Fundamental MEMS, an Introduction to MicroElectroMechanical Systems (MEMS)

Texas Christian University Course ENGR 40970
The University of Texas at Arlington Course EE 5349/4328

Homework 1

(problems elaborated by Dr. Edward Kolesar)

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Problem 1 (Silicon Crystal)

(0 points)

Assemble the silicon origami handed out in the first class.
Also available as a pdf file at: http://mems.uta.edu
Note: this will require scissors, glue and calm hands and state of mind.

Problem 2 (MEMS Community)
(20 points)
A list of people who have contributed to MEMS research for many years follows: Mark Allen, Henry Baltes, Bernhard Boser, Wolfgang Ehrfeld, Miko Elwenspoek, Hiroyuki Fujita, Toshio Fukuda. Henry Guckel, Roger Howe, Tom Kenny, Greg Kovacs, Dorian Liepman, Noel MacDonald, Richard Muller, Khalil Najafi, M. "Ash" Parameswaran, Kurt Petersen, Al Pisano, Kris Pister, Nico de Rooij, Martin Schmidt, Steven Senturia, lsao Shimoyama, Bill Tang, Ken Wise, George Whitesides. For two of these individuals, find the answers to the following Questions and provide a narrative response:

1. Where do they currently work?
2. What is the major topic of their research?
3. Where do they publish their results (conferences, journals, etc.)?
4. Find a recent paper (co-)authored by them and state in one sentence the primary new result that they are reporting.

Solution / Answer:

Chosen scientists are **Al Pisano** and **Chris Pister**.

The first one, **Al Pisano**, currently works at University of California at Berkeley. He holds the FANUC Chair of Mechanical Systems and he with the Department of Mechanical Engineering as well as the Department of Electrical Engineering and Computer Science. From 1997 through 1999, he was the Program Manager for Microelectromechanical Systems, Defense Advanced Projects Research Agency.
Al Pisano's research interests are the invention, design, fabrication, modeling, and optimization of microelectromechanical systems such as microinertial instruments, microinformation storage systems, and microfluidic systems. He has over 80 refereed applications, many of them in Journal of Microelectromechanical Systems. He is attending MEMS conferences, for example IEEE International Conference on Micro Electro Mechanical Systems. One of his recent papers is:

> **Microgimbal torsion beam design using open, thin-walled cross sections** *Muller, L.; Pisano, A.P.; Howe, R.T.* Microelectromechanical Systems, Journal of, Volume: 10 Issue: 4 , Dec. 2001 Page(s): 550 -560

The paper addresses the thin micromolding process enabled the construction of microtorsional springs with unique cross sections designs by combining high aspect ratio beams with horizontal surface features like T bars, pi sections and channels

The second one, **Kris Pister** joined the faculty of Electrical Engineering and Computer Sciences at the University of California, Berkeley, as an Associate Professor in 1996. From 1996 to 1999, he was a Member of the DARPA ISAT group, and in 1997 he was chosen to be a part of the Defense Science Study Group. During the last five years, his primary research interest has been the development and use of standard MEMS fabrication technologies, microrobotics, and CAD for MEMS. He is the inventor of the polysilicon hinge, now in use by many MEMS groups around the world. Most recently, his work has been in wireless sensor networks and microoptics. He publishes his work both in journals and conferences. For example, the Journal of Microelectromechanical Systems and IEEE International Conference on Micro Electro Mechanical Systems. His recent publications were on 15^{th} IEEE International Conference on Micro Electro Mechanical Systems where he published two papers. The first one is:

> **Assembled corner-cube retroreflector quadruplet**, *Lixia Zhou; Pister, K.S.J.; Kahn, J.M.*, Micro Electro Mechanical Systems, 2002. The Fifteenth IEEE International Conference on , 2002, Page(s): 556 –559

Where a MEMS corner cube retroflector (CCR) is presented. The CCR is used as the free space optical communication transmitter in the smart dust project. The optical and electrical properties are greatly improved as compared to CCRs fabricated previously in the MUMPS process. Improvements include a tenfold improvement in mirror curvature, a threefold reduction of mirror misalignment, fivefold reduction of drive voltag, a tenfold increase in resonant frequency, and an improved scalability due to the quadruplet design.
And, the second one is:

> **Addressing the needs of complex mems design**, *Clark, J.V.; Bindel, D.; Kao, W.; Zhu, E.; Kuo, A.; Zhou, N.; Nie, J.; Denime, J.; Bai, Z.; Govindjee, S.; Pister, K.S.J.; Gu, M.; Agogino, A.*, Micro Electro Mechanical Systems, 2002. The Fifteenth IEEE International Conference on ,2002, Page(s): 204 –209

In this paper, authors report several advances in the Sugar2.0 MEMS system simulation package, including reduced order modeling techniques, simple hierarchical description of complex structures, synthesis tools, a variety of models, and a web based interface. Given examples include the modeling of a torsional micromirror with lateral actuatorscompared to experiment, and the prototyping of a microrobot.

Problem 3 (Seminal MEMS Papers - Richard Feynman)

20 points

Nobel laureate, Richard Feynman, gave his famous lecture "There is Plenty of Room at the Bottom," in 1959. Read this paper and list his predictions in two categories: (1) predictions that have come true, (2) predictions that have not come true. In category (2) mark (a) the predictions that may come true within the next decade, and (b) those that were completely unrealistic.

Solution:

Predictions that come true

Predictions that not come true

The predictios that may come true within the next decade

The predictions that were completely unrealistic

INTRODUCTION

"In the year 2000, when they look back at this age, they will wonder why it was until the year 1960 that anybody began seriously to move in this direction". **– that is true, although philosophical question.**

It will be possible to put all of the Encyclopaedia Britannica on the head of the pin. One dot will take 80 angstroms (8nm). – **I think it is possible to do something like that but I am not sure if anybody has done it. Question is: who need it just now?**

Technique (existing one) is to press the metal into a plastic material and make a mold of it, then peel the plastic very carefully, evaporate silica into plastic to get a very thin film, then shadow it by evaporating gold at an angle against the silica so that all the little letters will appear clearly, dissolve the plastic away from the silica film, and then look through it with an electron microscope. Copies will be easily done by pressing the same metal plate again into plastic and we would have another copy. **– this is not true, we have better techniques to do something like that**

HOW DO WE WRITE SMALL?

"We can reverse the lenses of the electron microscope in order to demagnify as well as magnify. A source of ions, sent through the microscope lenses in reverse, could be focused to a very small spot…" **– it is feasible, (I think something similar exists, electron beam litography)**

Improved method (61, top 1st) through the mask (not sure if exists)

Another lithography (61, middle, 1st)

120000 volumes to the library card **–I think it is feasible but I am not sure if anybody did it. We have different, cheaper techniques to do it and, therefore, we use them-** (still impossible but will be soon)

INFORMATION ON A SMALL SCALE

It will be possible to put 24 milion books on the barest piece of dust (2/100 inch) – theoretically possible - see biology and DNA **– it is possible or at least, it will be possible**

BETTER ELECTRONIC MICROSCOPE

Theoretically it is possible to make electronic microscope to resolve 0.1 angstrom (electron wave length – 1/20 of the angstrom)! Until 1960 it was 10 angstroms – **is it possible?**

All mentioned biology problems on page 62 (Structure of the RNA, DNA, organization of microsomes … etc.) are resolved.

Synthesis in chemistry – to see atoms, predict the properties of the chemical substance **– I think it is possible or, at least, they would be possible during the next decade**

THE MARVELOUS BIOLOGICAL SYSTEM

"Consider the possibility that we too, as well as nature, can make a thing very small, which does what we want – that we can manufacture an object that maneuvers at that level" **– still impossible but will be possible within the next decade**

"Much more interesting to a computer is a way of writing, erasing, and writing something else. We do not want to waste the material. Yet, if we could write it in a very small spac, it would not make any difference. It could be thrown away after reading" – **we do not have exactly this type of memory – maybe it is CD? It is cheap and read only.**

MINIATURIZING THE COMPUTER

"For instance, the wires should be 10 or 100 atoms in diameter, and the circuits should be a few thousands angstroms across" **– That's almost true and it will be true in within 10 years**

"If they had millions of times as many elements, they could make a judgements. They would have time to calculate what is the best way to make the calculation that they are about to make. They could select the method of analysis…" – addressing the artifitial intelligence, almost possible, it will be possible during the next decade. **– here, the artifitial intelligence is addressed. The computer still does not work like that (if we neglect software "intelligence") but I am sure it will during the next decade.**

"Yet, there is no machine which, with that speed, can take a picture of the face and say even that it I a man, and much less that it is the ame man that you showed it before – unless it is exactly the same picture"**– It is possible**

“The computer I am carrying in my head…” – **still impossible but will be possible in next 10 maybe 20 years**

“But there is plenty of room to make them smaller. There’s nothing that I can see in the physical laws that says the computer elements cannot be made enormously smaller then they are now. In fact, there may be certain advantages” **– true**

MINIATURIZATION BY EVAPORATION

One possibility – evaporate conductor then evaporate the insulator next to it – **still impossible and I think we are never going to do something similar – we have developed different technologies**

Little “atomic” car **– still unfeasible**…

Some electrical equipment should be redesigned to be scaled down. **- true**

PROBLEMS OF LUBRICATION

Swallowing the surgent **–** “surgent” is inside blood vessel **– maybe next decade**
Little machines to help particular organs **– there exists pressure sensor which control and supervise the lifetime of artifitial brests**

Master and slave hands for making tiny mechanisms…- **microassembly, one of ideas is pantograph… Actually we are trying to do something similar here at ARRI**

A HUNDRED TINY HANDS
“There is the problem that materials stick together by the molecular (Van der Waals) attractions. It would be like this: After you have made a part and you unscrew the nut from a bolt, it isn’t going to fall down because the gravity isn’t appreciable; it would even be hard to get it off the bolt.” **- true**

Problem 4 (Seminal MEMS Papers - Kurt Petersen)
20 points
Kurt Petersen published his paper, “Silicon as a Mechanical Material” in 1982, which is now considered by many as the event that defined the field of MEMS. 1. Read the paper and summarize the MEMS processing technique that the author is proposing. 2. Briefly state what are (a) the benefits and (b) the limitations of using high purity crystalline silicon as a mechanical material?

SOLUTION
the MEMS processing technique that the author is proposing here are:

Etching – all types of etching, isotropic/anisotropic, wet/dry. Types of wet etching are given in table II. Etching is required to have great selectivity. In the other words we want to be able to mask some areas not to be etched. Etching is actually the most important MEMS technique and allows us to make a variety of shapes and useful devices. It takes place in almost all MEMS processes. Except mentioned terms like etch stopping, crystallographic facet definition are addressed and explained (bulk micromachining, planes 111, 110…etc.), *Electrochemical etching*…

Epitaxial process- very important process for micromachining, especially bulk micromachining. The main reason for that is the important property of maintaining the highly perfect single crystal orientation of the substrate. This means that complex vertical and/or horizontal dopant distributions (fast and slow etching regions for subsequent micromachining by etching) can be generated over many tens of micrometers without compromising the crystal structure or obviating subsequent anisotropies process. The epitaxial growth can be accurately controlled and is dependent on temperature and gas mixing dynamics.

Thin film deposition or growth – deposited thin films have obvious applications in passivation, wear resistance, corrosion protection, fatigue strength enhanchment, and very thin high – precision spacers.

Metal plating – covering the particular areas with metal to change resistance, to “make wires”.

Thermomigration – The migration, caused by temperature difference, of the liquid eutectic Al/Si alloy droplets through single-crystal- silicon. Maximum stress intrinsic to the process can be substantially reduced by post migration thermal annealing.
One obvious utilization of thermomigration is the connection of circuitry on one side of a wafer to a mechanical function on the other side. Another application may be dopant dependent etching of long narrow holes through silicon. Third – to join silicon wafers. Fourth, to serve as a feed throughs for solid state ionic concentration sensors. Address also laser driven thermal migration

Field Assisted Thermal bonding – used for chip packaging. For majority of the sensors, the package is usually the integral part of it. Sensor has to sense environment. On the other hand bonding can be used to close some chambers … etc.

Low pressure processing techniques such as high pressure and plasma assisted oxide growth and CVD depositions – there were not said to much about those technigues except regarding to passivation which is described below.

Passivation- growth of tough, hard corrosion resistant, thin film coatings such as CVD SiC or Silicon Nitride in order to prevent direct mechanical contact to the silicon itself, especially in the applications involving high stress and/ or abrasion

Briefly state what are (a) the benefits and (b) the limitations of using high purity crystalline silicon as a mechanical material

Benefits:
Young's modulus of silicon (1.9 x 10e12 dyn) approaches that of stainless steel (2.1). Knopp hardness of silicon (850) is close to quartz and just little below the chromium (935), twice as high as nickel, iron and most of the glasses. Tensile strength is at least three times higher than the one from the stainless steel wire. All these mentioned above say that silicon has excellent mechanical properties. There are some limitations described below.
On the other hand silicon has very interesting electrical properties at the same time.

Limitations:
Brittle material, yielding catastrophically rather than deforming plastically. It is not as fragile as it is often believed. Silicon will yield by fracturing (at room temperature) while metals usually yield by deforming inelastically. Stress concentration, Silicon has a tendency to cleave along crystallographic planes.
The main problem with silicon is stress together with its brittleness. There are some techniques to overcome stress caused damages known to semiconductor industry. The problem is aggressively attacked by semiconductor industry.

Problem 5 (MEMS "Killer Applications")

10 points

Suppose you are a venture capitalist and your firm wants to invest a couple million dollars in a MEMS product. What product would you try to develop? Describe your idea using no more than 1/2 page of 8.5 x 11 inch paper.

Solution:

(private info)