

## Teaching Micro System Design by using Multi-User Micro Avionics System Laboratory in Aerospace Educational Reform Program of Taiwan

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**ABSTRACT:** *Students in Micro System Design class from 2001 to 2004 have been able to design and fabricate their own micro systems by using Multi-User Micro Avionics System Laboratory (MASL) in Department of Aeronautics and Astronautics, National Cheng Kung University, Taiwan. The new arising micro system technology (MST) is one of the miniaturization technologies that have many applications in the future aerospace systems. However, the cost of MST education is too expensive to afford by most of the academic organizations. Therefore, under the support of Aerospace Educational Reform Program in Ministry of Education (MOE), ROC, Micro Avionics System Laboratory (MASL) is set up to share the resources. Multi-User MASL is a project that provides schools with access to new arising MST technologies for teaching activities. Multi-User MASL is designed for general purpose micromachining by various students who wish to learn how to design and fabricate micro systems. Since its inception in January 2001, Multi-User MASL has tried in coordinating and providing foundry service for educational purposes. Recently, students are able to conduct their microfabrication in MASL through intensive training courses. It aims to provide students from academic organizations nationwide utilizing Multi-User MASL as a springboard to design and test prototype components and accelerate their learning processes.*

### 1 INTRODUCTION

With the arising of new developing Micro-Electro-Mechanical System (MEMS) in the aerospace market of new sensors, actuators, micro systems and materials, the study of MEMS technology have become a most important subject in aerospace engineering courses. A methodology, based on progressive steps, has been developed, so that the students be prepared to design and implement typical projects, such as accelerometers, gyroscope, temperature/flow sensors, micro actuators and others. They start with a micro system described by basic theoretical model. Based on basic principles, ordinary differential equations, from which an analog circuit model, are generated. The systems that are studied for implementation on MEMS simulation tools. This is very important for the study of MEMS design concepts, such as system stability, system performance, and so on. The projects are simulated with CAD tools, and they are then implemented with device micro-fabrication. The simulation helps the students to understand a system design process. The fabrication results obtained with the students in the course show the efficiency of this methodology. A large part of the success must be credited to micro system fabrication, which stimulate the students, and enable them to implement micro system fabrication they are interested in.

Students have shown great interest in being able to carry through and to implement real projects and not only didactic ones. They are encouraged to complete the whole design processes with the modeling, simulation, micro-fabrication and testing. Based on this it was decided to convey to their interest and to adopt a methodology, with practical aspects, for the project and implementation of micro systems. This work presents a teaching methodology that is based on the study of cases, from modeling to synthesis, using micro-fabrication facilities in Multi-User Micro Avionics System Laboratory (MASL).

## 2 METHODOLOGY

The main objective is to help the students to learn micro system design and carry out a project in stages, through gradual steps, in subjects related with micro system fabrication processing. They should also be able to relate their knowledge to others disciplines of the engineering courses. The project is carried through in the following three stages:

- **Theoretical Model Analysis of Micro Avionics System** - In the first stage, there is a theoretical model for a micro system, where the students acquire basic knowledge, and then a case study is made, where the physical model of a micro system is explained. In micro avionics system design project, the study is based on a MEMS accelerometer, very common in the MEMS industry, which is based on a mass-spring system. These theoretical analyses are implemented by the students and later simulated with MEMS CAD tools. The basic governing equation is a second order ordinary differential equation (ODE) that related to a natural frequency, as well as damping coefficient. The ODE that represents a micro system is very useful for the study of micro system design, such as system stability, system performance, and system order, as well as its interface circuits.
- **Computer-Aid-Design (CAD) simulation of Micro Avionics System** - In the second stage, computer-aid-design (CAD) tools are used, with numerical examples and case study, such as micro accelerometer and others, before fabrication in the laboratory. Figure 1 shows the software used in the Micro Avionics System CAD Laboratory. In Figure 1, L-Edit Pro software is facilitated for 2D mask layout design. MEMS Designer software can be used to generate 3D models, as well as grid generation, of the devices for further thermal, fluid and structure analysis. Initially CAD tools for micro systems are introduced, where the student are given reasonable knowledge of CAD tools, and then a case study is made, where the mask layout of a micro system is explained. CAD tool simulation results are implemented by the students and later compared with previous theoretical analyses.
- **Microfabrication and Test of Micro Avionics System** - In the third stage, after the project has run correctly in the Simulator, the students start microfabrication of a micro avionics system. It is implemented in Micro Avionics System Micro Fabrication Laboratory. Figure 2 and Figure 3 shows the layout and major facilities in Micro Avionics System Micro fabrication Laboratory. In the Micro Avionics System Micro Fabrication Laboratory, there are spin coater, mask aligner (Figure 3a) and hot plates for students to learn photolithography process. For thin film deposition, there is a RF sputter (Figure 3b) for both metal and dielectric material deposition that helps students practice thin film deposition process. For test and package, probe station (Figure 3c) and wire bonding machines (Figure 3d) are equipped to help student test and package their own devices.

## 3 MULTI-USER MICRO AVIONICS SYSTEM LABORATORY (MASL) SETUP

Multi-User Micro Avionics System Laboratory (MASL) is a new-established project that provides schools with cost-effective access to MEMS technology for teaching activities. Multi-User MASL is designed for students who wish to learn how to design and fabricate MEMS devices. Since its inception in 2001, Multi-User MASL project has promoted MEMS teaching and coordinated MEMS foundry services for educational purpose. It aims to provide students from academic organizations nationwide utilizing Multi-User MASL process as a springboard to design and test prototype components and accelerate their learning processes. Following are setup milestones of Multi-User MASL:

- In 2001, Multi-User MASL set up Micro Avionics System Computer-Aid-Design (CAD) Teaching Laboratory in Department of Aeronautics and Astronautics of National Cheng Kung University (NCKU). MEMS design software has been used for the design of a micro device before fabrication in the laboratory. At the same time, foundry services currently available in Taiwan are introduced to students. For examples, CMOS process in Chip Implementation Center (CIC) and Multi Project MEMS Chip (MPMC) in Central MEMS Center of National Science Council (NSC) are utilized in the class as design rules. L-Edit layout environment is set up, as shown in Figure 4, to help student in mask design by using currently available foundry fabrication process. For examples, cross sectional views of the mask layout environment for Multi-Project MEMS Chip (MPMC) foundry service [1] provided by National Science Council's Central MEMS Center in Taiwan are illustrated in Figure 5. To encourage students in MEMS design course, students in MEMS design class of Department of Aeronautics and Astronautics of National Cheng Kung University design their first MEMS devices by

using MPMC foundry service. Figure 6 are several examples of micro devices designed by the students by using the first run of MPMC foundry service.

- In 2002, Micro Avionics System Micro Fabrication Laboratory is setup. Now, not only students can design their own micro systems in the class, send the design to foundry services for micro fabrication, but also get hand-on experience on micro fabrication process, and test their devices in school.
- In 2003, micro electroplating facilities (Figure 6) also set up for high aspect ratio LIGA-like microstructure fabrication. The fabrication processes of LIGA-like device are shown in Figure 7. There are 5 steps of LIGA-like process shown in Figure 7:
  - (i) Clean silicon wafers by using standard RCA cleaning processes. Metal thin film is deposited as a seeding layer by using RF sputter.
  - (ii) Spin coat SU-8 photoresist on the substrate. Soft bake the SU-8 photoresist
  - (iii) Design a mask for photolithography. Photolithography processes include (a) expose SU-8 photoresist under the mask aligner, (b) post expose bake by using hot plate. (c) develop to form the pattern. (d) hard bake by using hot plate
  - (iv) Micro electroplating process
  - (v) Strip the SU-8 to form metal microstructures

Micro Avionics System summer training course has been held to teach students how to design and fabricate a LIGA-like micro accelerometer from June 30-July 4, 2003. Sacrificial LIGA-like process (shown in Figure 8) is used as design rules in the training course. The design processes is shown in Figure 9. Before fabrication, computer-aid-design (CAD) analysis is performed for LIGA-like micro accelerometer design. In CAD analysis, micro accelerometer structures under acceleration are analyzed by using ANSYS software. Figure 10 shows the deflection diagram of a micro accelerometer beam structure. Once CAD simulation results satisfied the design specification, students can start the fabrication of sacrificial LIGA-like processes. Pictures, shown in Figure 11, are two different LIGA-like micro accelerometer under test and evaluation to verify if they satisfy the specification.

#### **4 STUDENT PROJECTS IN MULTI-USER MICRO AVIONICS SYSTEM FOUNDRY SERVICE**

Ultimately, the project will lead to multi-user foundry service with the alignment with three NSC MEMS Centers in National Taiwan University (NTU), National Tsing Hua University (NTHU), and National Cheng Kung University (NCKU), as well as Precision Instrument Development Center (PIDC), Industrial Technology Research Institute (ITRI), Chip Implementation Center (CIC), National Nano Device Laboratories (NDL) and other industrial foundry service fabrication center. The service process flow is shown in Figure 12. In Figure 12, instead of expensive cost in single process service, single process service users can share the cost by fabricating their device at the same time under the coordinate of Multi-User foundry service. LIGA-like foundry service provided by Multi-user MSAL will be one of service open to MEMS design students in Taiwan in the near future.

#### **5 CONCLUSIONS**

Aerospace educational reform program is a program that advocates the new developing technology in aerospace engineering education. By ‘aerospace educational reform’, we mean that the educational system must accept new technology, revise new contents, adopting new process to adapt to both the needs of subjective and objective environments. When aerospace industry impacts seriously after 911 terrorist attack in 2001 and SARS virus infection in 2003, it is urgent for us to prepare students for future aerospace technology evolution. One of the new arising technologies that have many applications in the future aerospace engineering is so-called micro-electro-mechanical system (MEMS) technology. Several MEMS applications in aerospace have been discussed include the ventilation system inside an aircraft may need to incorporate MEMS-based biosensors to detect and kill airborne virus or biological weapon in near future. MEMS sensor array may be applied to monitor the aircraft structures, and powerplane system for early detection in order to prevent aircraft crash accidents. To stop terrorist attack, RF tags, similar function as barcode, may tagged to both passengers and their carriers for personal and luggage identification. Therefore, to prepare aerospace engineering students for MEMS technology is urgent,

especially their applications in aerospace. However, the cost of MEMS education is too expensive to afford by most of the academic organizations. Hence, under the support of Aerospace Educational Reform Program in Ministry of Education (MOE), ROC, a cost-effective Multi-User Micro Avionics System Laboratory (MASL) project is promoted to share the resource and reduce the cost.

## ACKNOWLEDGEMENTS

Special thanks to Ministry of Education (MOE) and Central MEMS Center of National Science Council (NSC) in Taiwan for providing funding and opportunities for Multi-User Micro Avionics System Laboratory Project. All the students in Multi-User Micro Avionics System Laboratory Project are also appreciated for their hard working during the project.

## REFERENCES

MPMC design rules <http://nsc-cmems.nthu.edu.tw>

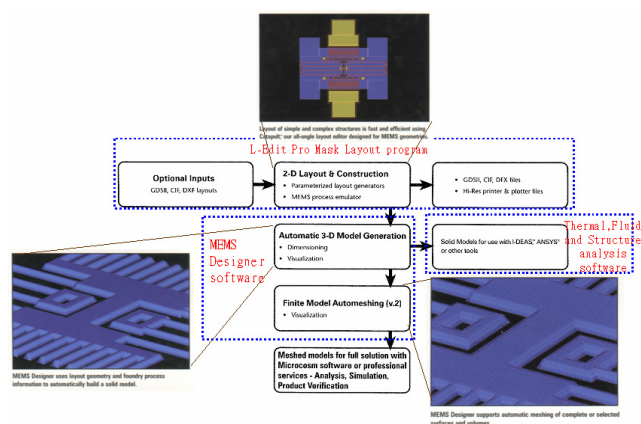


FIGURE 1,  
Software used in the Micro Avionics System CAD Lab.

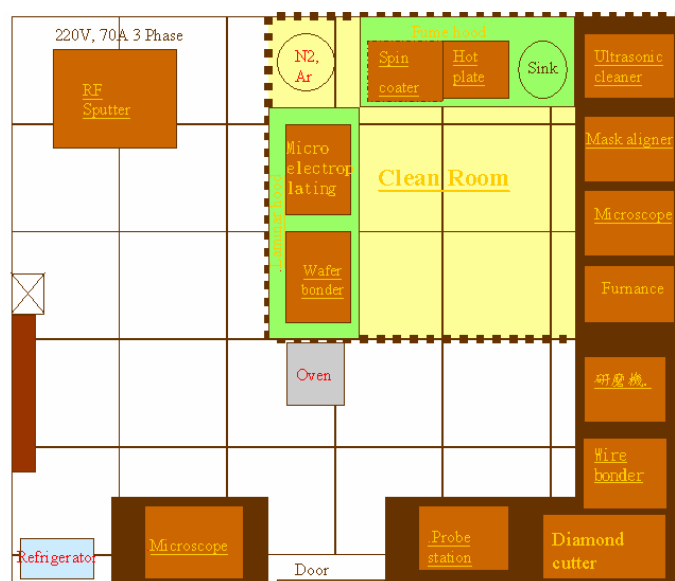


FIGURE 2,  
The floor plane layout in Micro Avionics System Microfabrication Laboratory.



(a)



(b)



(c)



(d)

FIGURE 3

Major facilities in Micro Avionics System Microfabrication Laboratory. (a) Mask aligner (b) RF sputter (c) Microelectroplating (d) Wire bonding

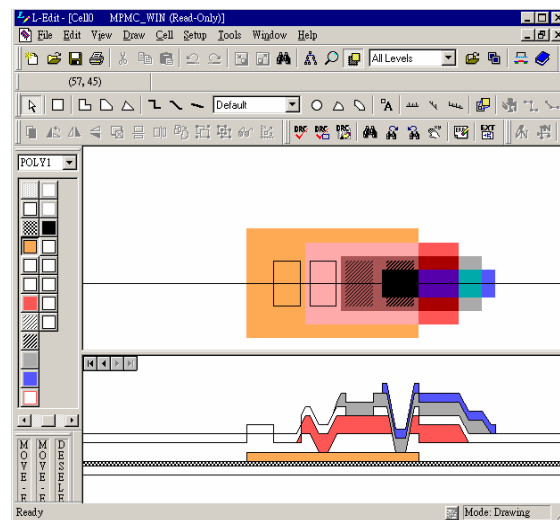
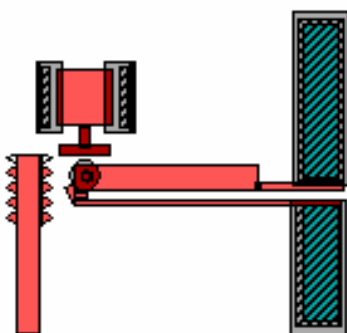
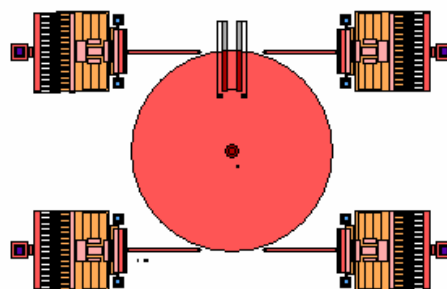


FIGURE 4

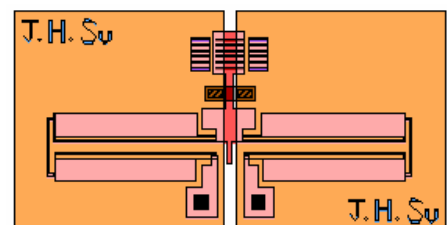
L-Edit layout environment set up for Multi-Project MEMS Chip (MPMC) foundry service[1] provided by National Science Council's Central MEMS Center in Taiwan



(a)



(b)



(c)

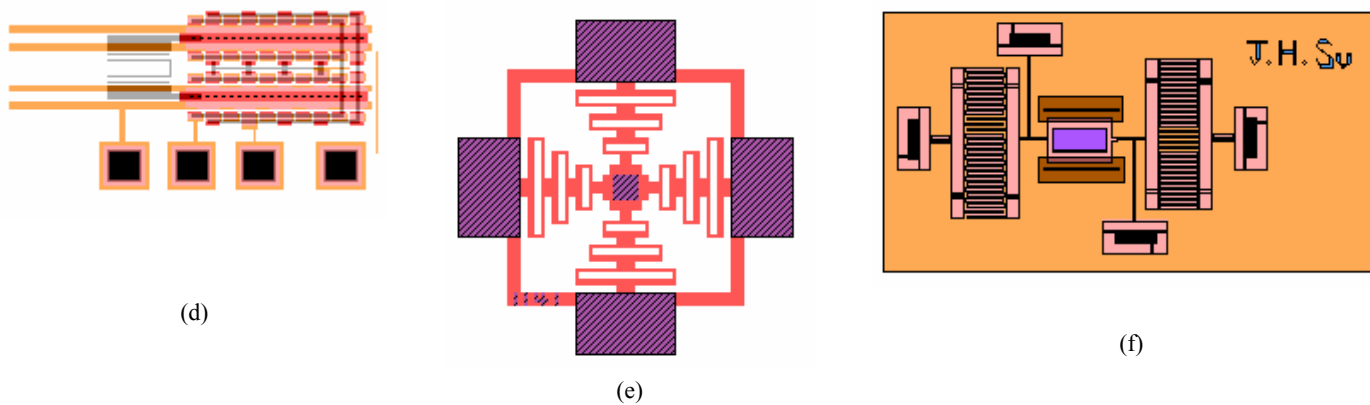


FIGURE 5

Micro devices designed using MPMC process by students (a) Micro slider driven by micro thermal actuators with vernier gauge (b) Micro optical turning table driven by comb drivers (c) Linear motion micro thermal actuators. (d) Micro translation stages driven electrostatic force (e) Out-of-plane motion micro thermal actuators (f) Testing structures for comb drive actuators.

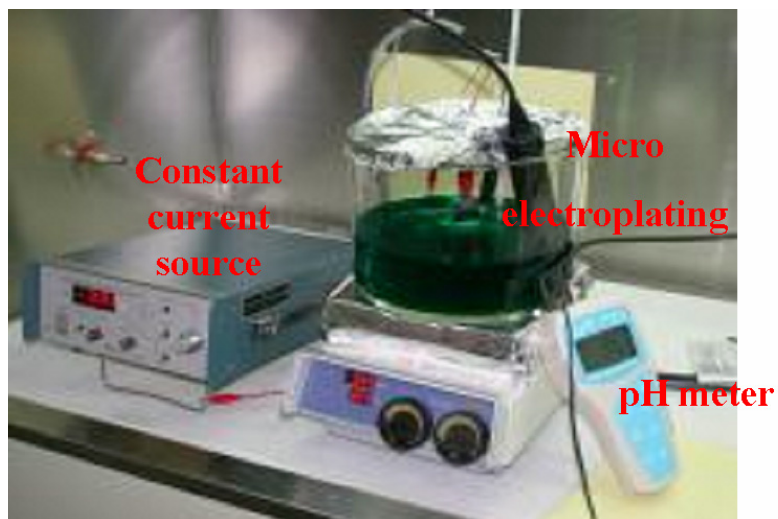


FIGURE 6 Micro electroplating facility for high aspect ratio microstructure

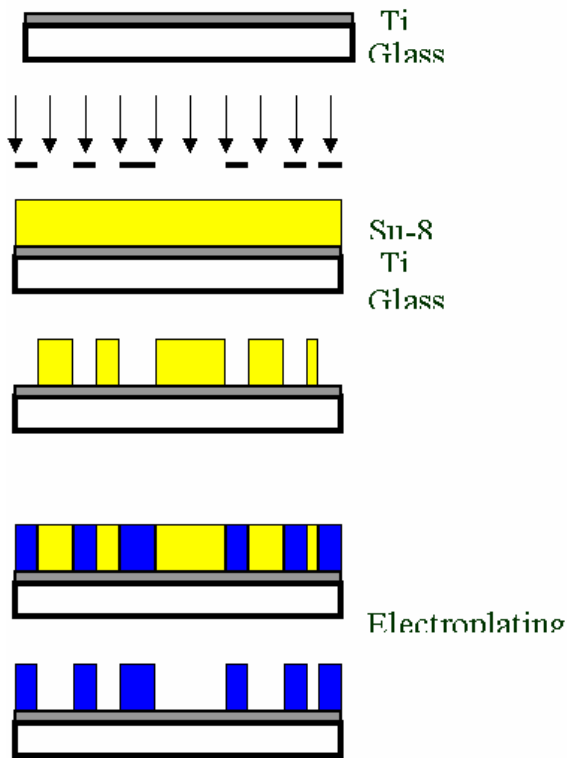


FIGURE 7 LIGA-like fabrication process

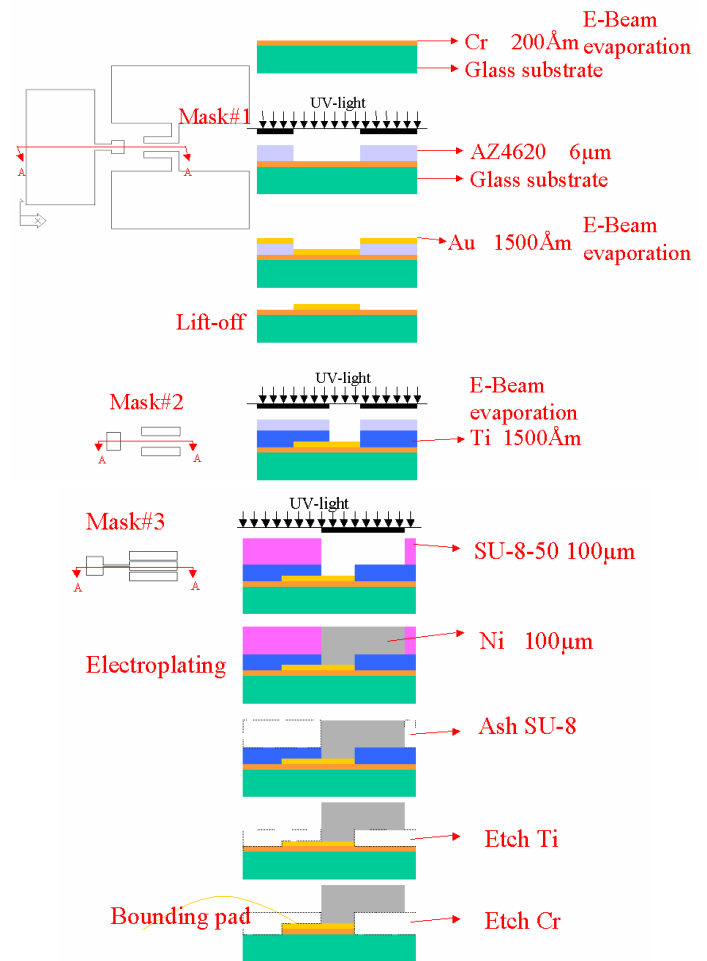


FIGURE 8 Sacrificial LIGA-like process

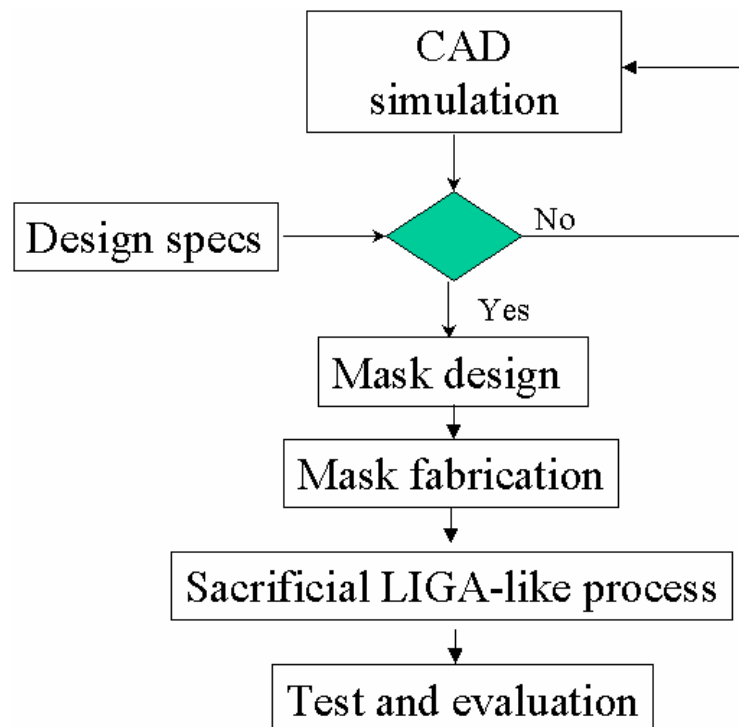


FIGURE 9 LIGA-like micro accelerometer design processes



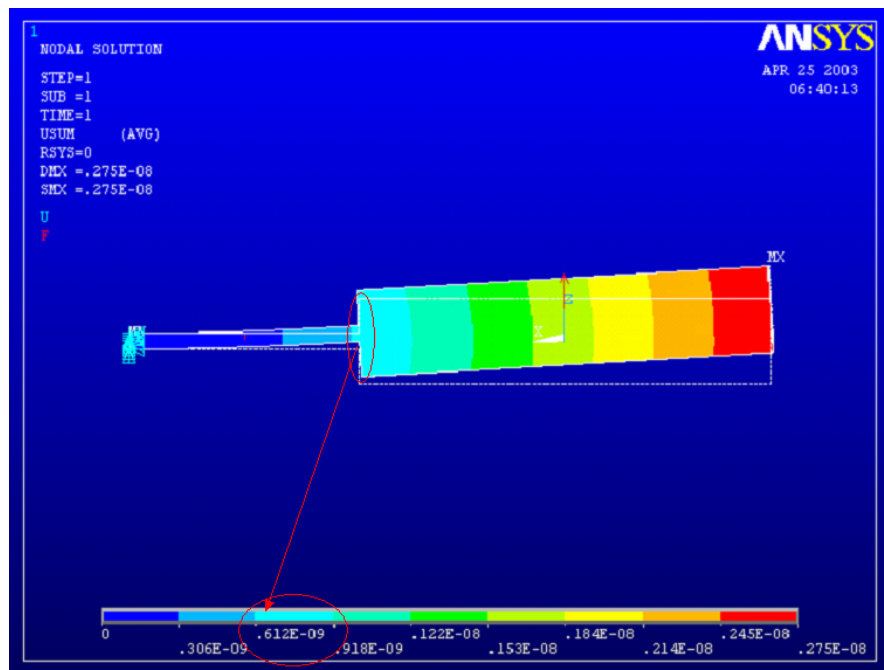


FIGURE 10 ANSYS simulation results of a micro accelerometer beam structure

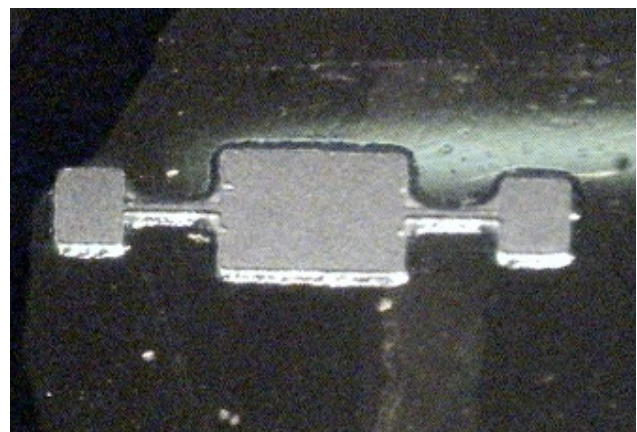


FIGURE 11 Pictures of two different LIGA-like micro accelerometer during microfabrication.

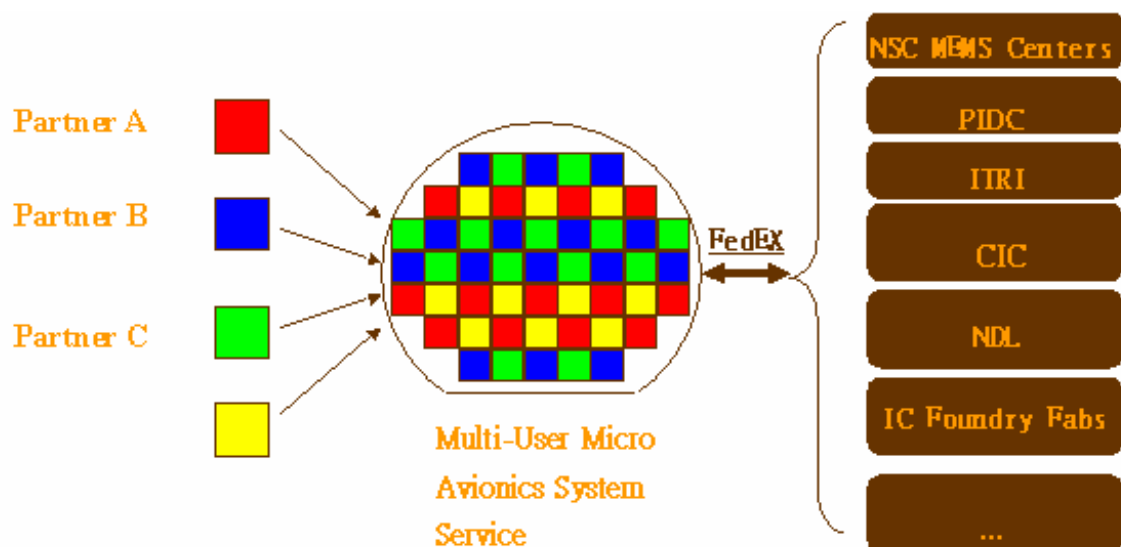


FIGURE 12 Multi-User Micro AVionics system Foundry Service