Design and Simulation of Micro Electro Wetting Liquid Lens for Miniature Cameras

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Abstract: ***The present work reports the design of micro lens for miniature cameras using COMSOL 4.3. The contact angle over the lens are obtained by electro-wetting effect, this effect can be understood in terms of forces. When the voltage (force) is applied, the wetting effect alters the focal length of lens as variance of contact angle of the lens. The two immiscible fluids were taken for fluid-fluid and wall-fluid interfaces to obtain boundary properties and contact angle over the lens respectively. The world is integrated by the electro-wetting lens due to their reliable properties. Finally, the analyses of the results would help us in selecting better design to get optimum focal length for given inputs among all the proposed designs and the concept shown in this paper can be open to various designs and also applicable for real time applications.***

Keywords: Micro lens, wetting, Focal length, Contact angle, Comsol

1. Introduction

With the merger of nanotechnology the micro electro mechanical systems (MEMS) has been majorly focused in the development of new fabrication techniques for semi conducting devices which are used in various optoelectronic spices like miniature cameras, e-readers etc.., with more efficiency. The micro machining technology has been emerged in the late 1980's.Recently this technology plays major role in most of the optoelectronic for present spices into very small scale integrated products which works with more efficiently, without losing their any physical or chemical properties as mentioned in practical industries, which has been oriented to produce solutions data sheet.

By understanding the emerging trends in this society the present module is designed basis on the properties of nano field for efficient usage. The mechanism of wetting properties can be understood in terms of forces, that result from the applied electric field, in other words as the voltage is applied to the fluid molecules the contact angle over the solid surface changes accordingly, this effect is referred as electro-wetting effect. By this effect the focal length alters with respective to the contact angle between liquid and solid surface.

The main reason for selection of this design is due to their lesser in size, variable focal lenses with small applied voltage and same module can be taken for many aspects in the various designs of optoelectronic industries. Many industries use this technique called ewod, it means the solid-liquid surface consists of a thin dielectric deposited onto a conducting layer, this often referred as electro-wetting on dielectric (EWOD). This technique can be determined easily by this module design.

2. Software Tools

The software package selected for solution of this module is COMSOL MULTIPHYSICS fluid flow V4.3.This is an global software which is used in many essential designs of MEMS. This is powerful interactive software with the environment for modeling and simulation of any physics based products. The first Comsol flag ship product was released in 1996.At present this software can solve almost problems in multi physics systems and it creates the real world of multi physics systems without varying there material properties. The operation of this software is easier to understand and easier to implement in various aspects for designers, in the form of finite element analysis system. This software can operate by remote connection mode, by this the designers can analysis there design in different forms. This software can simulated for multiple interfaces like fluid-fluid interface and wall-fluid interface which are highly essential for this module.

With this software the mechanism of the module is constructed and simulated by basing on the four steps as described below:

(i) Defining geometrical properties
(ii) Adding physical interfaces
(iii) Providing materials to the solid structure
(iv) Meshing, simulation of model with the provided input potentials.

3. Design Techniques

3.1 Geometrical Properties:

The Comsol multi physics provides a number of features for creating geometric primitives and for operating on them, from the available geometry structures in Comsol multi physics , The solid structure of the electro-wetting lens are obtained by taking geometrical properties of rectangle and Bezier polygon with the length of units in millimeters (mm) and width of 1.5mm is placed for the rectangle. The Bezier polygon is a set of polygon segment which has two sets of rows which are divided as row1 and row2 for easier approach of control points in the structure, with R=1.5mm and Z=0.55mm respectively. All the properties of the structure is chooses under linear phase, but Bezier polygon is generally taken under chain formation of line segments and quadratic or cubic curves (simulation can also be carried out for other structures also) with a set of control points. By choosing an appropriate control points a closed curve formed a deformed structure is carried out for analysis of the design is meshed up. The meshed part of the geometrical structure is referred in figure 1.

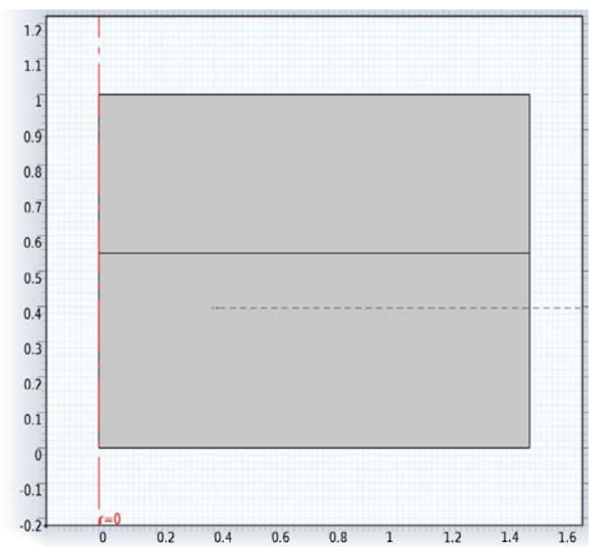


Figure 1: The messed part of geometrical structure

The contact angle plays a key role in the obtaining of focal length over the lenses. Generally, contact angle refers the theta (θew) over the electro-wetting effect. This effect can be obtained by using the described formulae. The parameters defined for the finding of focal length over the lens is obtained from the formation of contact angle between the liquid and solid surface. The input potentials provided for the solvation of this module is (described as below).As per young's equation the contact angle before switching the voltage is Contact angle (θ_o): $\gamma s_1 + \sigma_{12} * \cos(\theta_o) = \gamma s_2$(i)

Here ' γs1' is the surface energy per unit area between fluid 1 and the solid surface(substance), 'γs2' is the surface energy per unit area between fluid 2 and the solid surface(substance), and 'σ12' is the surface tension at the interface between the two fluids.

In electro-wetting the balance of forces at the contact point is modified by the application of a voltage between a conducting fluid and the solid surface. For the case when a voltage difference occurs between fluid 1 and the conductor as solid surface (substance) of dielectric substance, then Young's equation is modified in equation2.

$$\gamma s_1 - \frac{\epsilon V^2}{2 * d\_f} + \sigma_{12} * \cos\theta ew = \gamma s_2 \qquad \text{(ii)}$$

Here 'ε' is the permittivity of the dielectric, 'V'is the potential difference applied, and 'd_f' is the dielectric thickness. By using the above equations of (ii) and (iii) the modified young's equation for finding the wetting effect over fluid is:

$$cos\theta_{ew} = \cos\theta_o + \frac{\in V^2}{2 * d\_f * \sigma_{12}}$$

This is the basic equation for the physical formation of the structure in the module and used for calculation of electro-wetting effect over fluid. The input potentials provided for the analyzing of wetting properties are referred in table1 and the materials added for the formation of solid structure is described in table2 and table3 (described below).

Table1: Providing Inputs

Parameter	Expression	value
Zero Voltage Contact Angle	theta0(θo)	140[deg]
Surface Tension	gamma(r)	0.05[N/m]
Insulating Fluid Viscosity	muoil	$8e^{-3}$ [Pa*s]
Relative Dielectric Constant	espr	2.65
Dielectric Constant	d_f	3[um]
Applied Voltage	Vapp	100[v],120[v]

Next step is addition of material to the proposed geometry. Browsing all the available databases a specific material is chosen and properties are assigned to the chosen material in two forms of materials like material1 and material2 for clear modules for solid structure of the design with its respective domains in their field as below:

Table2: Material Properties (i)

Property	Expression	value
Density	rho	1000
Dynamic Viscosity	mu	muoil

The material properties are fixed as natural properties and obtain their properties by selecting the required materials for designing the module.

Table3: Material Properties (ii)

Property	Expression	value
Density	rho	1000
Dynamic Viscosity	mu	$1.5e^{-3}$

By using these potentials the study of wetting properties is done.

3.2 Physical Interfaces

To solve the problem over the physical settings we use interface concept. The Interfacing for this design is based upon the two laminar phase flow of moving mesh. To obtain the conditions for the interfacing concept we take two non miscible liquids for fluid-fluid interface and wall-fluid interface. By selecting the fluid-fluid interface in module is obtain the conditioned for two phase boundary for the design and contact angle for the module is settled by taking wall-fluid interface is clearly obtained. In fluid-fluid interface section the molecules u_1, u_2 are used in equation (i).

$$u_1 = u_2 + M_f\left(\frac{1}{\rho_1} + \frac{1}{\rho_2}\right) \text{------- (i)}$$

For easies meshing we take same properties for molecules.

i.e.,$u_1 = u_2$

After meshing is completed in two phase flow, the meshing molecules formation is as per equation (ii).

$$u_{MESH} = (u_1 u_2) - \frac{M_f}{\rho_1} n_1 \text{ -------- (ii)}$$

The Navier Slip is one of the boundary condition of two phase boundary; it must be used in the moving mesh interface for a boundary on which a contact point moves. Let assume the built molecule is neutral by taking '$u.n = 0$'.

By using this condition for the navier slip the prescribed mesh is deformed and fixed to the boundary conditions of upper and lower boundaries by selecting the domains of 2 and 5 as prescribed above and it is allowed to move on the wall with three phase contact for effective focal length, but the contact angle produced at wall θ_{ew} is equal to the contact angle after switching the voltages over the fluid.

i.e, $\theta_{ew} = \theta_C$

The contact angle of a two-fluid interface with a solid surface is determined by the balance of the forces at the contact point. The finite quadrilateral elements are used for integrating the material elements for the meshing, as they are typically stiffer and its formation is plotted in figure2.

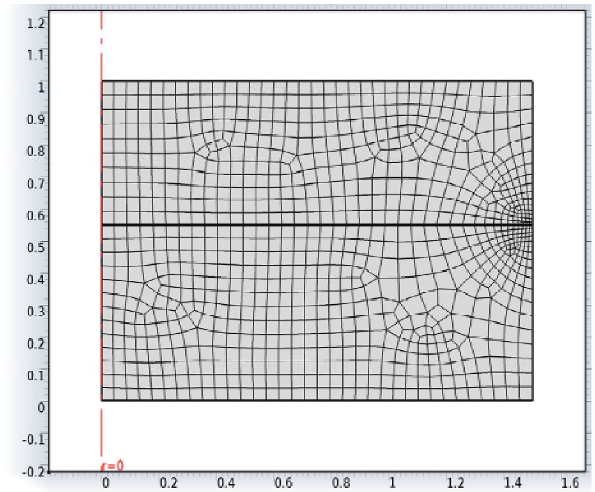


Figure 2: The webbed geometry structure

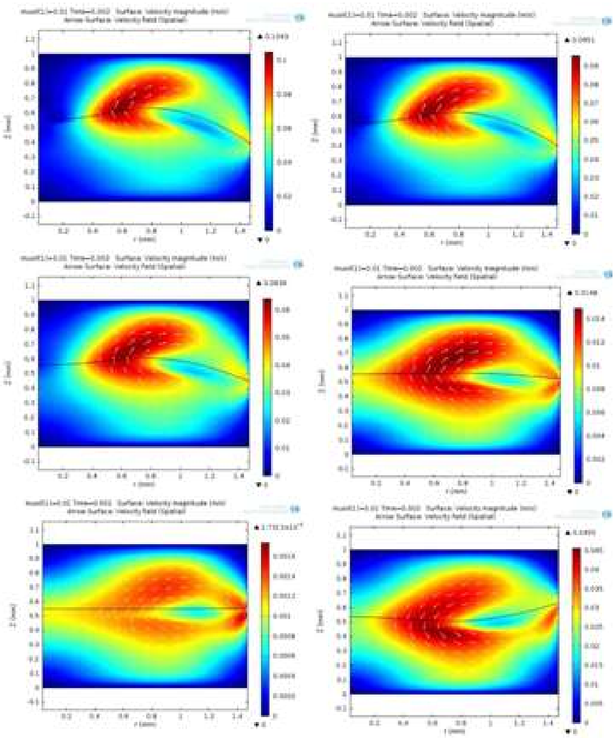
4. Simulation and Results

The final step after providing essential input potentials to the design is simulation. The simulation process of this design is carried out in two steps. Initially the parametric sweep is added to the insulating fluid viscosity and next adding an appropriate time interval to the module for ranging an oscillation of meniscus in that time. After adding the initial conditions the module is messed up by using appropriate methods and the builded module is simulated using COMSOL software and finally the result of this module is analyzed by applying different voltages on the fluid in terms to change the contact angle with the solid surface. In this model the response of the fluid surface is modeled as per given time interval after the voltage is switched from (0,120) volts. It is desired to optimize the viscosity of the insulating fluid to achieve a fast response time for the switching of the lens, by taking the insulating fluid viscosity (muoil) in between ($10e^{-3}$, $30e^{-3}$, $50e^{-3}$) and time in range (0, $1e^{-3}$, $50e^{-2}$) for clear damping of oscillations over the lens. The study of contact angle with fluid velocity and fluid pressure by switching different voltages by taking interval of 30[V] is clearly figured in the table (described below).

Table 4: output analysis

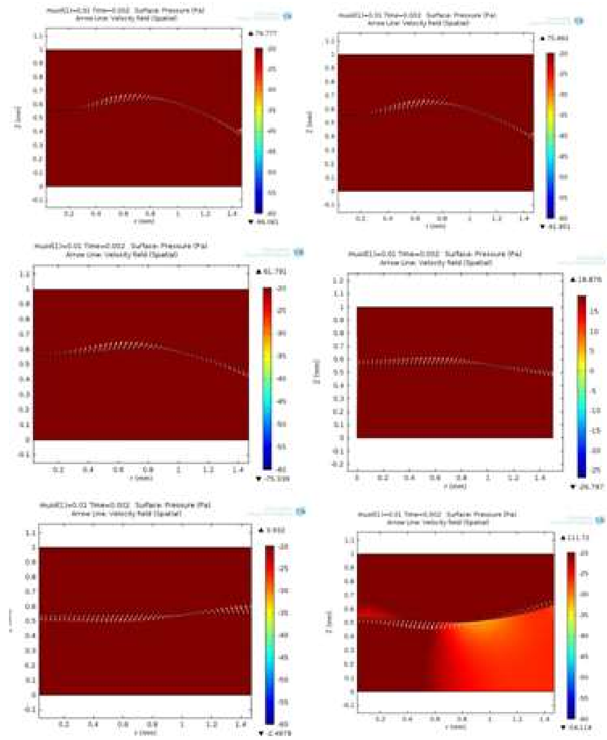
S.No	Applied Voltage [V]	Fluid Viscosity								
		muoil:0.01			muoil:0.03			muoil:0.05		
		Fluid velocity (v_1)	Fluid Pressure (p_1)	Contact Angle (θ_1)	Fluid velocity (v_2)	Fluid Pressure (p_2)	Contact Angle (θ_2)	Fluid velocity (v_3)	Fluid Pressure (p_3)	Contact angle(θ_3)
1	0	0.1043	79.777	0.0925	0.0525	67.792	0.0407	0.0403	59.596	0.0397
2	30	0.0951	75.892	0.0823	0.0492	57.895	0.0379	0.0369	47.832	0.0251
3	60	0.0639	61.793	0.0521	0.0374	51.413	0.0270	0.0273	44.721	0.0155
4	90	0.0148	18.876	0.01435	0.0105	19.656	0.0079	0.0096	19.676	0.0061
5	100	$1.713*10^{-3}$	3.932	$1.691*10^{-3}$	$1.426*10^{-3}$	8.292	$1.395*10^{-3}$	$1.189*10^{-3}$	11.165	$1.101*10^{-3}$
6	120	0.0455	111.792	0.0387	0.0342	226.43	0.0299	0.0293	308.386	0.0183

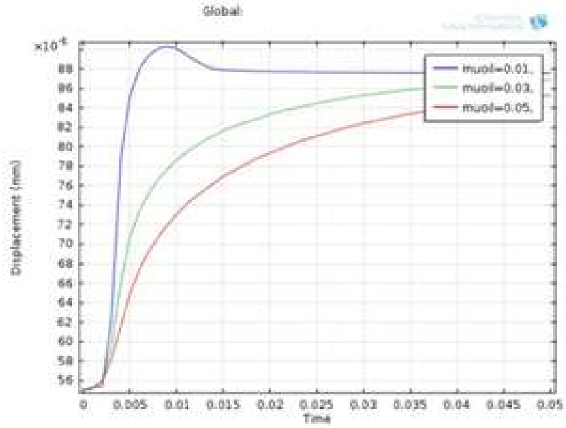
The velocity and pressure of the fluid is clearly analyzed by applying different voltages over the lens and at same time the contact angle of the lens is clearly verified and pointed the focal length of the lens. At 90[V] and 100[V] the contact angle of the lens is highly reduced (neutral), here the image of focused object is clear without any damping oscillations. The focal length of the lens is clearly represented in the below figures.

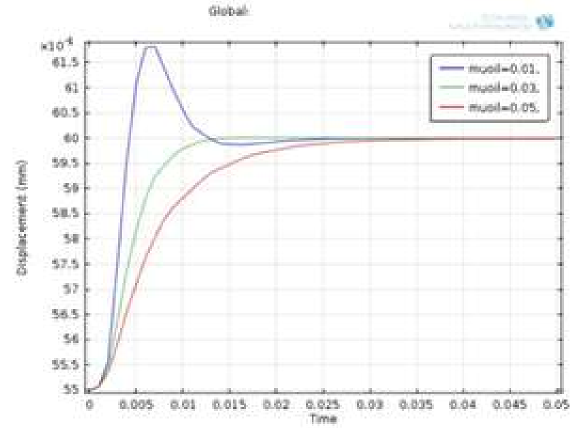


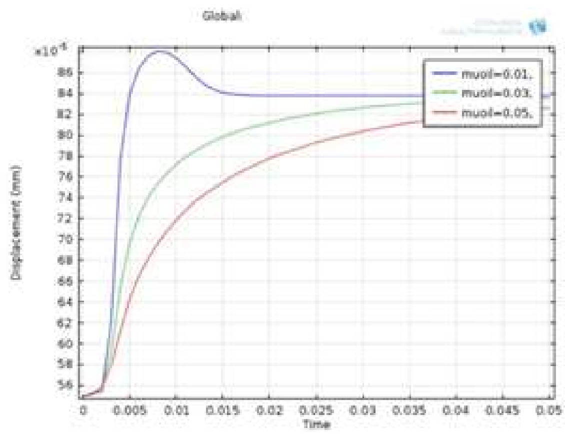
(1) Figures i, ii, iii, iv, v, vi represent the fluid velocity over the lens at different voltages 0[V], 30[V], 60[V], 90[V], 100[V], 120[V] respectively

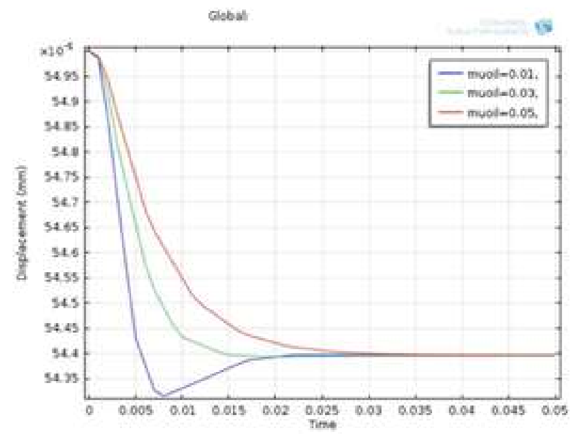
(2) Figures I, II, III, IV, V, VI represent the fluid pressure over the lens at different voltages 0[V], 30[V], 60[V], 90[V], 100[V], 120[V] respectively

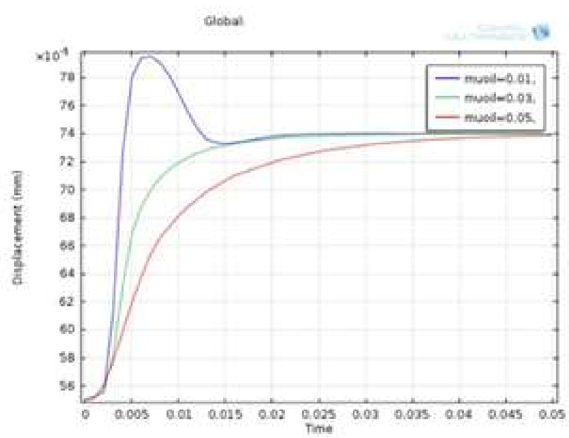


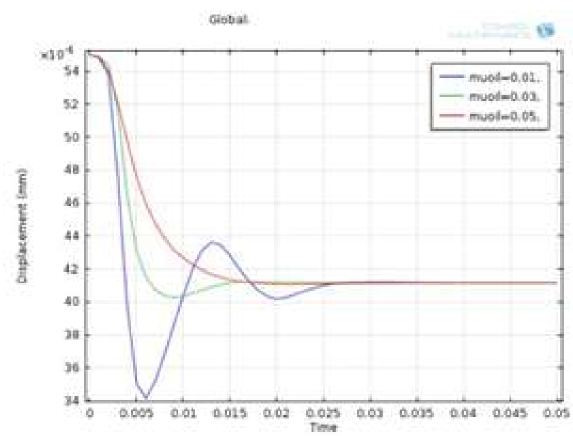












Figures 1, 2, 3, 4, 5, 6 represent the focal length of the lens at different voltages 0[V], 30[V], 60[V], 90[V], 100[V], 120[V] respectively

Clearly the high performance of the lens can be obtained due to the rapid change in oscillation of the meniscus, Because the contact angle between fluid and solid surface can be altered by changing its composition of the voltage switching over the fluid and it is possible to reduce the damping and hence to produce a lens with the fastest possible response time and higher displacement. Response of the system for three different values for the viscosity of the same insulating fluid.

5. Conclusion

Micro electro-wetting lens is designed and analyzed using OMSOL v4.3 by considering the four steps of as described in software description section. It reports the variance of focal length over the objects as based on the contact angle of the lens at various applied voltages.

The electro-wetting lenses with different conducting fluids for same insulating fluid have been designed and analyzed for their focal lengths of given input potentials. Finally, the analyses of results would help us in selecting better design to get optimum focal length for given input potentials among all the proposed designs. The concept shown in this paper can be applicable to various designs and same will be suggested for real time biomedical applications.

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