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Comparison of Polysilicon and Gallium Arsenide for Electro thermal Mems Actuator using Comsol

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***Abstract*—Silicon (Si) based Micro Electro Mechanical Systems (MEMS) are now well understood and widely used in various integrated micro machined microsensors and microactuators, In addition to this, gallium arsenide (GaAs) offers a number of material-related properties and technological advantages over Si . These include well known properties, such as direct band gap transition and high electron mobility but GsAs also offers some disadvantages due to which is it not so suitable for thermal actuator. This can be shown with the help of FEM simulation.. Heat transfer through and around these microstructures are very complex.In this paper we present an analysis of this microstructures and perform its FeM analysis using comsolmultiphysics 4.2. We have a model which is used to compare the behaviour of thermal microactuator made up from polysilicon and Gallium Arsenide.We will study the various others parameters also. With the applied voltage and varying geometrical dimension gives a clear understanding of the performance of the structure.**

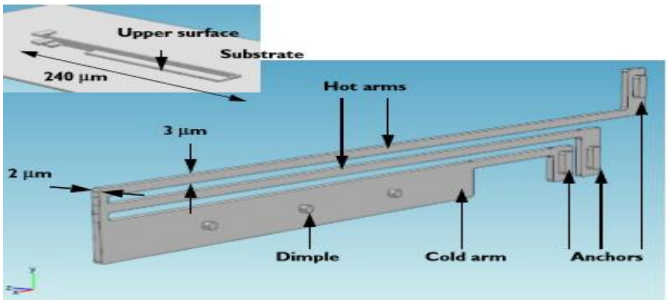
Keywords-FEM(finite element method),MEMS actuator,polysilicon ,GaAs

I. INTRODUCTION

In recent years, the Micro-Electro-Mechanical System (MEMS) technology is gaining importance because MEMS devices have superior sensing and actuating capabilities. MEMS basic include collaboration of micro electro and mechanical systems. MEMS devices like pressure sensors, accelerometers, and actuators based optical devices, micro grippers and micro motors are most useful device in MEMS currently and fabricated using Silicon micromachining technology. .The range of deflection and force provided by micro actuator increase their functionality in microsystems.[1] A various electrically driven actuators have been investigated for producing a large force and displacement in MEMS . The most common actuation modes are electrostatic and thermal expansion based actuators. It has been experimentally found that, force produce by electrostatic actuator tends to be small, and for large displacement, it is necessary to applied large voltage or change the geometry of the actuators. Electro thermal micro actuator provides an easily controlled micro-actuation method compatible with standard microelectronics. The basic two-arm electro thermal actuators design uses the principle of Joule heating for thermal expansion and movement.The potential application of electrothermal actuators includes optical switching ,microgrippers and micro robotic application . There are many types of thermal actuators developed for various applications, mainly are U shaped ,Vshaped and bimorph thermal actuator. Amongst them U shaped are more common type of actuators. It is basically based upon the principle of joule heating of thermal expansion which says when voltage is applied to the achor.pads that leads to temperature difference and cause thermal expansion which eventually leads to deflection in the arm.[3] In present work I basically work on the material used to manufacture u shaped thermal actuator. I performed its FEM simulation on comsolmultiphysics 4.2. I try to explain the behaviour of thermal actuator by using material GaAs. Usually we emphasize on displacement of the actuator by applying voltage across its anchors.but we come to know that there are lot of other parameters which greatly determine whether the given material can be use for actuator or not which is congregation of all the properties of the given material. Presently compare the FEM results of thermal actuator by using materials poly silicon and GaAs and get to know which one yeilds better results. Also,in order to improve the performance of thermal actuator specifically mechanical motion, a better way is to vary the geometrical parameter of the structure rather than change the applied voltage. This works includes variate the materials and its properties to get the desired results

II. MODEL DEFINITION

The defined model in the comsol has shown in the Fig 1 below taken from the [3]



BOUNDARY CONDITIONS

An electric potential is applied between hot arm anchors and cold arm anchors. All other surfaces are electrically insulated. The temperature of bases of these anchors and rollers are fixed to that of substrate..Because structure of this thermal actuator is sandwiched between sorrounding by conduction through thin layers of air. This can be implemented as thermal contact condition or 'convective

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heat flux' where heat flux coefficient represent one over the thermal resistance[3].In this model we used heat flux condition. The heat transfer coefficient is given bythermal conductivity of air by distance of surrounding surfaces for the system.

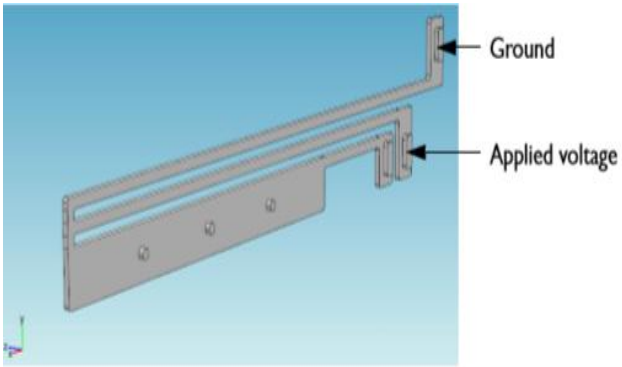

Fig 2 Electrical boundary conditions[3]

All three arms are mechanically fixed at three ends.The rollers can move freely in the plane of substrate xy but they cannot move in direction perpendicular to the substrate.

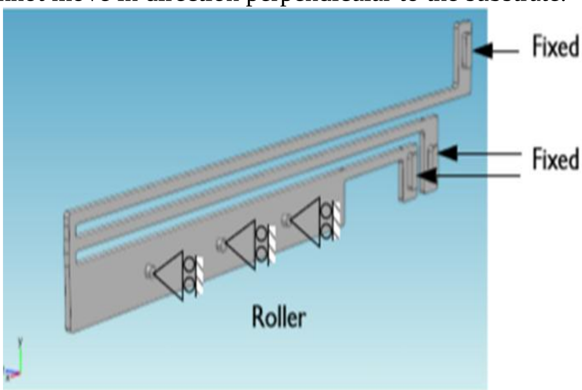

Fig 3: Structural boundary conditions and constraints[3]

DESIGN CONSIDERATIONS

The proposed model has been designed using CAD software,Comsolmultiphysics 4.2. The proposed model has following parameters.[2]

NAME OF PARAMETER	EXPRESSION	DESCRIPTION
HH	3[UM]	HEIGHT OF HOT ARM
HC	15[UM]	HEIGHT OF COLD ARM
GAP	3[UM]	GAPS BETWEEN ARMS
WB	10[UM]	WIDTH OF BASE
WV	25[UM]	DIFFERENCE
L	200[UM]-300[UM]	LENGTH OF THE ACTUATOR
L1	L-WB	LENGTH OF LONGEST ARM
L2	L-WB-WV	LENGTH OF HOTTEST ARM
L3	1-2*WB-WV- L/48-L/6	LENGTH OF COLD ARM THICK PART
L4	L/6	LENGTH OF HOT ARM THIN PART
HTC_S	0.04[W/(M*K)]/2[UM]	HEAT TRANSFER COEFFICIENT
HTC_US	0.04[W/(M*K)]/10[UM]	HEAT TRANSFER COEFFICIENT UPPER SURFACE
DV	5[V]	VOLTAGE APPLIED

[UM]= Micrometer

(A)Design of thermal actuator

The Simplified model for propose thermal microactuator is shown in Fig. 1. This thermal actuators consist of thinner arm is called as the hot arm and the wider arm is called as cold arm where each beam have different dimension but same materials is used for actuator beams. In this structure, both cold and hot arms are fixed at anchor one end and another end free to move . When voltages are applied across the anchors , current is passed through the actuator from anchor to anchor, and the hot arm is heated to higher temperature than the cold arm due to the resistance difference.[5] The temperature difference causes the hot arm to elongate more than the cold arm, thus resulting in lateral actuation toward the cold arm side. The comsol CAD model is shown below

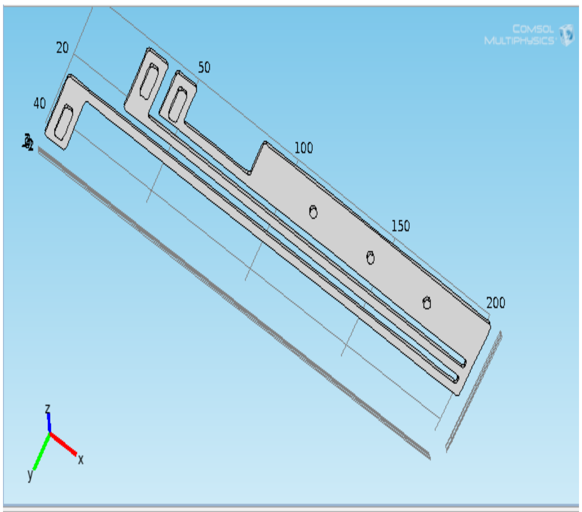

Fig 4.Comsol model of thermal actuator

Material properties of polysilicon[6]

Coefficient of thermal expansion	alpha	2.6e-6[1/K]
Heat capacity	Cp	678[J/(kg*K)]
Relative permittivity	Epsilonr	4.5
Density	Rho	2320[kg/m^3]
Thermal conductivity	K	34[W/(m*K)]
Electrical conductivity	sigma	5e4
Young modulus	E	160e9GPa
Poisson ratio	Nu	0.22

Material properties of GaAs

Coefficient of thermal expansion	Alpha	5.7e-6[1/K]
Heat capacity	Cp	550[J/(kg*K)]
Relative permittivity	Epsilonr	12
Density	Rho	5316[kg/m3]
Thermal conductivity	K	33 W/(m*K)]
Electrical conductivity	Sigma	1e5
Young Modulus	E	89.9e9G[Pa]
Poisson ratio	Nu	0.31

These materials are classified as MEMS materials These seven properties are desirable to analyse the performance of electrothermal MEMS actuator. If we compare the properties of these material, .poisson ratio is lower in polysilicon as compared to other materials.More,thepossion ratio,.softer the material is. If we sum up all the properties of these two materials.,then we will come to know that which material is better for our thermal actuator. This can be prove after performing FEM simulation.

RESULTS AND DISCUSSION

In order to analyse the behaviour of the actuator using material polysilicon and GaAs using comsol 4.2, we have applied voltage across its anchors at its different length and then compare the values of its different parameters

First we applied 5 V across the arm anchors which are fixed to the substrate.

(a) Displacement of the actuator

Length of the actuator	Polysilicon	GaAs
200[um]	1.2[um]	5[um]
250[um]	1.4[um]	6[um]
300[um]	1.6[um]	7[um]

These result implies that with varying in actuator length, displacement of actuator increases which are valid results. But if we observe the displacement of GaAs which are unreliable .At this much actuator length we get extra needed displacement which is not desirable.This is because GaAs has lesser values of poisson ratio and Young Modulus that makes it not suitable for use in mechanical motion or for loading purposes.

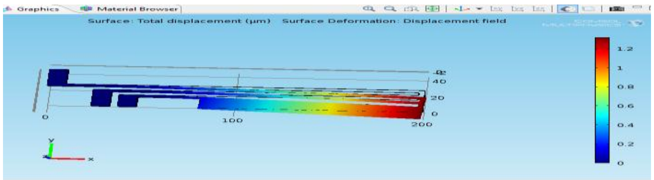

Fig.5

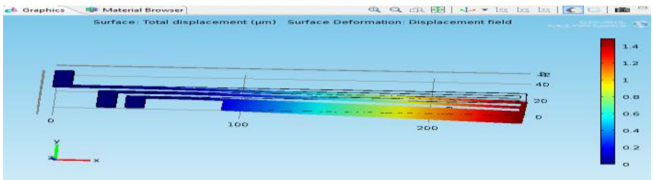

Fig.6

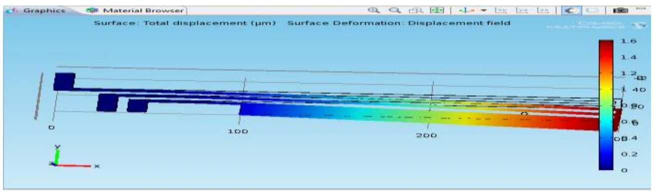

Fig.7

All three figures from fig 5 to fig 7 are shown displacement of the actuator at different actuator length of polysilicon which implies that displacement of actuator increases with increase in the length of actuator i.e geometrical variations have huge impact on its performance.

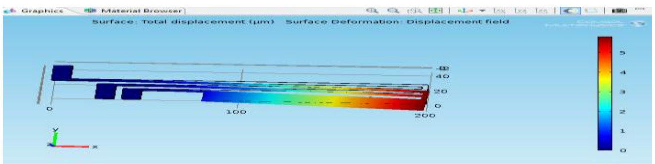

Fig.8

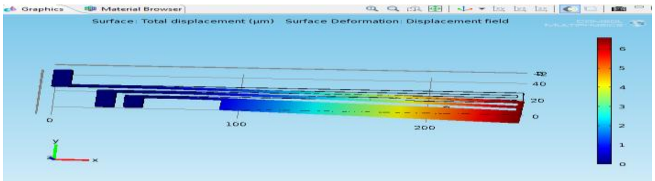

Fig.9

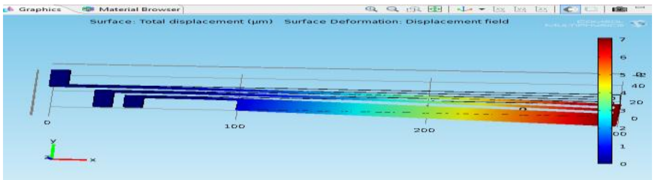

Fig.10

These figures represent the displacement of actuator using GaAs material which shows surge in its displacement values.

(b) Volumetric strain in the actuator

Again with the same applied voltage we computed the values of strain in the actuator at different length of the actuator

Length of the actuator	Polysilicon	GaAs
200[um]	2.5 *10^-3	12*10^-3
250[um]	1.5*10^-3	8*10^-3
300[um]	1.2*10^-3	5*10^-3

From these values of volumetric strain we obsreved that GaAs produces much larger strain that polysilicon which implies that GaAs is more flexible as compared to polysilicon.

Volumetric strain profiles are simulated in comsolmultiphysics

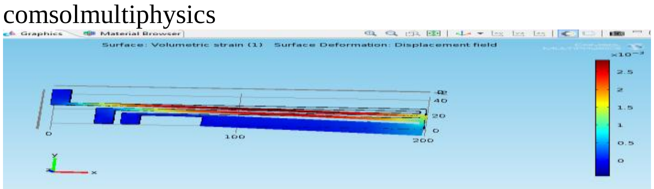

Fig.11

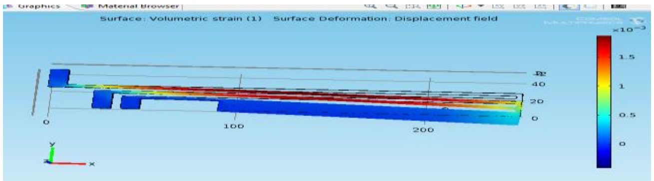

Fig.12

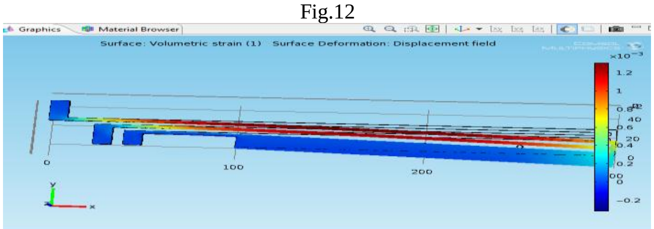

Fig.13

Figure 11 to 13 shows the volumetric strain profiles of polysilicon actuator at different actuator length

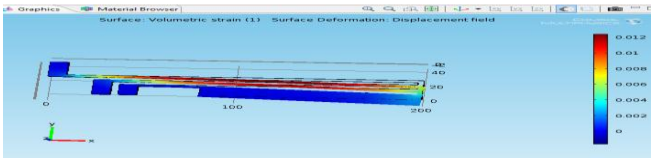

Fig.14

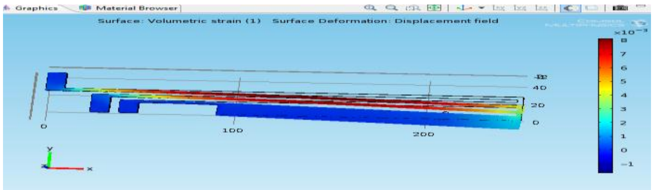

Fig.15

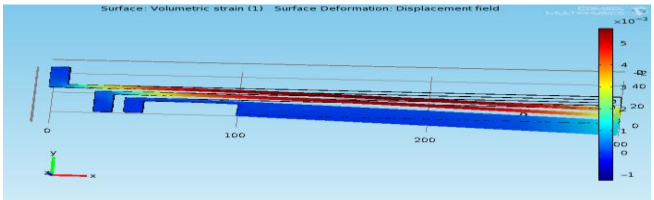

Fig.16

c) Power dissipiation density of the actuator

The power dissipiation density of the actuator made up of Polysilicon and GaAs found using comsolmultiphysics at different length of actuator

Length of actuator	polysilicon	GaAs
200[um]	3.43*10^13	6.887*10^13
250[um]	2.13*10^13	4.227*10^13
300[um]	1.44*10^13	2.89*10^13

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(d) Von mises stress of the actuator

The von mises stress is used tocheckwhether the design can withstand a given load condition

The von mises stress values of actuator made up of polysilicon and GaAs found using comsolmultiphysics at different length of actuator.

Length of actuator	Polysilicon	GaAs
200[um]	1.22*10^8	3.06*10^8
250[um]	0.875*10^8	2.17*10^8
300[um]	0.65*10^8	1.62*10^8

Graphical comparison of different parameters of both the materials shown below in following graphs

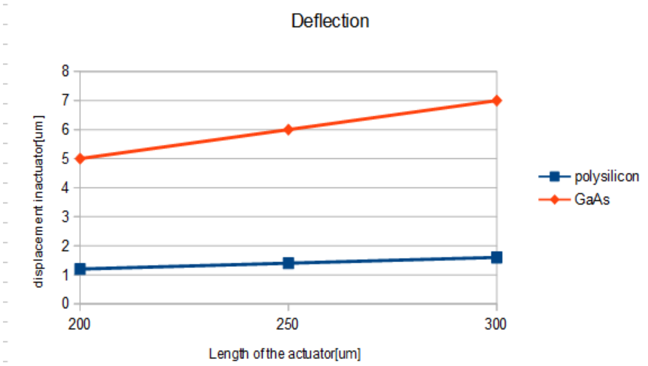

Fig: 17 Length vs displacement

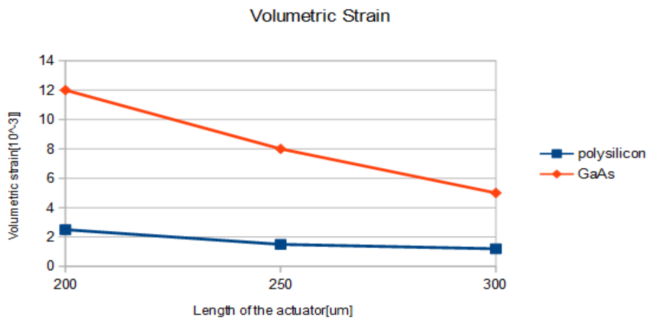

Fig:18 Length vs volumetric strain

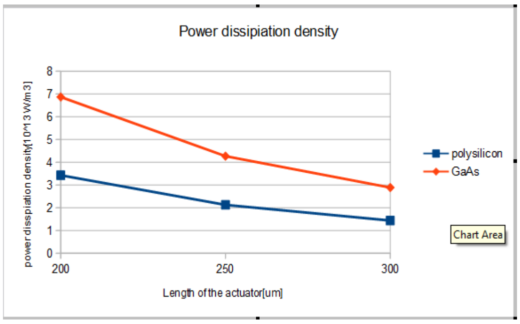

Fig:19 Length vs power dissipation density

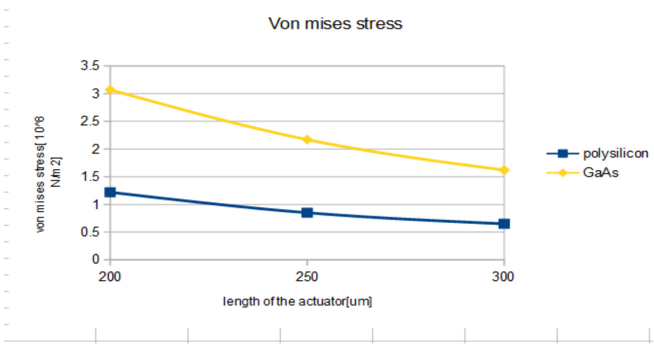

Fig 20: Length vs von mises stress

It is observed that as the length of the actuator increases the tip deflection or displacement of the actuator also increases which implies that for the greater tip deflection ,we have to increase that actuator length but from the graph we infer that GaAs shows anomalous behaviour. GaAs shows gaint deflection for same applied voltage. So we cannot consider the material for electrothermal actuator on the basis of displacement. We considered some other parameters also.

If we consider the volumetric strain values for both the devices,GaAs shows more volumetric strain which is not fit for the actuation purposes. Also power dissipation density of GaAs is greaterthan polysilicon and same follows forthe von misesstress.Thus we can anticipate that GaAs cannot be used for actuation purposes although it shows greater displacement than polysilicon.

CONCLUSIONS

Three arm thermal actuator with two hot and one cold arm is simulated using the comsol/Multiphysics software.The results are different for different actuator length and results are improvised if we increases the actuator length. But we have to maintain the value of voltage applied and length of the actuator if we want better results.Only increasing the length will increase the resistance and more strains induced in them. So The appropriate length of the actuator is between 200[um] to 250[um] for better results.GaAs induced more power dissipation density as compared to polysilicon It is observed that von mises stress of GaAs is greater than Polysilicon which eventually leads to the breakdown of the actuator.

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[6] Modelling and Simulation of three Arm Electrothermal Actuator using Comsol B. Jyoti* and Dr. S.V Halse** *Assoc. Prof. Department of Electronics, Bi Bi Raza Degree College for Women, Kalaburagi, Karnataka, India **Chairman, Department of Electronics, Karnataka state women university, Vijayapur, Karnataka, India,2016