Design and Simulation of a MEMS-Based Capacitive Micro-Machined Ultrasonic Transducer for Viscosity Sensing Applications

Rahul Goyal[1], Divya Mohan Yadav[1]

1. Centre for Nanoscience and Engineering, Indian Institute of Science, Bangalore, Karnataka, India

Introduction: For rheological applications, due to the advancement in micro fabrication techniques, the technology of capacitive micro-machined ultrasonic transducers (CMUTs) has emerged as a competitive technology in the field of viscosity measurements. The most commonly adopted method utilizes the interaction between the fluid and the transmitted acoustic wave. In this paper, a unique strategy dependent on capacitive micro-machined ultrasonic transducer is demonstrated for the monitoring of viscosity which works on the principle of oscillating structure based detection method.

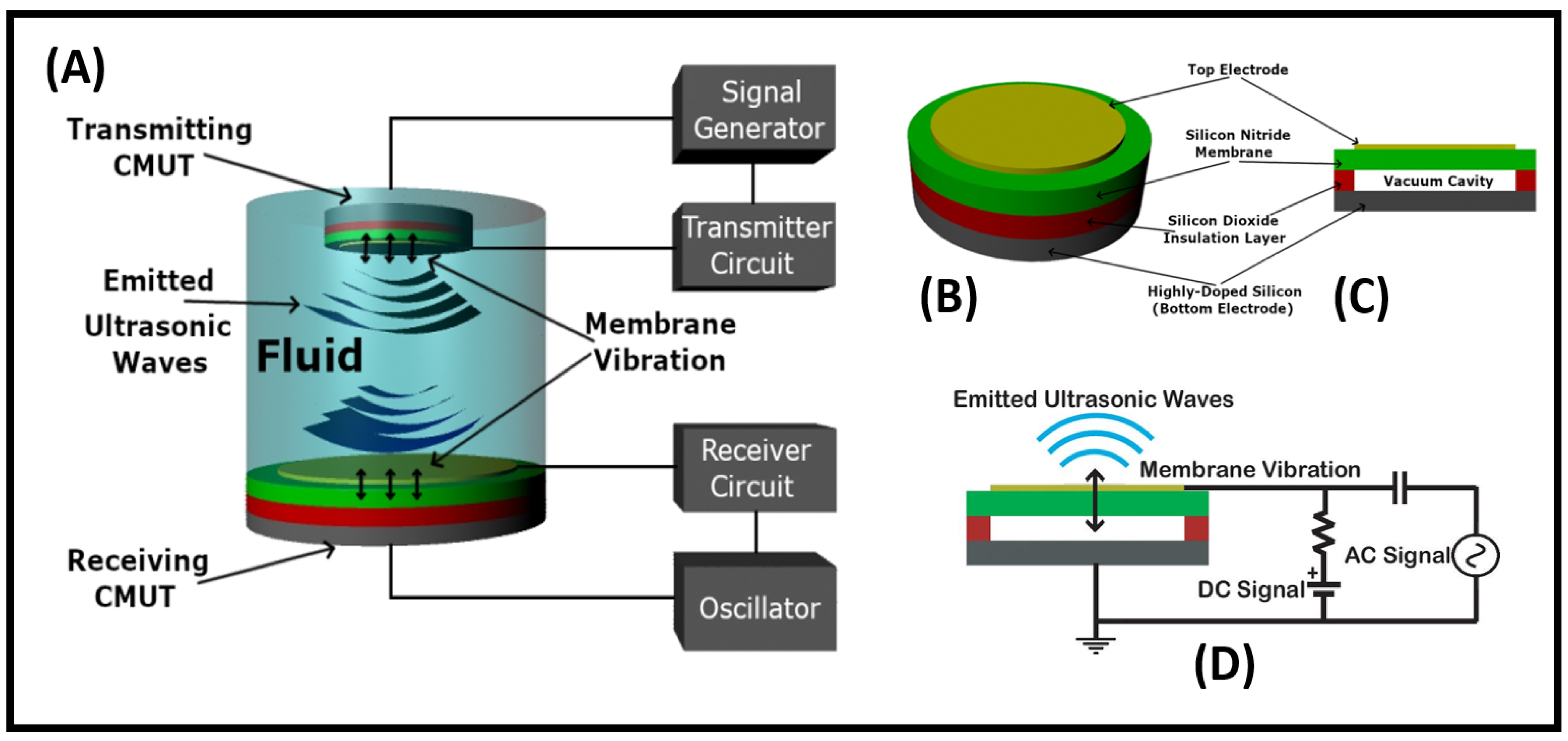

Figure 1. Schematics of capacitive micro-machined ultrasonic transducer. (A) Illustration of the working principle of the MEMS-based viscosity sensor. (B) Orthographic view. (C) Cross-sectional view. (D) Actuation circuit of the ultrasonic transducer.

Simulation Methods: In this paper, to study the entire working of the rheological device, simulations were done in parts using various COMSOL physics in COMSOL Multiphysics® software. Time domain and frequency domain studies are computed to understand the functioning of the device. As the device was axis symmetric, a 2D axis symmetric geometry was used to reduce simulation time and have a 3D idea of the simulation results.

•CMUT parameters using desired materials to operate at desired ultrasonic range. – **Solid Mechanics.**

•Actuation of CMUT – **Electro Mechanics.**

•Generation and transmission of pressure wave – **Acoustic Structure Interaction.**

•Applying impulse signal on receiver CMUT – **Solid Mechanics**

•Change in resonant frequency of the receiver CMUT in different fluids – **Acoustic Structure Interaction.**

•Signal sensing in receiver CMUT – **Electro Mechanics.**

Parameters	Transmitter	Receiver
Resonance Frequency	40 MHz – 50 MHz	40 MHz – 50 MHz
DC voltage	30V	10V
AC voltage	5V V_{pp}	-
Membrane Thickness	100 nm	400 nm
Membrane Diameter	5.85 µm – 6.35 µm	11.65 µm - 13 µm
Vacuum Cavity	0.1 µm	0.5 µm
Pull-in voltage	67 v	> 67

Table 1. Optimized dimensions of simulated viscosity sensor

Results:

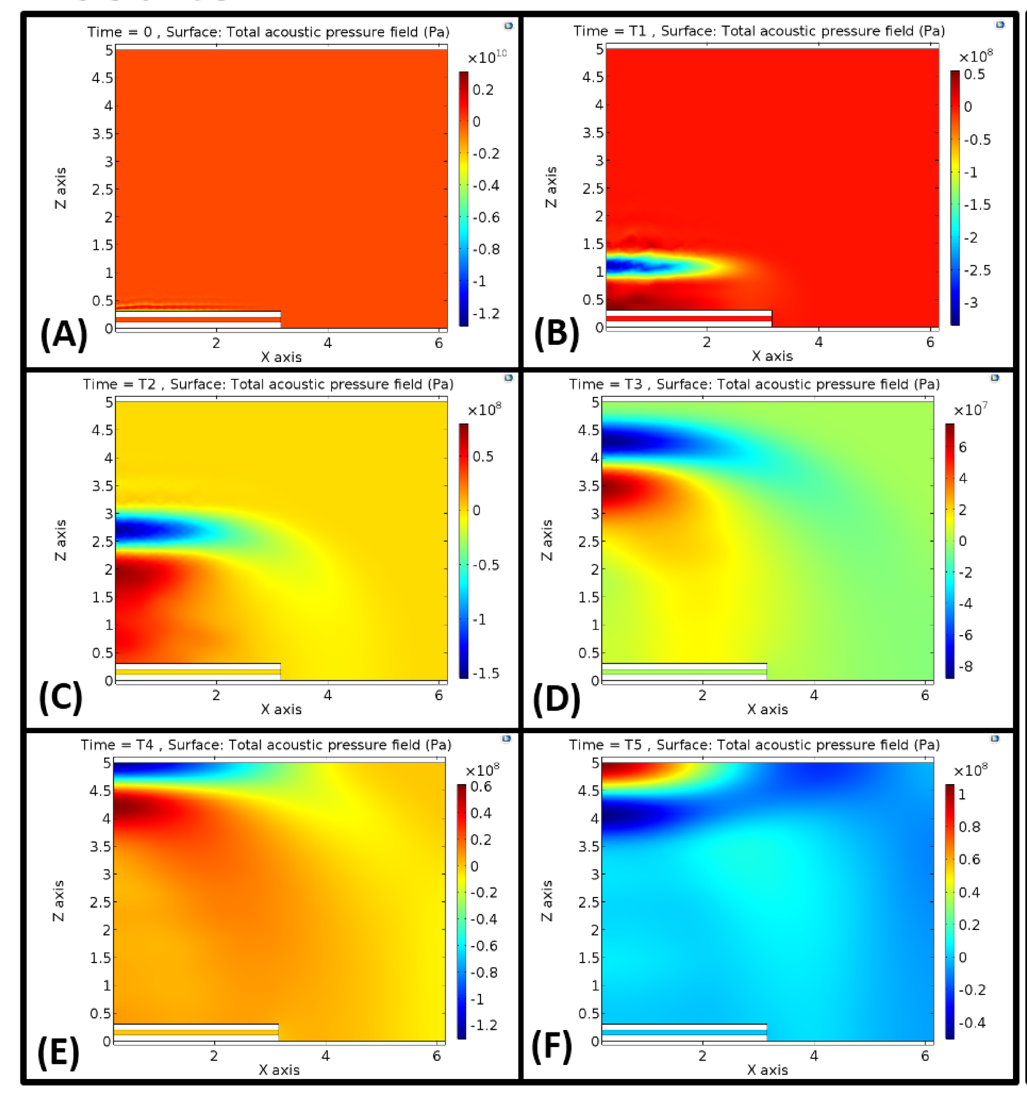

Figure 2. Simulated distribution of pressure inside the liquid column at different instants of time.

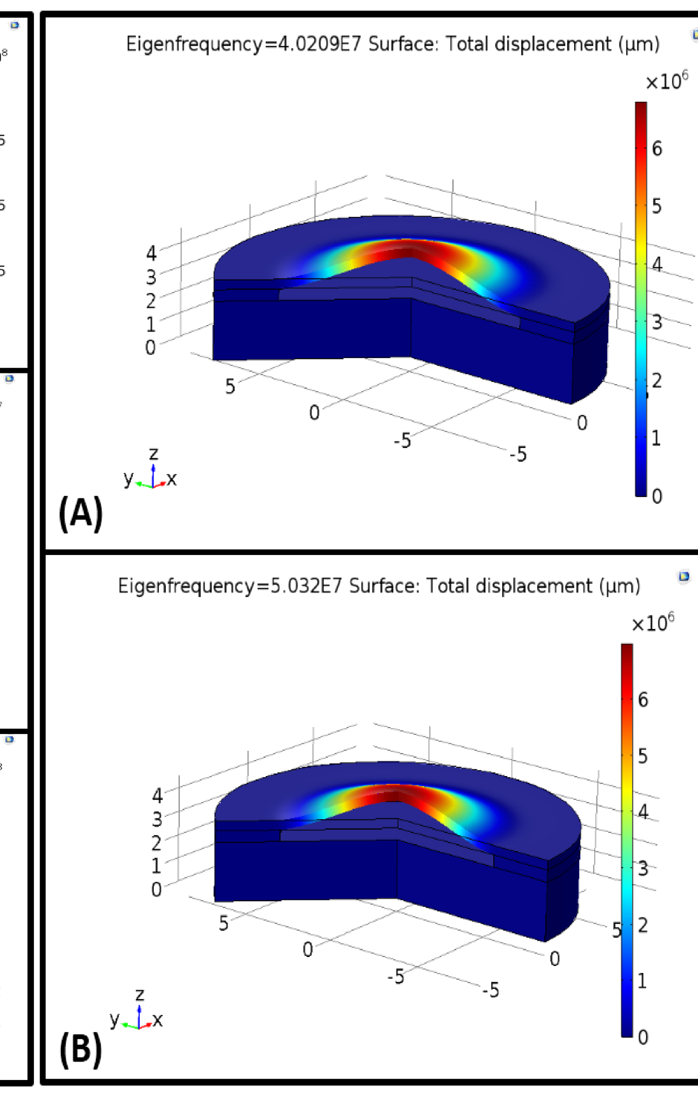

Figure 3. Analysis of the Eigen mode resonant frequency.

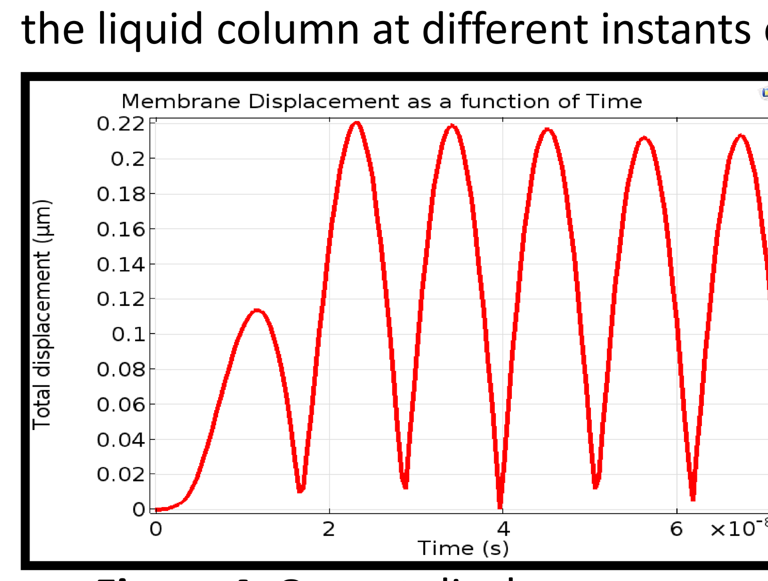

Figure 4. Output displacement.

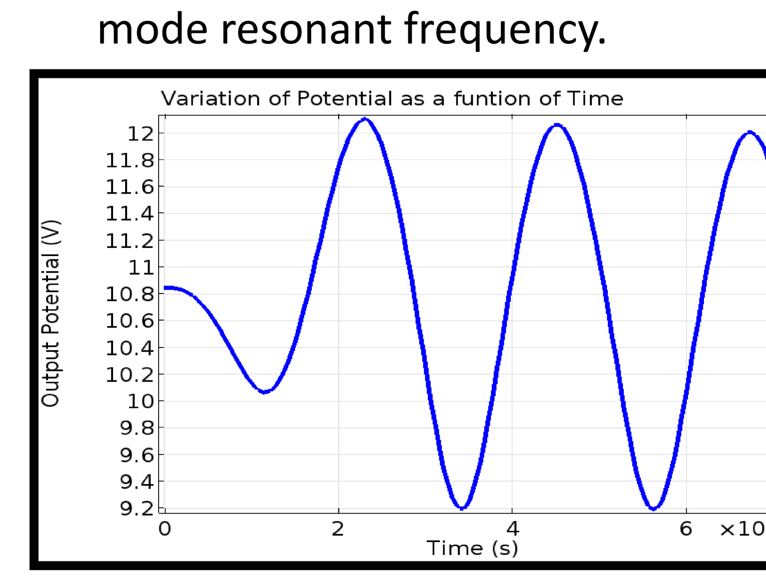

Figure 5. Output Voltage.

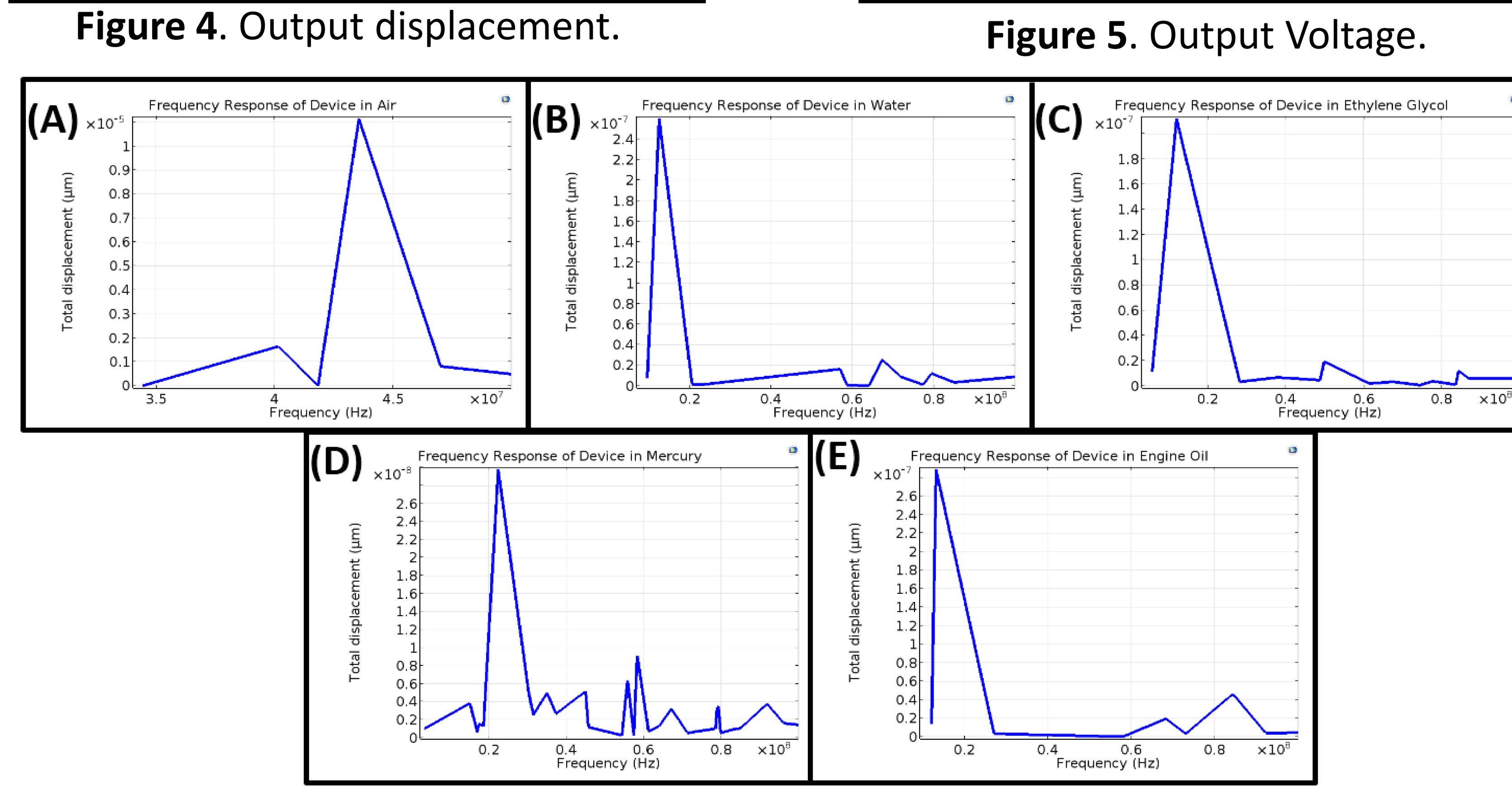

Figure 6. Frequency response of the viscometer in different fluidic medias.

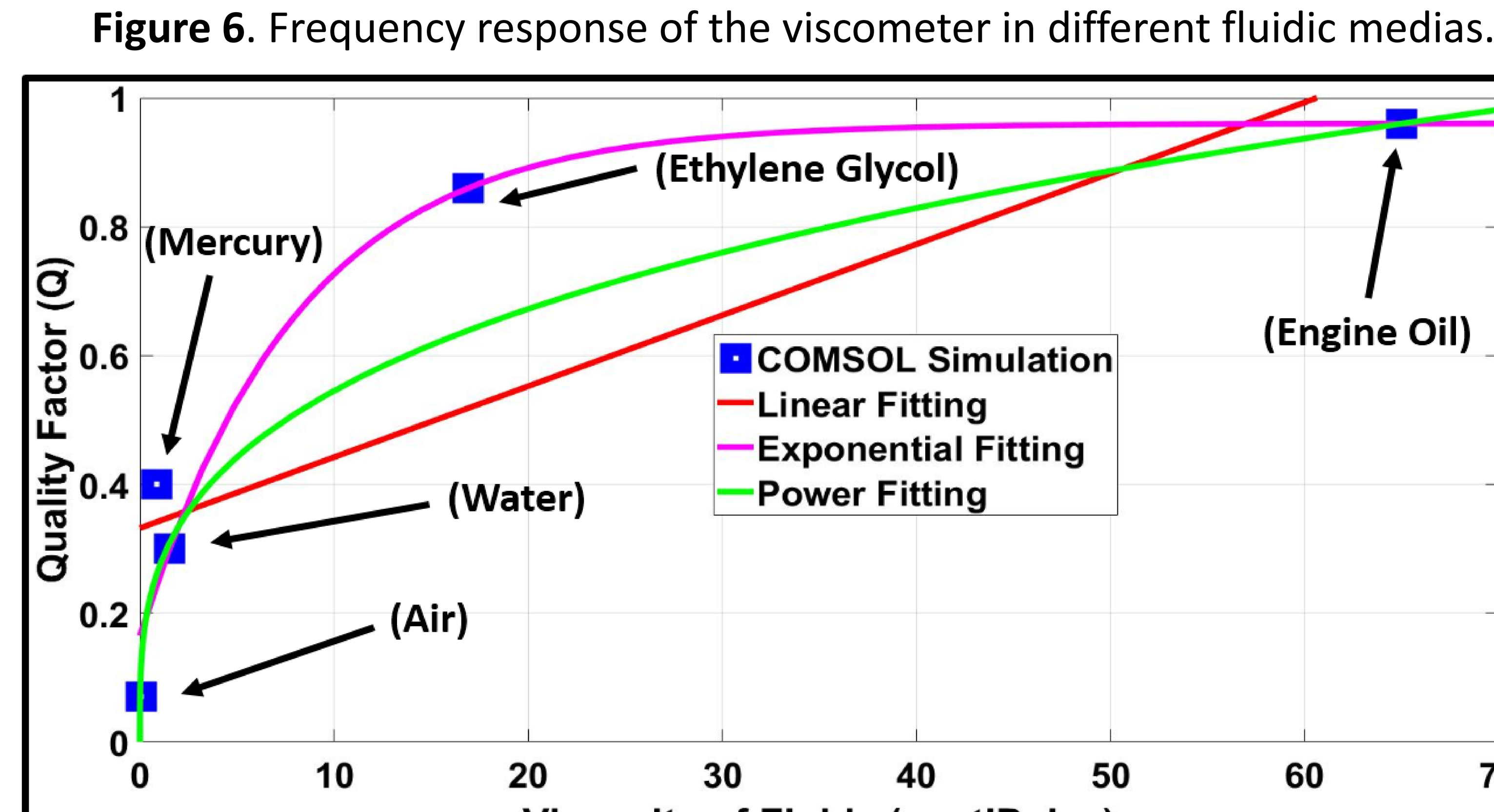

Figure 7. Variation of the quality factor of the device in different fluidic medias.

Conclusion: A novel CMUT based micro viscosity sensor is demonstrated in which the frequency response of CMUT will be affected by the viscosity of fluid in contact with it due to the resultant damping effect. The currently proposed viscosity sensor can be easily used to achieve in-situ viscosity measurements, and is suitable for application in rigorous environments and structure health monitoring, thus benefitting industry.