
Coated substrate
Grind
Dense ceramic
Fibers
Dense thin film
Powder