Finite Element Electromagnetic and Mechanical Analysis of Micropump

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Abstract- **Micropumps are used extensively in biomedical field and are finding its way to other areas. Development in micropumping technology is necessary, in a time where electronics is moving towards the nano scale and its conventional cooling is useless, and where the biomedical science is opting for less insidious surgical procedures and more precise drug delivery methods.**

In this paper, 3D model of a micro electromagnetic pump was created and its electromagnetic and mechanical analysis was performed. The parts of the conventional micropump were replaced with compatible MEMS materials and analysed. A 3D model of pump's diaphragm was also created using Ansys and its mechanical analysis was done with the various electromagnetic forces obtained from the electromagnetic analysis. These analysis were done with first the diaphragm material as Polyimide and then as PDMS. Comparisons were also performed with diaphragm deflection corresponding to the various micropump configurations taken.

Keywords- **Micropump, electromagnetic, diaphragm, Polyimide, PDMS, AlNiCo**

I. INTRODUCTION

Pumps with their dimensions in the micrometer range are called micro pumps. There is a growing interest on these types of pumps due to their potential cost, overall miniaturized size, and improved accuracy in dosing, compared to existing miniature pumps, especially in biomedical field and cooling of microelectronic components.

In this paper, a 3D model of micro electromagnetic pump was modeled using Ansoft Maxwell 16.0 software. The electromagnetic force acting on the diaphragm of the pump at various currents was obtained by electromagnetic analysis using the same software. From this analysis, the optimum value of current for maximum force on the diaphragm was obtained. Then, the magnet and diaphragm of micropump were replaced with materials AlNiCo and Polyimide respectively for finding out the performance of these materials in micro pumps. 3D model of the diaphragm is modeled and analyzed using Ansys 15.0 software. Mechanical analysis was also performed by replacing diaphragm material with PDMS. Various diaphragm deflections obtained at different electromagnetic forces were found out and compared to obtain the optimum current for a particular deflection.

II. STRUCTURE OF MICROPUMP

The modeling of the micro electromagnetic pump and the parameters was based on the design and modeling factors from journals [2], [3] and [4]. The micropump should have the following parts:

A. Diaphragm

The diaphragm should be flexible, and must have high yielding strength. It must provide a safe and efficient pumping effect even under resonance conditions andcan be made in various shapes. Commonly used shapes are circular, square, rectangular etc. The best suited shape for the required purpose must be selected.

B. Micro Coil

The basic coil design parameters include the inner and outer radius of the coil, the spacing of the turns, and the cross sectional area of the conductor material. The objective here is to create a coil with minimum number of turns and minimum number of coils and optimize inner radius, outer radius, and width of the coil. The best material for coil is copper.

C. Magnet

When specifying appropriate dimensions for the magnet, it is necessary to design a magnet of sufficient size which experience sufficient magnetic field to actuate the diaphragm and also it should not create any obstruction to the diaphragm movement. Commonly used magnetic materials are Iron, Nickel, and Manganese etc.

D. Valve

Valves in a micro pump refer to the inflow valve and the outflow valve. These valves may result in fluid leakage at high operating pressures. It may become clogged when biological fluids are pumped through the device. Therefore, to improve the operational performance of micro pumps and to avoid the limitations imposed by the use of mechanical components, many researchers have proposed valve less micro pump. In this paper also the valve less approach was taken.

E. Current and voltage

The value of the magnetic force generated by the actuator depends on the value of the coil input current. Input currents are in the range: 0.1–0.9 A and Voltage is around 200 V.

The diaphragm shape should be circular rather than rectangular or square to obtain the maximum diaphragm deflection, which is favourable for micropump flow. Thus, the whole micro pump assembly was chosen as circular. The micro coils were to be in a spiral shape. The materials in the initial micro pump model were selected as follows:

- Diaphragm- PDMS
- Micro coils- Electroplated copper
- Permanent magnet – CoNiMnP

In the model, the permanent magnet was attached to the bottom of the diaphragm. The coil is attached to the glass substrate under the channel of the micro pump. In a real life scenario, when current passes through the coil, it acts as an electromagnet. This attracts the permanent magnet embedded on the diaphragm, and thus the diaphragm actuates, pushing fluid through the channel.

The dimensions of the various parts in the micropump were determined after consulting the various journals:

Diaphragm radius - 1955µm

Diaphragm thickness - 70µm

Permanent magnet radius - 1222µm

Inner radius of coil - 1250µm

Outer radius of coil - 1825µm

Thickness of coil - 20µm

Spacing between coil – 57.5µm

Number of turns in the coil - 10

Current applied – 0.1 to 0.9A

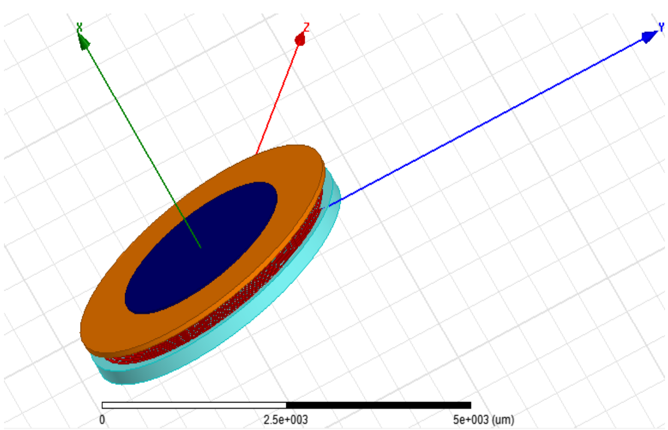

Fig. 1 3D view of modeled micro pump

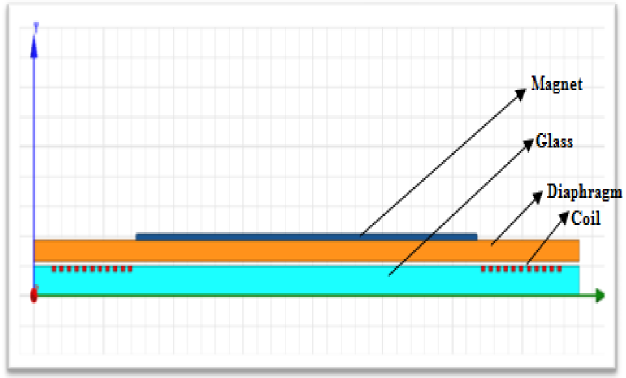

Fig. 2 Elevation of modeled micro pump

III. ELECTROMAGNETIC ANALYSIS OF INITIAL MICROPUMP MODEL

For the initial analysis, a 3D model of micro pump was drawn in Ansoft Maxwell 16.0 software using the dimensions and parameters obtained from study. The material properties are shown in the table below.

TABLE 1: PROPERTIES of the SELECTED MATERIALS

Part	Material	Relative Permeability (H/m)	Bulk Conductivity (Siemens/m)	Magnetic Coercivity (kA/m)
Coil	Copper	0.999991	58000000	0
Diaphragm	PDMS/ Polyimide	1	0	0
Magnet	CoNiMnP	1.88	0	93

After analyzing and plotting the electromagnetic forces for various values of current, it was found out that the total electromagnetic force increased with increasing current. Based on the different electromagnetic forces, maximum obtained value was 112.28µN at a current of 0.9A. The distribution of electromagnetic field lines around the magnet and the field intensity can also be obtained from this analysis using the above said software. The various values of force obtained at different current can be obtained from the graph plotted during the electromagnetic analysis which is shown in fig. 3

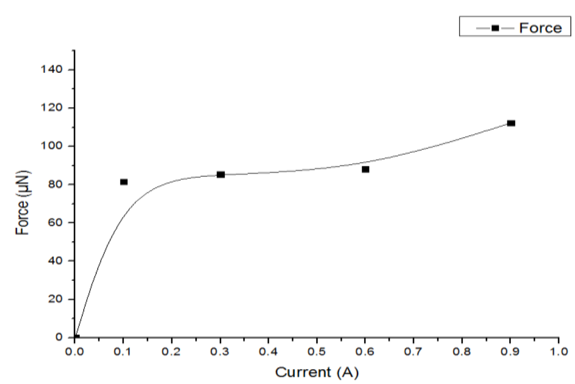

Fig. 3 Plot of force vs. current obtained after electromagnetic analysis

IV. ELECTROMAGNETIC ANALYSIS OF MODIFIED MICROPUMP

After the electromagnetic analysis of the initial model of micro pump, the materials used for magnet was replaced with compatible MEMS materials. The dimensions of the pump remained same.

The magnet material is replaced with AlNiCo. After the modeling of the micro pump with this variation, two analyses were done. In the initial analysis, the diaphragm material was PDMS and in the second analysis it was Polyimide. The change in diaphragm material doesn't influence the force exerted by the magnet on diaphragm but the change magnetic material exerted greater force on the diaphragm for the same current applied. The influence of change in magnetic material for the same current applied is shown in fig. 4

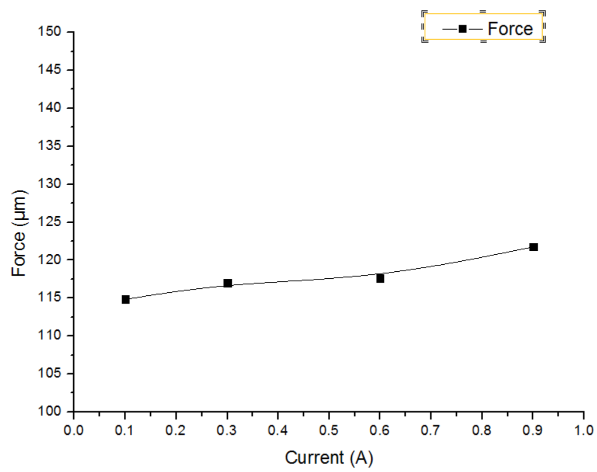

Fig. 4 Force vs. current when magnetic material is AlNiCo

After analyzing and plotting the electromagnetic forces for various input current, it was found out that the total electromagnetic force increased with increase in current, which was similar to the initial micro pump model. The maximum obtained electromagnetic force was 121.73µN at a current of 0.9A, which was greater than the 112.28µN when magnet material was CoNiMnP.

V. FINITE ELEMENT ANALYSIS OF MICROPUMP DIAPHRAGM

The electromagnetic force acts on the diaphragm, causing its deflection. Hence, only the diaphragm is considered for the structural analysis. The 3D model of the diaphragm is created using Ansys 15.0. The dimensions of the diaphragm were same as the analysis from Ansoft Maxwell 16.0.

The Finite Element analyses were first performed with materials as mentioned in Literature [2]. Then the material for diaphragm was replaced with Polyimide and the magnet as CoNiMnP. Then the diaphragm material is replaced with PDMS and magnet as ALNiCo. The magnitudes of electromagnetic forces exerted on the diaphragm were obtained from the electromagnetic analysis performed earlier.

A. INITIAL MICROPUMP MODEL

Initial analysis of the diaphragm is based on Literature [2], i.e.; the diaphragm material is PDMS, Coil as Copper and Magnet as CoNiMnP. After modeling the diaphragm in Ansys 15, the material was assigned. Then the structural analysis was performed. The electromagnetic force obtained at each current was given to the diaphragm and the defection obtained was found out through analysis. The magnitudes of force were obtained from previous electromagnetic analysis.

The magnitude of current applied are 0.1A, 0.3A, 0.6A and 0.9 A and the force corresponding to these value obtained from electromagnetic analysis were applied. Maximum deflection of the diaphragm was found out to be 0.24987 mm from Ansys at a force of 1112.28 µN.

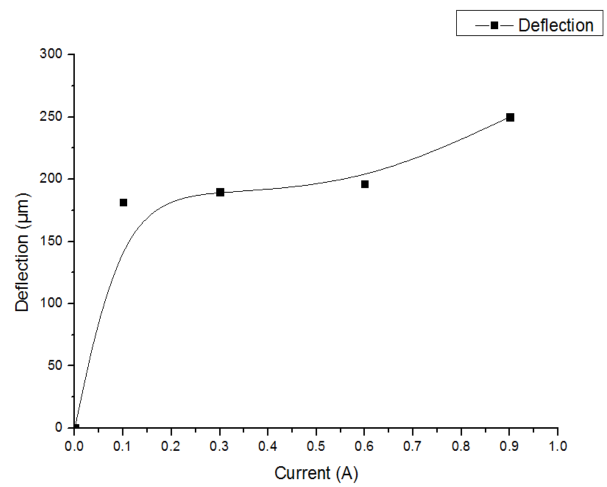

Fig. 5 Deflection vs. current when magnet material is CoNiMnP

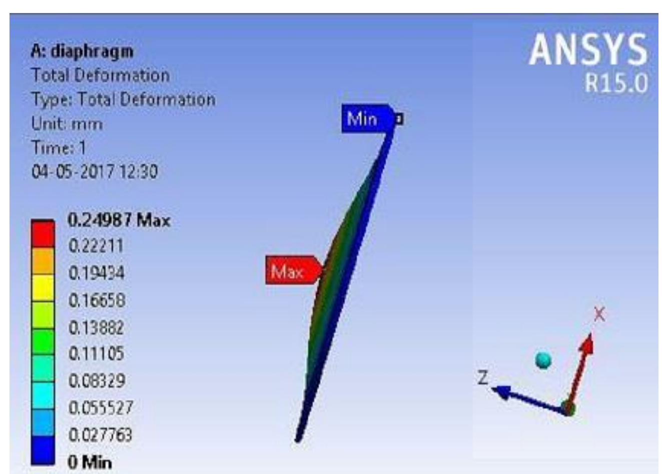

Fig. 6 Deflection of diaphragm when magnet material is CoNiMnP and diaphragm material as PDMS

B. DIAPHRAGM MATERIAL AS POLYIMIDE

Polyimide is a MEMS material with high elasticity and stiffness value. This material was selected as diaphragm material in order to check that whether the flow rate of fluid through the pump can be increased. High elasticity and stiffness means, the material can regain its shape very fast when the electromagnetic force applied on the diaphragm is removed. This will in turn help in rapid pumping action. But during the analysis it was found out that the deflection of the diaphragm is very less even at 0.9A. Maximum deflection was only 5.4031e-5 mm. This shows that the material cannot enhance the pumping ability of the micro pump. In the above analysis, the magnitude of electromagnetic force applied was those obtained from the electromagnetic analysis when the magnet was CoNiMnP.

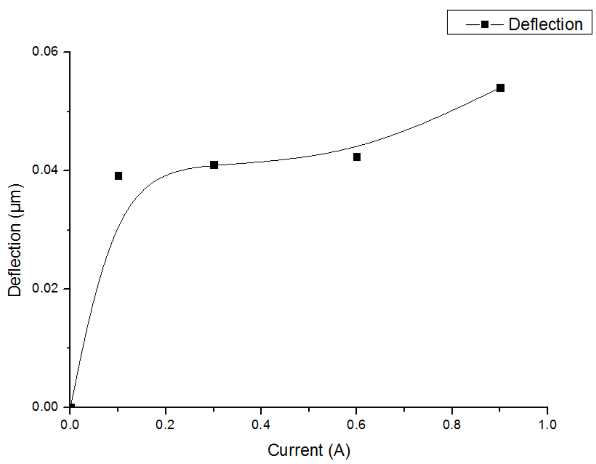

Fig. 7 Deflection vs. current when magnet material is CoNiMnP and diaphragm is polyimde

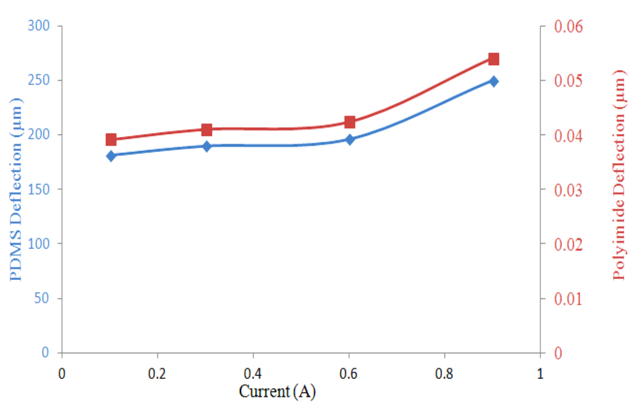

Fig. 8 Comparing the deflection vs. current value when diaphragm material as PDMS and Polymide.

When the diaphragm material is changed to polyimide, the deflection curve is as shown in Fig. 7. The deflection of the Polyimide diaphragm is so small compared to the PDMS diaphragm, so it can be neglected. Since this deflection cannot produce effective pumping action, this material and similar material cannot be chosen for the diaphragm.

C. MAGNET MATERIAL as AlNiCo

From the electromagnetic analysis, it was observed that the AlNiCo magnet is experiencing a greater force than the magnet that is mentioned in the Literature [2]. So the performance of the same micropump can be enhanced by replacing the magnet with AlNiCo.

The deflection of the diaphragm for this alteration was found out from the structural analysis of diaphragm using Ansys 15.0. The diaphragm material is not changed; it is selected as PDMS, which is mentioned in the reference journal. From the analysis it was observed that when a current of 0.9A is given to the coil, an electromagnetic force of 121.73 µN is generated and this force causes the diaphragm to a maximum deflection of 0.27086 mm.

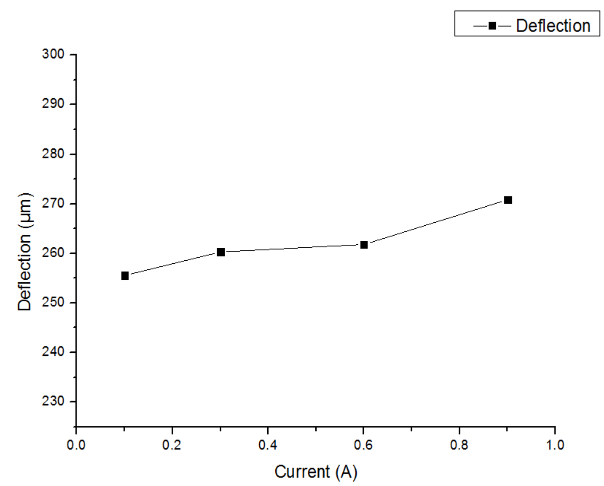

Fig. 9 Deflection vs. current when magnetic material is AlNiCo and diaphragm is PDMS.

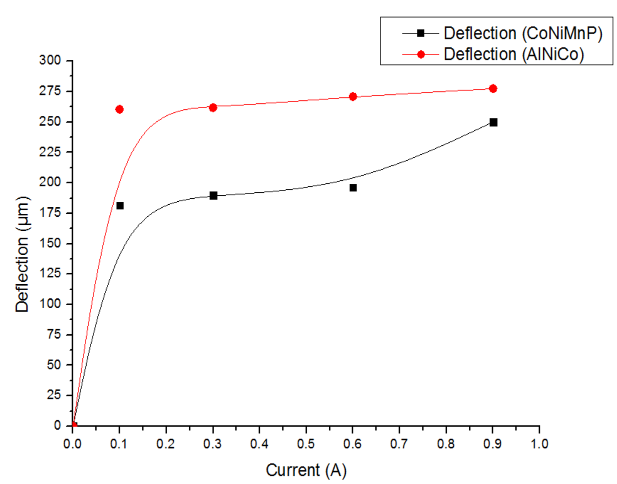

Fig. 10 Comparing the deflection vs. current value when magnet material as CoNiMnP and AlNiCo.

Fig. 10 shows the variation of diaphragm deflection with two magnetic materials, i.e.; CoNiMnP and AlNiCo, with change in the input current. From this graph it is clear that when AlNiCo is used as the magnet, diaphragm deflection is more compared to CoNiMnP. Thus AlNiCo magnet is capable of producing improved pumping action for the same applied current.

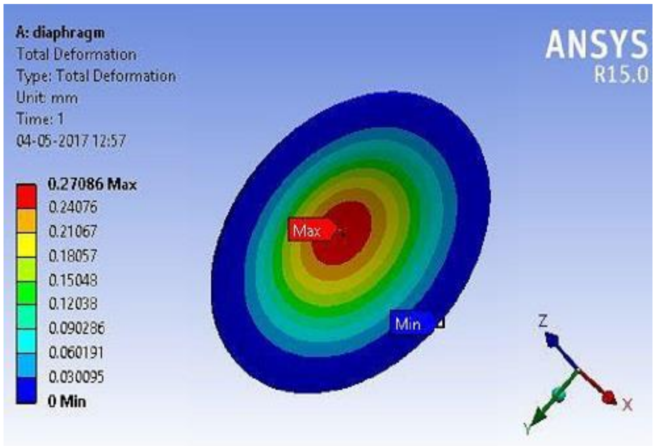

Fig. 11 Deflection of diaphragm when magnetic material is AlNiCo and diaphragm material as PDMS

VI. CONCLUSIONS

The micropump has been steadily growing with a diverse range of technical concepts, and applications. Development in micropumping technology is necessary, in a time where electronics is moving towards the nano scale and conventional cooling is useless, and where the biomedical science is opting for less invasive surgical procedures and more precise drug delivery methods.

In this paper, a 3D model of the micro electromagnetic pump was analysed. The model was validated with reference journal. Then parts of the micro pump were replaced with compatible MEMS materials and analysed. As the current increases, the electromagnetic force acting on the diaphragm also increases. Since the deflection is proportional to the applied electromagnetic force, the diaphragm deflection also increased. Considering permanent magnet materials, AlNiCo gave greater electromagnetic force compared to CoNiMnP. In structural analysis of diaphragm materials, PDMS diaphragm gave significantly more deflection compared to Polyimide.

The optimum output conditions of the pump, such as discharge, discharge pressure, and the selection of best fluid for pumping can be considered for future studies. The same electromagnetic analysis with more number of material combinations can be considered as continuation of this paper.

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