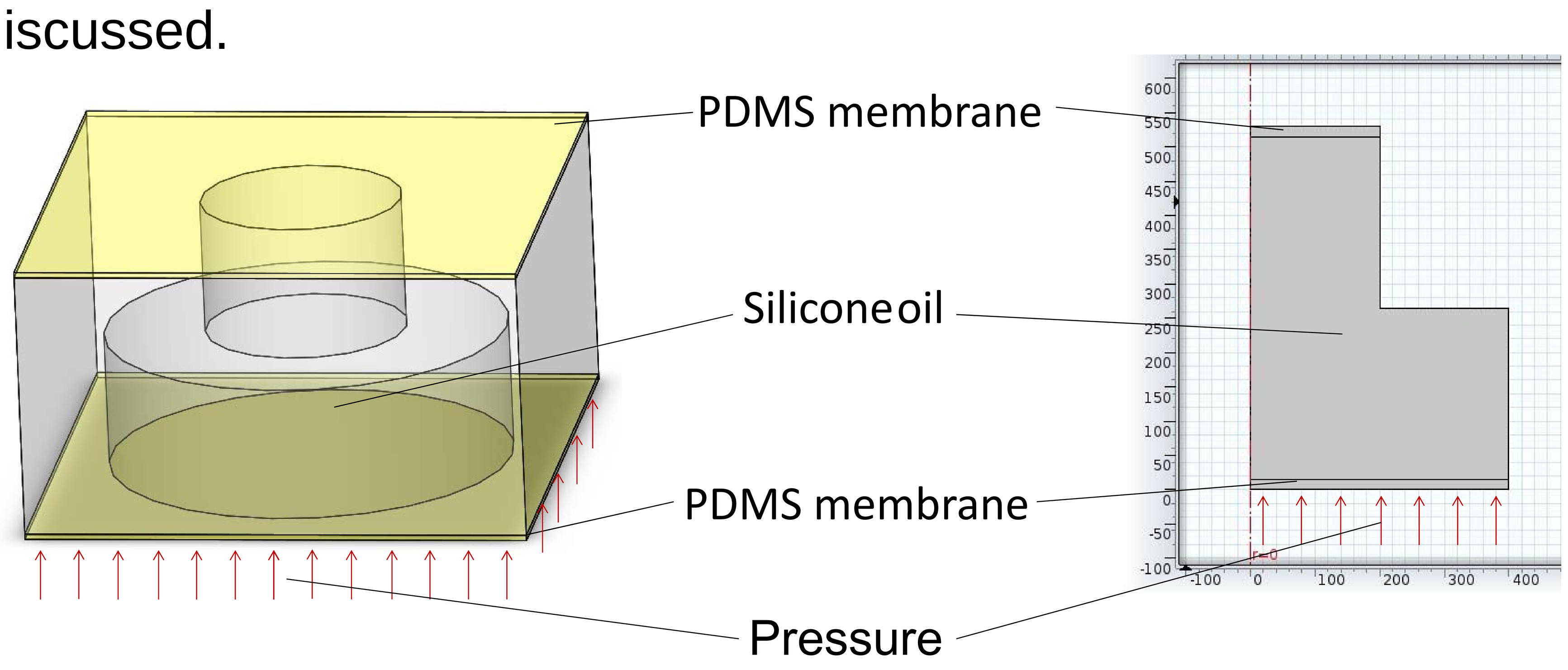
Proof of Concept and Properties of Micro Hydraulic Displacement Amplifier

R. Zhu [1, 2], A. Malisauskaite [1], U. Mescheder [1], U. Wallrabe [2]
1. Furtwangen University, Department of Computer & Electrical Engineering, Institute of Applied Research (IAF), Robert-Gerwig-Platz 1, 78120, Furtwangen;
2. Freiburg University, Institut für Mikrosystemtechnik (IMTEK), Georges-Köhler-Allee 106, 79110, Freiburg.

Introduction:
Microhydraulic principle, which can be used to convey power and displacement, was used to design a micro hydraulic displacement amplifier[1]. The liquid is encapsulated in a chamber with two hyperelastic membranes sealing it from both sides. A displacement of the upper membrane occurs when a certain pressure is applied on the lower membrane. A hydraulic displacement amplifier coupled with fluid mechanics and hyperelastic material is studied through 2D axisymmetric FSI (Fluid-structure interaction) model in COMSOL. The actuation behaviors, the liquid movement inside of the chamber, the pressure distribution and the amplification ratio, are studied and discussed.



Governing equations:
To define the liquid inside of chamber, Navier-stokes equation is employed. Since the PDMS is an elastomer material, the hyperelastic model (Mooney-Rivlin model) is coupled to the model as well. The pressure applied on the down membrane is varied using ramp function, which results in rise of pressure from 0 to 10 KPa in the first second and holds this value for 2 seconds.

Ⅰ. Navier-Stokes equation [2]

$$\frac{\partial \vec{u}}{\partial t} + \vec{u}\cdot\nabla\vec{u} + \frac{1}{\rho}\nabla p = \vec{g} + \nu\nabla\cdot\nabla\vec{u}$$

$$\nabla\cdot\vec{u} = 0$$

- $\vec{u}$ Velocity of fluid
- ρ Density of fluid
- p Pressure that the fluid exerts on anything
- t Time
- $\vec{g}$ Body force applied on fluid
- ν Kinematic viscosity of fluid

Ⅱ. Mooney-Rivlin equation [3]

$$W = C_1 J_1 + C_2 J_2$$

$$J_1 = \lambda_1^2 + \lambda_2^2 + \lambda_3^2 - 3$$

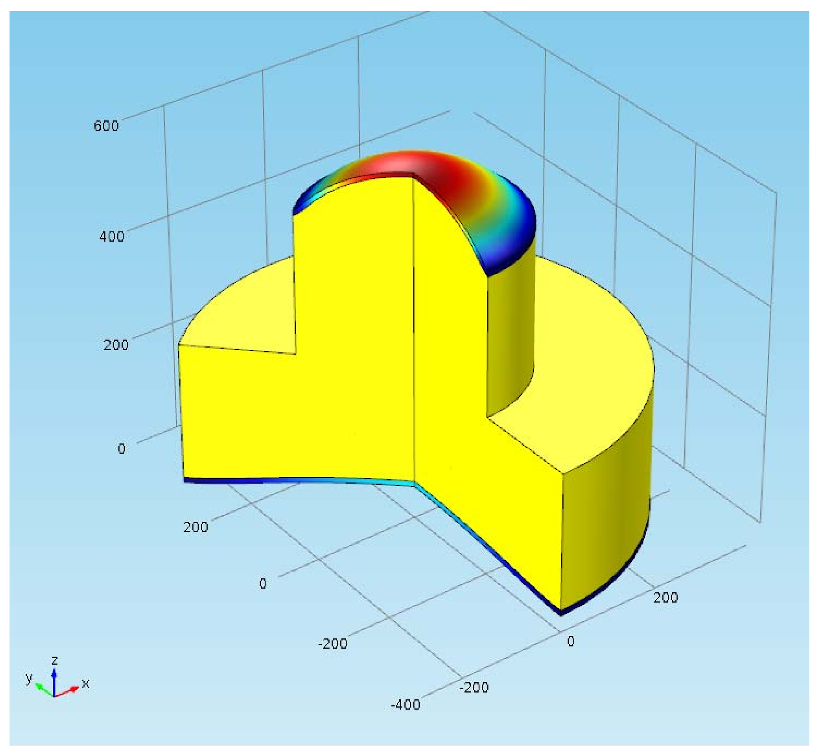
$$J_2 = \lambda_1^2\lambda_2^2 + \lambda_2^2\lambda_3^2 + \lambda_1^2\lambda_2^2 - 3$$

$$J_3 = \lambda_1^2\lambda_2^2\lambda_3^2 - 1$$

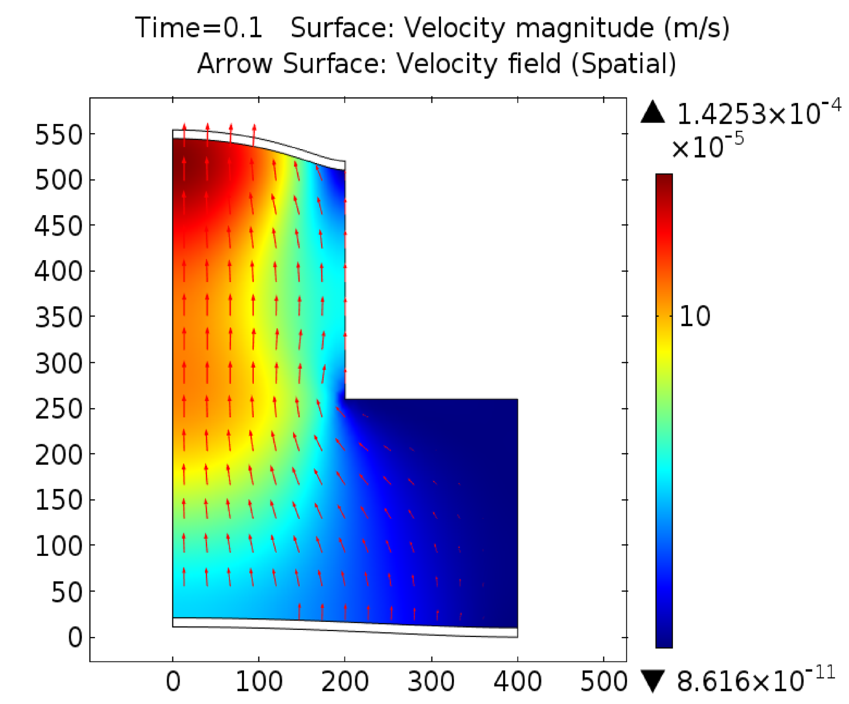
- W Strain energy density
- λ_i Principal stretch ratios
- C_i Material constant

Variables	Value	Units
Density of liquid	120	Kg/m³
Dynamic Viscosity	1.49	mPa.s
Membrane thickness	10	µm
Upper membrane radius	200	µm
Lower membrane radius	400	µm
Membrane bulk modulus	1214.84	MPa
C_1	0	MPa
C_2	0.1342	MPa

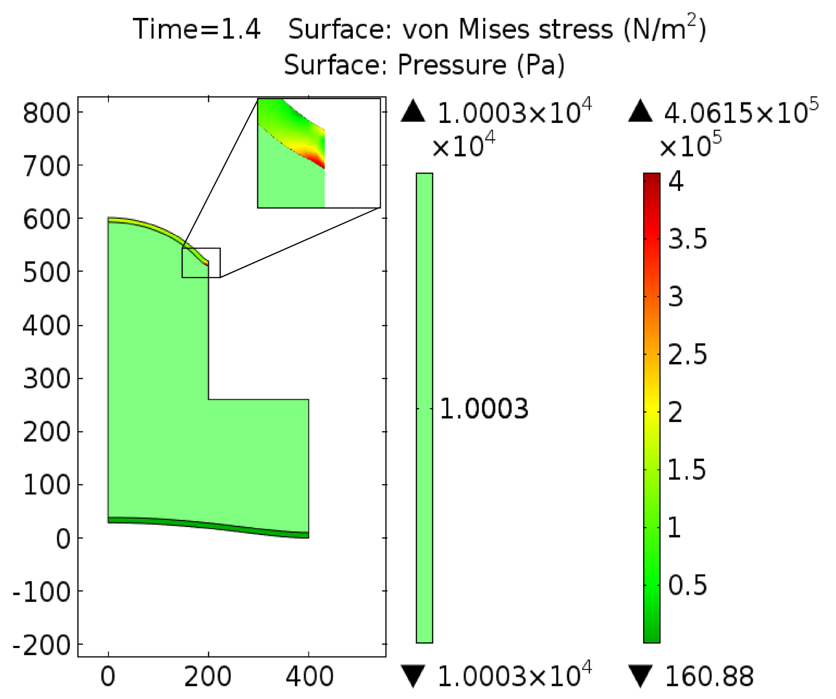
Results:



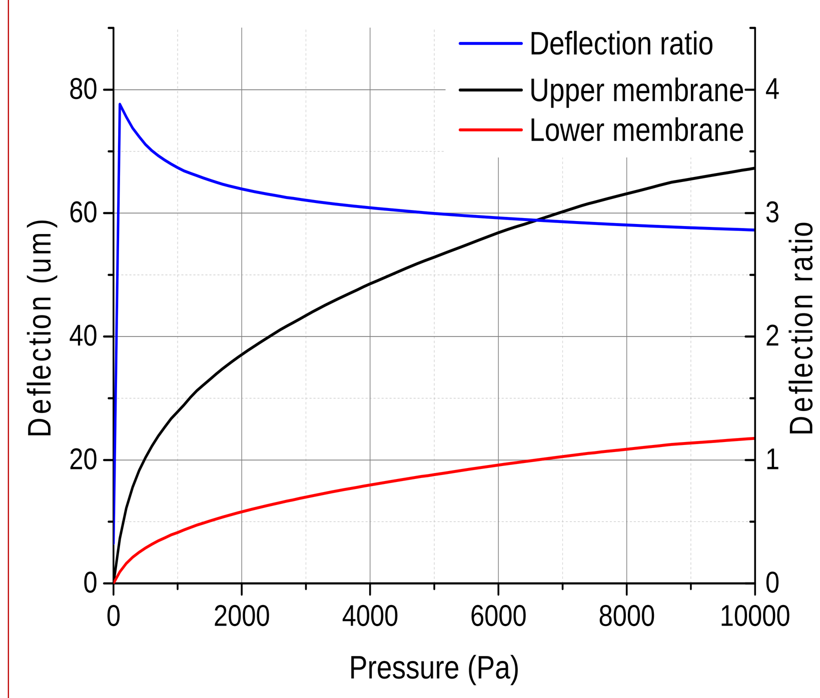
Simulation result of actuated amplifier in 3D view



Liquid movement inside of amplifier



Pressure distribution in amplifier



Amplification ratio and deflection of membranes versus pressure

Conclusion:

- Since the maximal velocity of the liquid is quite small, it results in a very small viscous force.
- Since the total pressure will be applied to the upper membrane, to analyze deflection of the amplifier the easiest way is to analyze deflection on the upper membrane only.
- Amplification ratio is defined as the ratio of the center deflection of upper membrane to the center deflection of lower membrane, it is found that the amplification ratio jumps from zero to a certain value once the pressure is applied, and then drops with the increase of applied pressure.

References:

1. J. Watanabe, H. Ishikawa, X. Arouette, Y. Matsumoto, N. Miki, Artificial Tactile Feeling Displayed by Large Displacement MEMS Actuator Arrays, MEMS IEEE, 1129-1132 (2012)
2. G. Hou, J. Wang, A. Layton, Numerical Methods for Fluid-Structure Interaction - A Review, Commun. Comput. Phys., 337-377 (2012)
3. Alan N. Gent, Engineering with Rubber 2nd Edition, Page 50, Hanser, Munich (2001)

Excerpt from the Proceedings of the 2013 COMSOL Conference in Rotterdam