DYNAMIC BEHAVIOR OF MICRO STRUCTURE IN MICRO FLUIDIC CHANNEL

MD Shakhawat Hossain[1], **Muthukumaran Packirisamy**[2], **Subhash Rakheja**[3]
[1, 2, 3]Optical BioMEMS Laboratory, EV.13.235, CONCAVE Research Center, Department of Mech. & Ind. Engineering, Concordia University, 1515 St. Catherine (W), Montreal, Quebec, Canada H3G2W1,
sojib1612@yahoo.com

1. INTRODUCTION

The potential of Micro-fluidics devices such as micro pumps, micro valves, micro viscometer, biomedical related micro fluidic chip, etc, draws the vital attention towards the investigation about fluid-solid interaction issue in micro level. However, there are several energy dissipations that dominant the performance of those Micro-fluidic devices. Among those energy dissipation viscous fluid damping leads above all and it creates the most significant change in the response of the micro devices operating in the fluid [1]. The result of relevant literature for the micro structure operating in fluid showed that there is dramatic shifting and broadening in the fundamental resonance peak to structural vibration in gases compared to the inviscid model [2]. Cantilever-fluid model is the simplest model for the investigation of microfluid-microstructural interaction. The experimental [3] and analytical [4] both types of studies indicate that micro or nano cantilevers operating in liquid is a heavily damped system, with a large shift in the resonant frequency away from the natural frequency of the system. If the cantilever is excited by other source rather than fluid, then the quality factor in air is typically higher than the estimated quality factor in water for the same resonator. Therefore, lower quality factor is found in air rather than other liquid when the cantilever is excited by any kind of fluid excitation such as Brownian force [5], which is the opposite result to the earlier one.

The current study presents the finite element modeling of micro cantilever excited by the fluid force. The quality factor of the cantilever is greatly influence with the pressure force loading and viscosity of the fluid. However, the length of cantilever also controls the quality factor for particular fluid. This paper explores all this issues comprehensively with the microfluid-microcantilever Finite element model.

2. THEORY

In the current model the cantilever is excited by a fluid pressure force created by the fluid flow, which is kind of step input action on a cantilever beam. For this type of model the equation of motion will be

$$M\ddot{y} + EI\frac{d^4 y}{dx^4} + c\dot{y} = F$$

Where, M is beam mass per unit length, y is beam deflection at its free end, E is Young's modulus of elasticity, c is damping coefficient per unit length and F fluid force per unit length. This force is causes by pressure difference as well as flow difference between the top and bottom side of the cantilever. However for un-damped system the natural frequency is,

$$\omega_n = (\beta_n L)^2 \sqrt{\frac{EI}{ML^4}}$$

Where, β_n is a coefficient and product $\beta_n L$ values are 1.8751, 4.6940, 7.854 radians correspond to first 3 modes, respectively.

3. FINITE ELEMENT MODEL

3.1 Finite Element Model

COMSOL Multiphysics is used to develop the Finite Element model where, 3 different Modules are used. They are micro fluidics module (Incompressible Navier Stokes transient analysis), structural mechanics module, and deform mesh (moving mesh with transient analysis) module. In fluid module the inlet flow used as input boundary condition. The load developed due to this flow is used as input for structural module. The moving mesh application mode makes sure the flow domain is deformed along with the cantilever.

3.1 Boundary Conditions and Geometrical Parameters

Two different types of finite element modeling is done with the same geometry, which is showed in figure 1. In The first one for a particular length of cantilever and particular flow of fluid different quality factor and response is characterized with respect to the viscosity of different fluid. In second model for the particular fluid (air) and flow, quality factor is characterized with respect to different Aspect ratio of cantilever.

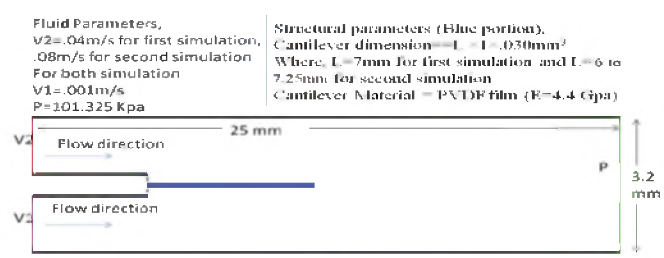

Figure 1: Geometry and boundary conditions

4. RESULT

4.1 Viscosity and Quality Factor

The quality factor with respect to different fluid is shown in figure 2.

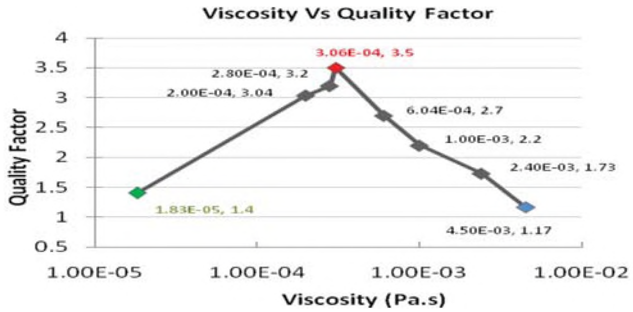

Figure 2: Viscosity Vs Quality factor. Highest quality factor is seen for Acetone indicated with red color and lowest is seen for Fluid XP indicated in blue color

Table1: Fluid parameters and frequency of the cantilever

Fluid	Viscosity (Pa.s)	Density (kg/m^3)	Frequency (Hz)	Pressure Difference Across Cantilever Tip (Pa)
Air	1.83E-05	1.2	156	0.01
Freon-12	2.00E-04	5.11	136	0.14
Water at 100°C	2.80E-04	958	16.1	1.67
Acetone	3.06E-04	790	17.12	0.42
Benzene	6.04E-04	878.6	15.5	2.83
Water at 20°C	1.00E-03	1000	13.89	3.86
Isopropyl Alcohol	2.40E-03	786	15.7	2.89
Fluid XP	4.50E-03	1029	12.6	4.54

The density and viscosity of fluid both control the quality factor for the fluid excitation to the cantilever. The fluid density is responsible for pressure load which creates the dynamic motion of cantilever. However, viscosity tries to resist this dynamic motion. Though air has the lower viscosity which is a good condition of high quality factor but air has very low density comparative to the other fluid. This creates lower amplitude where, higher amplitude is another significant condition for higher dynamic behavior or good quality factor. In figure 2 it is clearly shown that highest quality factor is found for the response in Acetone which has higher density than air but lower than water. However, when the cantilever starts moving (due to the stiffness) opposite direction to the flow after initial deflection by pressure loading (due to the flow) then the pressure and viscosity both resist the motion of the cantilever. Therefore, the amplitude decrement is faster in hot water (100°C) rather than Acetone though hot water has lower viscosity but has higher density.

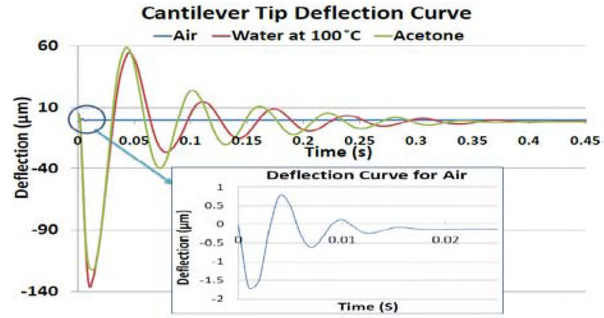

Figure 3: Deflection curve in Air, Hot water, and Acetone. Response in Air is shown as zoomed view in the bottom box

4.2 Aspect Ratio and Quality Factor

The quality factor is also characterized with respect to aspect ratio (length/width) which is showed in figure 4. However the peak value was found in 7, that was 7mm long cantilever as the width was consider as 1mm.

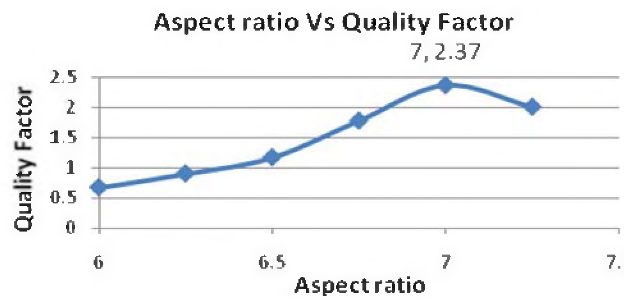

Figure 4: Aspect ratio Vs Quality factor.

5. DISCUSSION

It is clear that acetone is the good fluid as an actuation element for micro structure. In figure 4 after peak quality factor the value decreases as because of the size of the cantilever increases which causes increment of damping.

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