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Status of HARMST in Taiwan

Yao Cheng

Synchrotron Radiation Research Center, #1, R&D Rd. VI, 30077, Hsinchu, Taiwan

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This paper summarizes recent progress in the research and development of high-aspect-ratio microsystem technologies (HARMST) in Taiwan. Four major processes are addressed: deep X-ray lithography (LIGA), UV LIGA, laser LIGA, and deep-etch reactive ion etching (RIE). Due to the increase in research funding from the National Science Council (NSC) and Ministry of Economics Affairs (MOEA), research in microsystem technologies is expanding throughout Taiwan. The recent recession in the microelectronics industry has freed manpower needed for the research and development of microsystem technologies.

1. Introduction

The Taiwan light source (TLS) at the Synchrotron Radiation Research Center (SRRC) was established in Oct. 1993. At the same time, Dr. Y.C. Liu, the Director of SRRC, and I initiated the LIGA project. After the Micro-Electro-Mechanical Systems (MEMS) conference in Oiso, Japan, 1994, we invited several world-renowned experts to give keynote speeches at the first MEMS Workshop held at SRRC. The workshop was well attended and led to the successful promotion of research and development in microsystem technologies in Taiwan. LIGA technology was one of the major topics at the workshop. Many current projects pertaining to LIGA in Taiwan today were initiated at that time. After I returned from high-aspect-ratio microsystem technologies'95 (HARMST'95), I made a presentation on the progress in HARMST to the MEMS community in Taiwan. Four possible HARMST manufacturing processes were addressed: deep X-ray lithography (LIGA), UV LIGA, laser LIGA and deep-etch reactive ion etching (RIE). Today, these manufacturing methods are well established in Taiwan.

Since 1995, there have been two major funding agencies for microsystem technologies, the MOEA and the NSC. Two institutes, the Industrial Technology Research Institute (ITRI) and the Chung-Shan Institute of Science and Technology (CSIST), applied for grants from MOEA valued at 500 million NT$ (15 million USD) per year. These funds require research partners from various industries.

The NSC is the major funding agency for academic researchers at universities and national research institutes. The Precision Instrument Development Center (PIDC) and SRRC are institutes under the NSC. The NSC budget for microsystem technologies within NSC is around 100 million NT$ (3 million USD) per year. To provide foundry service, the NSC established three centers for development of micromachining technologies in Taiwan.

Most of the micromachining researchers whose backgrounds are in electrical engineering prefer to use a dry process. Deep-etch RIE has become very popular because of its ability to manufacture high-aspect-ratio microtrench with various selections of structure materials. The etching speed is quite high. It is suitable for microstructures less than 100 μm deep. No one in Taiwan has studied the molding process using a dry-etched die. A molding die generated using a LIGA or LIGA-like process is of great interest to those researchers with mechanical engineering backgrounds.

2. LIGA

Because of its unique position, SRRC has become the leading institute for developing X-ray LIGA in Taiwan. The micromachining laboratory at SRRC was founded in 1996.(1) To establish an in-house X-ray mask capability, a low-cost mask using UV LIGA was developed. Due to budget limitations, we focused on extending the structural depth rather than improving precision to the submicron level. In fact, Taiwanese industry is interested mainly in two types of microstructures, ten-micron-deep or millimeter-deep microstructures. Since the typical single exposure depth of TLS is 200 μm, an alternative is to use successive exposures with a conformal mask to increase the depth of microstructures. In the meantime, we found that the major constraint in forming a millimeter-deep trench is the wet developing process. This problem was resolved by increasing the exposure dosage and preventing dosage absorption on the wall from diffracted light. Microstructures on the order of one centimeter can be developed with high accumulation of irradiation dosage if stronger X-rays are applied to expose the resist without considering the photoelectron effect. This method is called the "ultradeep LIGA process."(2) To overcome the loss of precision due to contact printing, a new mask-fabrication process which uses laser direct-write to correct the error caused by the horizontal variation of the printing gap is currently being developed. The expected precision of this process is up to about one-half micron.

While computer-based process simulation has gained substantial popularity, our focus of modeling thick-film lithography depends mainly on analytical formulations. Our approach is capable of revealing explicit guidelines for quality control, technology extension, and user training. Specifically, we have developed a universal dosage formula for SR X-ray exposure (Fig. 1).(3) This formula is suitable for different synchrotron facilities and

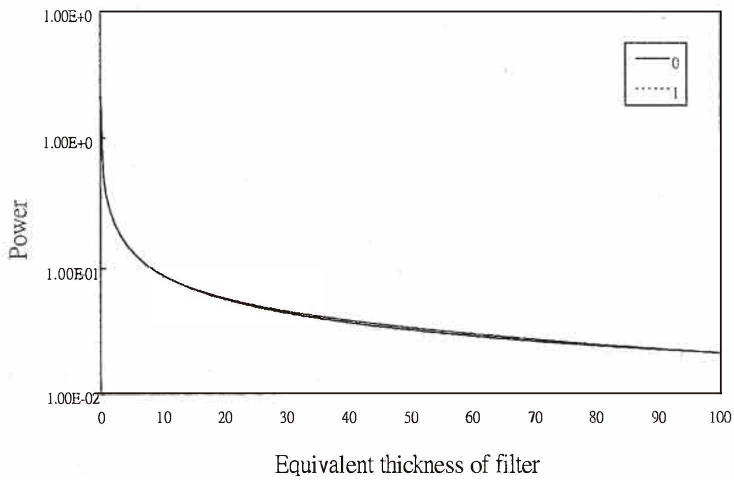

Fig. 1. The power of synchrotron radiation transmitted through a filter. The abscissa is an equivalent thickness t. Line 0 represents the numerical result, and line 1 is the analytical approximation.[3]

materials. In addition, we have developed a semiempirical formulation to estimate the developing time. Furthermore, we have developed a theoretical estimation of the wall-profile based on Fresnel diffraction and exposure attenuation.[4] The same formula is applicable to other lithographic processes including deep X-ray and UV. Information on precision, resolution and process optimization can be easily obtained using this formula.

Major projects pertaining to millimeter microstructures at SRRC include microfiber spinnerets, integrated leadframe punch and klystrino. The first two projects are related directly to the world-class industries in Taiwan. Commercialization is in progress with an SRRC spinoff.

Figures 2(a) and 2(b) show the design capability of an arbitrarily shaped cross-section of a spinneret capillary. Spinnerets for either direct spinning or composite spinning can be easily manufactured using ultradeep LIGA. The complicated cross-section provides the special functionality of the fiber. While the conventional EDM method is slow and unable to produce highly sophisticated cross-sections with the required high aspect ratio, LIGA provides a fast production method via injection molding (Fig. 3). The third project on the millimeter-wave klystrino is a collaborative effort between the Stanford Linear Accelerator Center (SLAC) and the SRRC. The SRRC is responsible for the fabrication part of the project. A klystrino is a high-power millimeter-wave source used to accelerate charged particles to obtain high energy within a very short distance. The development of a klystrino will have a significant impact on both the scientific and engineering fronts.

The SRRC provides a foundry service for LIGA and UV LIGA to the general micromachining community in Taiwan. In the past few years, ten projects ranging from scientific explorations to industrial applications have been carried out.

(a)

(b)

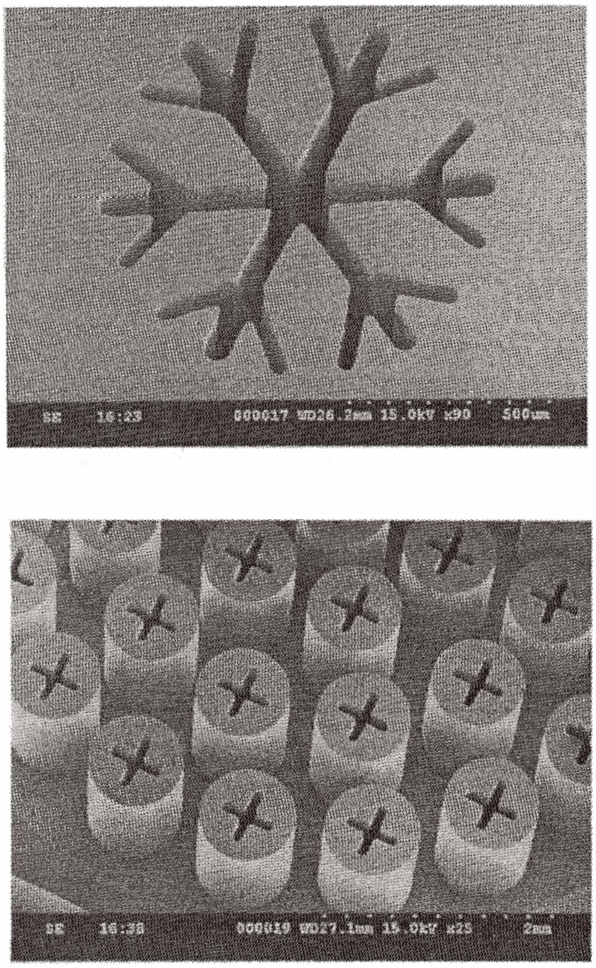

Fig. 2. (a) Spinneret capillary for direct spinning (1 mm deep and 70 μm wide). (b) Spinneret capillary for composite spinning (1 mm deep and 70 μm wide).

3. Plating

The lifetime of a plated nickel die is an important issue. We can increase the hardness of the plated pure nickel by adjusting the current density during plating and by selecting appropriate chemical additives in the electrolyte. Pure plated nickel with a hardness of Hv 400 was reported. However, these features can be obtained only in the low-temperature region. Some applications require that this mechanical property be extended to the high-temperature region. Nanopowder composite plating has been greatly improved with

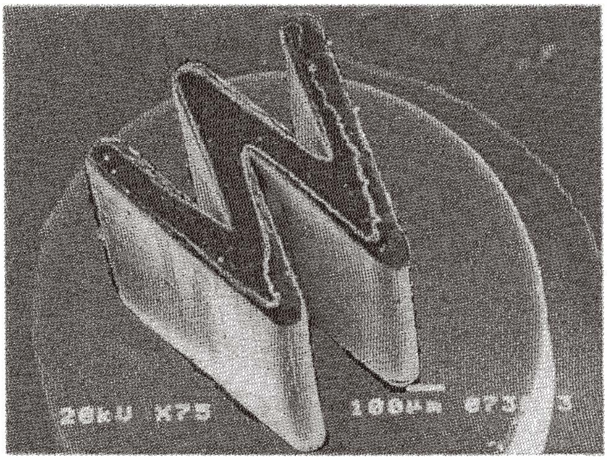

Fig. 3. Complimentary structure of a spinneret capillary manufactured using injection molding (2 mm deep and 70 μm wide).

respect to the hardening and thermal reliability of plated nickel. A cooperative program between the Department of Material Science, National Taiwan University, and the Wah Lee Industrial Corporation has contributed to this effort.

Figure 4 shows a typical hardness behavior of the sliced crystallization due to chemical additives in the electrolyte of plated nickel. This crystallization is unstable under thermal treatment. Recrystallization occurs in the temperature region between 200°C and 320°C, resulting in softening of the plated nickel. On the other hand, crystallization becomes isotropic when we add a nanopowder of SiC to the electrolyte for composite plating. The composite nickel is much harder (Hv 500) than pure nickel even in the case of high-speed plating. The most important result is that the temperature behavior is dramatically improved. Figure 4 shows stable hardness for temperatures up to 500°C. The SiC nanopowder content is less than 5%. We will extend this method to plating of copper, nickel/iron and others. Usually, it is difficult to eliminate internal stress when plating very hard materials such as tungsten and chromium. Our technique for controlling internal stress during nickel and nickel/cobalt plating is easy and commonly used. Composite plating has become a straightforward way to obtain hard but low-stress microstructures.

4. PIDC

PIDC is an institute of the NSC which provides precision mechanics manufacturing services for researchers in Taiwan. While the capability of commercially manufacturing precision mechanics in Taiwan is continuously improving, PIDC is also moving toward advanced process technologies. Its micromachining program started with the micro-EDM

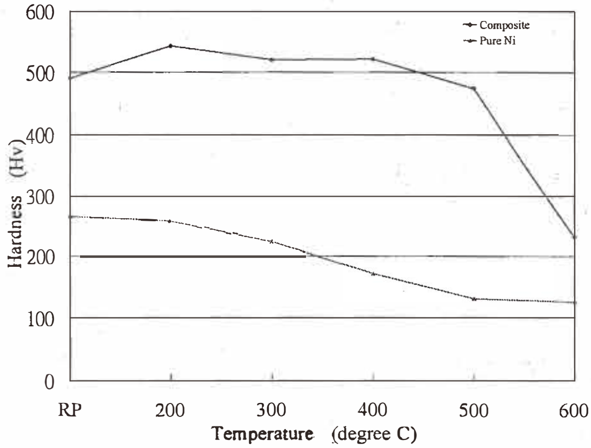

Fig. 4. Hardness of plated pure nickel and composite nickel as a function of temperature.

five years ago (Fig. 5). In 1996, a rapid expansion of the program extended the application of its technology to the areas of silicon-based surface micromachining and LIGA-like thick-film processes. The main approaches to thick-film technology are UV LIGA and laser LIGA. One team has focused on the contact printing of the thick photoresist SU-8 (Fig. 6). Another team has developed the laser ablation technology using a 248 nm KrF excimer laser (Fig. 7). They chose polymethyl methacrylate (PMMA) as the ablation material because it is easy to remove after the postplating process.

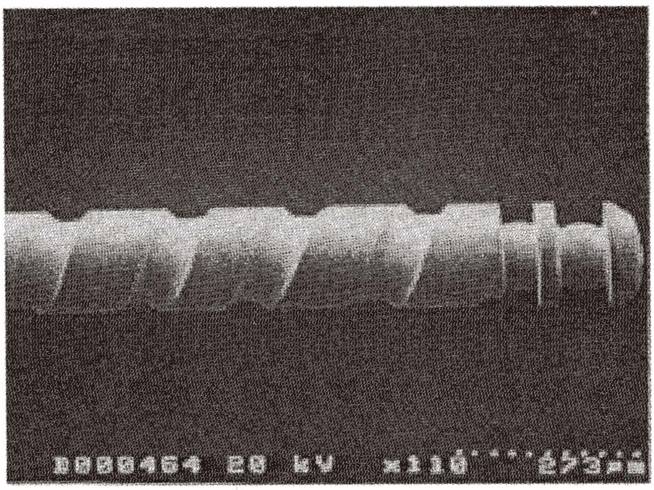

Fig. 5. Tungsten microstructure manufactured using micro-EDM.

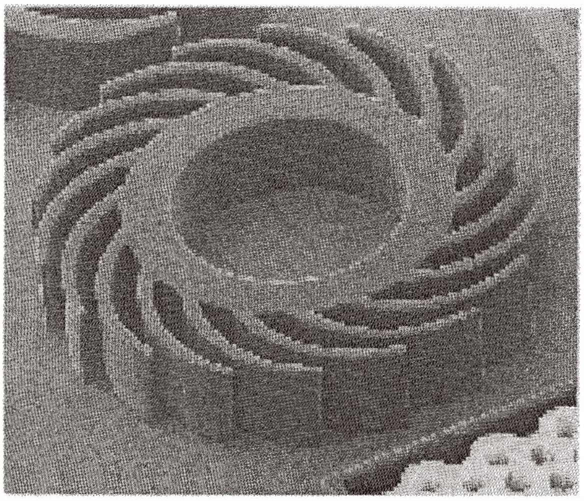

Fig. 6. Contact printing of SU-8 photoresist, 300 μm deep.

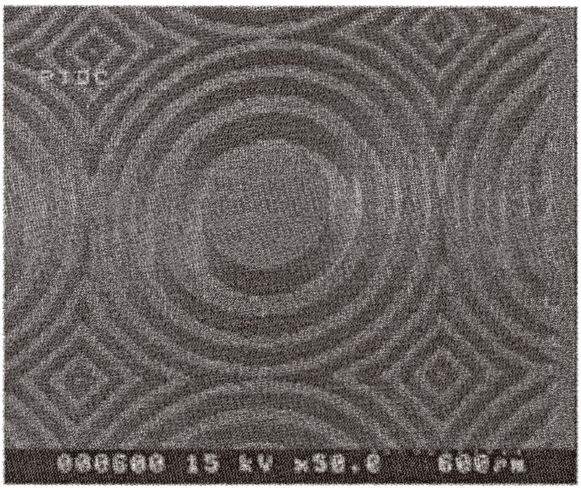

Fig. 7. Fresnel lens manufactured by laser ablation, 50 μm deep.

A special mass production method for aligned hot embossing in vacuum provides the capability of duplicating microstructures on a wafer. Other than nickel plating, PIDC has focused on the Ni/Fe alloy, which has the properties of low thermal expansion and high level of toughness. These properties are important especially for vibrating sensors and actuators.

5. ITRI

Taiwan is known as one of the major producers of IC packaging in the world. There are two main methods used to fabricate leadframe: etching and punching. Although the production costs of the punching method are lower than those of the etching method, it is very difficult to manufacture high-pin-count leadframes using the punching method. The Mechanical Industry Research Laboratories at ITRI initiated a project focusing on the production of an integrated leadframe punch using LIGA technology. They proposed the use of NiCo/SiC alloy composite technology to plate the punch head. The level of hardness of NiCo/SiC composite plating is expected to be higher than that of Ni/SiC composite plating.

The design specification of an integrated leadframe punch requires a depth greater than 3 mm and an accuracy of 1 μm. We are studying a strategy which uses successive exposures plus double-sided development to satisfy this requirement. To attain this degree of accuracy, we will use laser direct-write to generate the X-ray mask. Figure 8 shows the results obtained so far in this project.

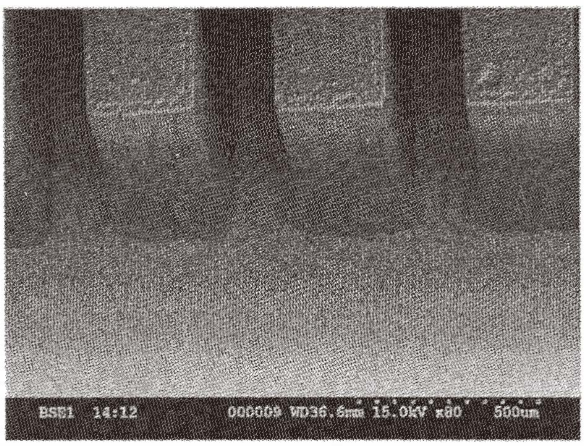

Fig. 8. Two-millimeter microstructure of the integrated leadframe punch manufactured using three successive exposures. The gold conformal mask on the photoresist has been stripped.

6. Future Prospect

Punches and dies manufactured by lithography to improve precision are the main interests of HARMST researchers in Taiwan. Therefore, the development of a plating process using hard materials with good mechanical properties will be one future objective. Thick-film technologies such as X-ray, laser, and UV will find niche applications. The technology of dry etching increases HARMST applications to silicon-related technologies.

The cost of buying and maintaining a synchrotron light source is the major problem that limits the expansion of the LIGA research community. A tabletop synchrotron light source using millimeter-wave acceleration provides one way to extend the activities of the LIGA research community. We need to use LIGA technology to fabricate thea millimeter-wave accelerator. This bootstrap relationship will delay LIGA research unless X-ray lithography can replace deep UV lithography in the microelectronic industry.

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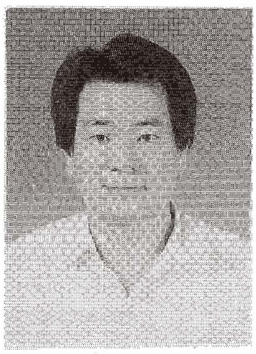

Yao Cheng received his B.S. in Power Mechanical Engineering from National Tsing Hua University in 1978. His Diploma Ing. in Electrical Engineering and Dr. rer. nat. in Physics and Astronomic were obtained from Ruhr-Universtat Bochum, Germany in 1984 and 1989, respectively. Since 1989 he has worked at the Synchrotron Radiation Research Center (SRRC) as an Associate Research Scientist. After the completion of storage ring of the Taiwan Light Source in 1995, he initiated the LIGA program at SRRC and established the micromachining laboratory. He is currently the Group Leader of the Microstructure Group working on LIGA-related micromachining technologies. His primary research area lies in thick-film lithography issues related to profile and precision control. One of his major contributions to thick-film technologies was the invention of ultra-deep LIGA process. Major micromachining projects conducted to date include LIGA foundry, microfiber spinneret, w-band klystron, X-ray zoneplate, microgyroscope and surface plasmon resonance (SPR) optical sensors.