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DESIGN OF VACUUM CHAMBER TO REMOVE STICTION PROBLEM IN POLYMER MICROSTRUCTURE

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ABSTRACT

The motivation for this thesis is the desire to overcome the problem associated with reliability and yield of these staggeringly small devices called MicroElecro Mechanical System (MEMS).The field of Microelectromechanical system involves the interaction of the physical environment with electrical signals through the use of micro batch fabricated devices. MEMS are an emerging technology which finds applications in diverse fields such as automotive medicine aeronautics communication and defense. The device dimensions range well into the micrometer regime and are soon approaching the length scales studied by nanotribologist though the MEMS technology has made a substantial impact over the past decade at the device or component level, it has yet to realize a wide range commercial success. Stiction, adhesion, friction and wear seem to be main deterrents to their lifetime, and hence full commercialization of these devices. These problems can be attributed to the high surface to volume ratio, substantial solid surface nano contacts, close proximity of microstructure and a myriad other device complications.

Several researchers have come up with solutions to avoid release -related stiction, but in use stiction and friction still persist, proving detrimental to the life span of these microstructures. Though a variety of engineering solutions have been employed to solve them . In this study ,an attempt is made to remove stiction by sublimating the resin via low melting point liquid t-butyl alcohol. An experimental setup is developed such that the microstructure would be rinsed by t-butyl alcohol directly by sublimation, to maintain the temperature peltier chips are used as they are pretty small and available and create freezing temperature.

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Key words : *MicroElecro Mechanical System (MEMS), nanotribologist , Stiction, t-butyl alcohol.*

1 INTRODUCTION

1.1 Significance

Microstructure is defined as the structure of a prepared surface or thin foil of material as revealed by a microscope above 25X magnification. The microstructure of a material (which can be broadly classified into metallic, polymeric, ceramic and composite) can strongly influence physical properties such as strength, toughness, ductility, hardness, corrosion resistance, high/low temperature behavior, wear resistance and so on which in turn govern the application of these materials in industrial practice. In particulars, Micromechanical and micro fluidic components made of polymer materials play an important role in biomedical microchips because they can effectively manipulate fluids or solids at small scales while having minimal chemical interferences with biological subjects.

When two nominally flat surfaces with asperities and valleys are placed in contact, surface roughness causes contact to occur at discrete contact spots. The sum of the areas of all contact spots constitutes the real area of contact or simply contact area, which is a small fraction of apparent area. The load is supported by the deformation at the tips of the contacting asperities. The proximity of the asperities results in adhesive contacts caused by inter atomic attractions. In a broad sense adhesion is considered to be either physical or chemical in nature. Experimental data suggest that adhesion is primarily due to due to weak van der waals forces. Because of adhesion or bonding across the interface a finite normal force is required to pull the two solids apart. If there is a liquid present and it wets the surface, the surface is referred to as hydrophilic, and if it does not wet, the surface is referred to as hydrophobic.

Polymeric solids are used in many industrial applications where inherently low adhesion, friction and wear is desired. Interaction of polymeric solids primarily results in van der waals attraction. There are other factors involved with polymers. First these materials are easily deformed by comparison with the other hard solids. With soft rubbers for example, large areas of intimate contact can easily be established; consequently, although the interfacial forces themselves are weak, it is not difficult to obtain relatively high adhesive strengths. A similar factor probably accounts for the strong adhesion between sheets of thin polymeric films. Furthermore, being highly elastic solids they can stretch appreciably under the influence of released elastic stresses without rupturing. Secondly inter diffusion of polymeric chain across the interface may occur. This will greatly increase the adhesive strength since valence bonds as distinct from van der waals bonds, will be established. Third for dissimilar materials, charge separation may lead to an appreciable electrostatic component.

Thus the polymer microstructures have to be rinsed to clear this substrate, but while rinsing many process fail to retain the shape of the microstructure due to surface bonding van der waals forces which cause adhesion and resulting to the collapse of the structure thus a method which would help retain the shape of the polymer microstructure is studied and experimented by defining the following problem statement.

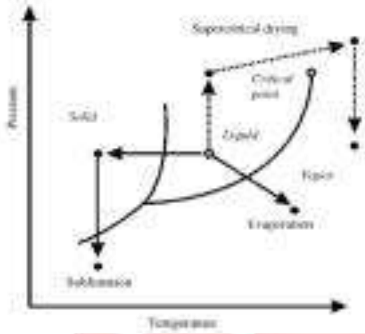

Fig. 1.1 Figure shows different way of changing liquid to vapor i.e. Sublimation, Evaporation and super critical drying.

1.2 Problem statement

With the capability of building structures in an additive layer by layer process at micrometer scale, micro-steriolithography (µSL) enables the fabrication of highly complex, three dimensional microstructures which is critical to the development of advanced micro electro-mechanical system devices inspired by the rapid prototype technique Ikuta first introduced the stereo lithography technique into micro scale fabrication. There are several distinct advantages making this method a unique and promising technique for 3D micro fabrication. After photo fabrication, un-polymerized resin has to be rinsed out to obtain the free standing 3D structures. Strong capillary force will be developed during the final evaporative drying which deforms the microstructures and cause the adhesion and collapse of polymer structures. The phenomena have been referred to as “stiction”, a problem that has been studied. If the adhesion energy is not strong enough to withstand the restoring elastic force, the deformed structures will be bounce back to original shape.

1.3 Objectives

There are several method to reduce the stiction problem thus,

1. Primary objective was to choose a proper method to rinse the microstructure, and choosing low surface tension liquid (t-butyl alcohol) to rinse the microstructures is one of the options. This will decrease the capillary force developed during evaporation. If the surface tension induced capillary force is not strong enough to attract the microstructures contact each other or touch to the substrate, stiction will not occur. Therefore, no surface tension induced capillary force will developed during drying.
2. We’ll take the sublimation approach to address the stiction problem, because it is easy to access and can be optimized for µSL. For this a setup is developed containing a vacuum chamber to hold the liquid and the microstructure along with the process that would rinse the microstructure by sublimation. Temperature will be maintained with the help of peltier chip and the required temperature at which the entire liquid will sublimate rinsing the microstructure will be noted as shown in Fig 1.1

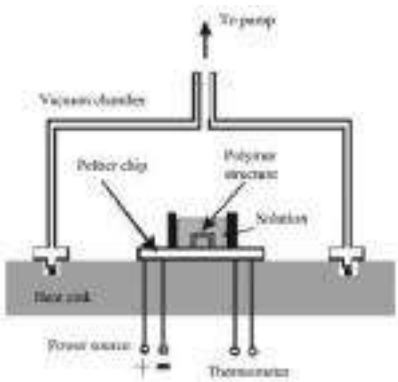

Fig. 1.2 Shows setup for the experiment

2 LITERATURE REVIEW

2.1 Introduction

Following were the literatures studied to define the problem statement and confine the objectives. First few papers talk about micro fabrication, stereo lithography and later adhesion problems, stiction and methods to remove it.

2.2 Literature Related to Microstructure formation and Adhesion Removal

Chemical role of oxygen plasma in wafer bonding borosilicate glasses, D M Hansen et al. used Borosilicate glass (BSG) layers deposited by low pressure chemical vapor deposition treated with an O_2 plasma in reactive ion etching mode for 5 min at 0.6 w/cm² and rinsed with DI H_2O readily bond to Ga As and Si.

Real three dimensional micro fabrication using stereo lithography and metal molding. Ikuta. K, A technique for three dimensional micro fabrication using stereo lithography is proposed. It is called the IH process (integrated hardened polymer stereo lithography) and is suitable for microstructures made of both polymer and metals. The experimental apparatus developed and the fabrication of various 3-D microstructures, such as bending pipe, micro coil spring, and one way valve, are described.

Stiction problems in releasing of 3D microstructures and its solution, Dongmin Wu. In this work, a theoretical model is developed to analyze the deflection and adhesion between thin polymer beams under capillary force. The detachment length of the test structures and adhesion energy of a typical µSL polymer (HDDA) are obtained experimentally which are important for MEMS structure design. Finally, we successfully developed a sublimation process to release the 3D microstructures without the adhesion.

Determining the optimal PDMS bonding technique for micro fluidic devices, M A Eddings et al. did optimal test conditions of 700 m Torr chamber pressure, 20 W RIE power and a 30 s exposure time were obtained from oxygen plasma bonding studies.

Evaluation of bonding between oxygen plasma treated polydimethyl siloxane and passivated silicon, K C tang et al. his study presents improvement in bonding quality of polydimethyl siloxane to passivated silicon using oxygen plasma treatment and also present analysis of the bonding quality. Four types of passivated silicon were used: phosphosilicateglass,undoped silicate glass, silicon nitride and thermally grown silicon dioxide. Bonding strength was evaluated qualitatively and quantitatively using manual peel and mechanical shear test respectively. Through peel test it is observed that the lowering of plasma pressure from 500 to 30 mTorr and using a plasma power between 20 to 60 W and duration 10 s helped to improve the bond quality for the first three types of passivation.

Method of fabrication anti-stiction micro machined structures, US 6815361 B1, patent for a method of fabricating micro-electromechanical system (MEMS) structures that can prevent stiction between a microstructure and a substrate or adjacent structures after etching for releasing the microstructure is provided. In a micromachining process for fabricating a microstructure suspended above a substrate using a sacrificial layer, which can be removed by dry etching, before or after stacking a sacrificial layer.

Stiction in surface micromachining, TasNIels et al, This is possible by coating the device with weakly adhesive materials, by using bumps and side wall spacers and by increasing the surface roughness at the interface. Capillary condensation should also be taken into account as this can lead to large increases in the contact area of roughened surfaces.

Vapor phase anti stiction coatings for MEMS, Ashurst, W.R, research is aimed at the development of vapor phase anti stiction processes that yield comparable or better films than their corresponding liquid phase processes. To date a variety of monolayer system that have been well established via liquid ahase deposition processes have been adapted to vapor processes. In this paper, surrent trends in anti stiction technology and a discussion of available vapor phase anti stiction methods are presented.

Adhesion and Stiction: Mechanisms, measurement techniques and methods for reduction, bhushan, B. Solid-Solid adhesion occurs at contacting asperities in two contacting solids. A thin liquid film with a small contact angle, present at the interface, can result in the so called liquid-mediated adhesion. This may result in high adhesion during normal pull and high static friction during sliding, both commonly referred to as "stiction." The problem of high stiction is especially important in an interface involving two very smooth surfaces under lightly loaded conditions. This article provides a critical and comprehensive review of mechanisms of adhesion and stiction, various measurement techniques, and methods used to reduce stiction in magnetic storage devices and micro/nanoelectromechanical systems.

3 EXPERIMENTS

3.1 Introduction

This chapter deals with experiment procedure, after learning the entire literature it was time to arrange the apparatus and start the experiment. The required instruments and apparatus i.e. peltier chip, dessicator, vacuum pump, solvent, power source and microstructure were arranged as required. Experiment was performed to first check the solidification time of the solvent and then sublimation time for the solvent, thus the effective minimum time can be used to release the stiction from the microstructure.

3.2 Details of experimental Set Up: Vacuum chamber is prepared with assumed dimensions for the experiment to fit in all the required equipments, it is made up of aluminum alloy and glass. Inside it has plates made up of copper. Peltier chip is placed between two slotted copper plates inside the vacuum chamber with applying the thermal grease. Plate is fitted with the Teflon screw. One port is connected to vacuum pump with intermediate pipe. Second port is connected to vacuum gauge. Third port is for electric connection where peltier chip is connected.

Regulated DC power supply is connected to third port of electric connection where peltier chip is connected. Inlet and outlet are connected with flexible pipes to flow of water. Vacuum chamber is enclosed by fitting a glass at the top. Temperature is measured by the temperature gauge. Electric supply given to vacuum pump and regulated DC power supply as 230V AC.

3.3 Working

First we apply thermal grease at the bottom of the pot in which polymer microstructure is kept and an upper surface of the plate below which peltier chip is placed. Then a polymer microstructure with small quantity of t-butyl alcohol is kept in pot and that pot is placed in vacuum chamber.

Then vacuum chamber is enclosed properly with fitting nut bolt at the top of the chamber, so that no air is passed from inside to outside and outside to inside. Air present in chamber should go in vacuum pump and from vacuum pump to outside, while pump is electrically "ON". Supply to vacuum pump is given 230V AC. Water flow should be continuous till the vaporization ends. Vacuum pump is attached to vacuum chamber with pipe. At one port vacuum gauge is connected to control the vacuum. Now set up is ready for experiment.

Vacuum chamber is kept on the stand. Peltier chip is placed inside the vacuum chamber where design of fixing of peltier chip is provide while manufacturing vacuum chamber. Peltier chip is placed in such a way that at one surface where microstructure is going to keep should be cold. And other one is hot. There are four ports to the vacuum chamber. At one port vacuum pump is connected. At second port vacuum gauge is attached and at third port supply terminals are attached. Fourth port is for seen what is going on inside the vacuum chamber. There is one inlet and one out let which provided for water circulation. 6 mm diameter flexible pipe is used to both inlet and outlet for supply of water and exit of water. Inlet flexible pipe is used one meter because supply line of water is at short distance and outlet flexible pipe is of three meter as exit line of water is at long distance. At supply line one coupling is used to connect vacuum chamber flexible pipe of 6mm diameter and 25 mm diameter pipe of water supply. Vacuum pump is connected to vacuum chamber of which exhaust port is kept open to allow the air and any exhaust gases inside the vacuum chamber. The connection holder at two terminals where from inside the peltier chip is connected. The supply to amplifier is given 230V AC.

First reading taken only when cooling is created. That time polymer is not placed and vacuum is not created. Connections of peltier chip are connected to connection holder which is provided inside vacuum chamber. In small port t- butyl alcohol which is in liquid form gets converted into solid form. We can see that whitish ahead. In the table following reading taken as initial temperature ,voltage, current final temperature voltage current , time taken for solidification. Same readings are taken for 9 Amp, 8.5Amp, 8Amp, 7.5Amp 7 Amp.

Second reading taken vacuum and cooling is created. That time polymer is not placed. Connections of peltier chip are connected to connection holder which is provided inside vacuum chamber. In small pot t- butyl alcohol (1ml) is taken. Then it kept in vacuum chamber with setting 9.5 Amp constant current. At some time t- butyl alcohol which is in liquid form gets converted into solid. Solidification time is more in case of without vacuum than with vacuum. In case of vacuum solidification time is less. In the table following reading taken as initial temperature, voltage, current, final temperature voltage , current , time taken for solidification. Same readings taken for 9 Amp, 8.5 Amp , 8 Amp, 7.5Amp, 7Amp.

Third reading taken when vacuum and cooling is created that time polymer is placed. Connections of peltier chip are connected to connection holder which is provided inside vacuum chamber.

A polymer structure is first rinsed in water. The shape of polymer structure changed. Then it is placed in small pot in which t butyl alcohol is taken. Thermal grease is applied between the beneath of the pot in which polymer structure is kept and upper part of cold surface plate which is inside the vacuum chamber, below which peltier chip is placed. Then it kept in vacuum chamber with setting 9.5Amp constant current.

The relatively high vapor pressure of t butyl alcohol ensures a short sublimation time (less than 30 min). However, t butyl alcohol has its drawbacks: it will absorb water vapor from atmosphere and from droplet during sublimation drying. This will influence the performance of the process. Therefore special consideration must be paid for moisture control. Thus after studying the entire process, all the required things were prepared for the experiment. The following figure shows the actual experimental arrangement.

4 RESULTS:

Following table 4.1 shows the reading taken from the experiment at different time intervals,

Table 4.1: Solidification Time evaluation without vacuum

Sr. No.	Quantity of t-butyl Alcohol (ml)	Current (Amp)	Voltage (Volt)	Power (V A)	Ambient Temperature (Deg)	Solidification Time (in min)
1	1	7.5	11.3	84.75	31	No Solidification Seen even after 70-80 min
2	1	8	12.2	97.6	31	
3	1	8.5	12.9	109.6	31	
4	1	9	13.5	121.5	31	
5	1	9.5	14.8	140.6	31	

For this reading, apparatus was kept open under ambient condition, it was observed that the t- butyl alcohol absorbed all the moisture from the atmosphere hence it was difficult to solidify it even when rest things around it were getting frost. Hence no graph could be plotted with it.

Following table 4.2 shows the reading when the apparatus was kept under vacuum,

Table 4.1: Solidification Time evaluation without vacuum

Sr. No	Quantity of t-butyl Alcohol (ml)	Current (Amp)	Voltage (Volt)	Power (V A)	Ambient Temperature (Deg)	Solidification Time (in min)
1	1	7	10.8	75.6	31	20
2	1	7.5	11.3	84.75	31	16
3	1	8	12.2	97.6	31	12
4	1	8.5	12.9	109.6	31	9
5	1	9	13.5	121.5	31	5
6	1	9.5	14.8	140.6	31	3

Thus you can see the solidification time it occurred really fast compared to when kept under ambient condition. So the graph was plotted Power (V/A) Vs Time taken to frost, which can be seen

The X axis shows the time (min) taken to get the desired solidification of the t-butyl alcohol, it was seen the more you increase the power the time taken decreases.

Next, Readings were taken with keeping the polymeric structure in the chamber, it is a structure which gets wet and changes the shape, so it has to retain the shape after sublimate of t-butyl alcohol.

Table 4.1: Solidification and then sublimation Time evaluation with vacuum and with subject

Sr. No	Quantity of t-butyl Alcohol (ml)	Current (Amp)	Voltage (Volt)	Power (V A)	Ambient Temperature (Deg)	Solidification Time (in min)	Sublimation Time (min)
1	1	7	10.8	75.6	31	20	211
2	1	7.5	11.3	84.75	31	16	175
3	1	8	12.2	97.6	31	12	185
4	1	8.5	12.9	109.65	31	9	93
5	1	9	13.5	121.5	31	5	67
6	1	9.5	14.8	140.6	31	3	47

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