Fabrication of 3D MEMS Antenna Array for Infrared Detector Using Novel UV-Lithography Apparatus, Plastic Micro Machining and Micro Assembly Technique

JONG-YEON PARK, KUN-TAE KIM, SUNG MOON and JAMES JUNGHO PAK*

Microsystem Research Center, Korea Institute of Science and Technology
SEOUL 130-650, Republic of KOREA, mems21c@empal.com
*Dept. of Electrical Engineering, Korea University, SEOUL, Republic of KOREA

ABSTRACT

This paper reports a novel UV lithography technique for fabricating a 3-dimensional(3D) feed-horn-shaped structure mold array, and obtaining parallel light by using a mirror-reflected parallel-beam illuminator (MRPBI) system.

A 3D feed-horn-shaped microelectromechanical systems (MEMS) antenna has some attractive features for array applications, which can be used to improve microbolometer performance and to enhance the optical efficiency for thin film transistor-liquid crystal display (TFT-LCD) and other display devices. Since MEMS technology has faced many difficulties in the fabrication of a 3D feed-horn-shaped MEMS antenna array itself, The purpose of this paper is to propose a new fabrication method to realize a 3D feed-horn-shaped MEMS antenna array by using a mirror-reflected parallel-beam illuminator (MRPBI) System with an very slowly rotated, inclined x-y-z stage [1]. With a conventional UV lithography apparatus, it is very difficult to fabricate high-aspect-ratio structures (HARS) because a typical UV lithography apparatus cannot produce perfectly parallel light. From a theoretical analysis, a columnar illuminator over 6 m in height is required to achieve parallel light, but generally a laboratory height is not 6 m.

An essential idea of this research is to make a light ray with long propagation by using a reflective mirror and a conventional UV-lithography apparatus for creating parallel light in a small lab space. Also, a novel method of lithography was tried to make a 3D structure array by exposing a planar wafer to the generated parallel light and rotating an inclined x-y-z stage at an ultra-slow rate. An optimization of the 3D structure array can be achieved by simulating a 3D feed-horn MEMS antenna. By using a high-frequency structure simulator (HFSS), a vertical sidewall array and 30° tilted sidewall array, we achieved a 300-ìm-high structure array using a MRPBI system, which was confirmed using scanning electron microscopy. A high-aspect-ratio, 300-ìm, thick structure with 30° tilted sidewalls was fabricated using a SU-8 negative photoresist, and a 100-ìm vertical sidewall structure array was fabricated using a PMER negative photoresist.

The feasibility of fabricating both a 3D feed horn MEMS antenna and a mold array was demonstrated. In order to study the effect of this new technique, we simulated the 3D feed-horn-shaped MEMS antenna array had been simulated with high frequency structure simulator (HFSS) and then compared the results with those from traditional 3D theoretical antenna models. As a result, it seems possible to use a 3D feed-horn-shaped MEMS antenna in the tera-hertz range to improve microbolometer performance and to fabricate several optical MEMS devices[2].

Keywords: Plastic Micromachining, PDMS, 3D MEMS, UV-Lithography

1 INTRODUCTION

Recent advances in the micro-electro-mechanical systems (MEMS) industries have given rise to the advent of various MEMS fabrication techniques to fabricate microstructures from various materials.

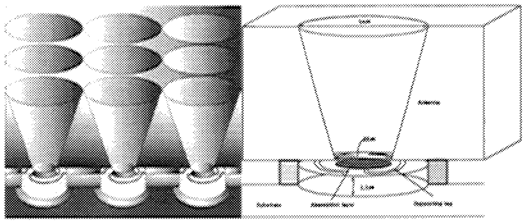


Figure 1: Schematic drawing of a 3D feed-horn MEMS antenna coupled with a microbolometer.

There is also a need for complicated 3-dimensional micro structures with high aspect ratios for such applications as enhanced microbolometer-coupled a 3D MEMS antenna arrays and enhanced optical efficiency TFT-LCD's and other display devices. Figure 1 present schematic drawing of a 3D feed-horn MEMS antenna coupled with a microbolometer. Although the 3D feed-horn MEMS antenna structures have many advantages, it is difficult to fabricate them using conventional UV (Ultra-violet) lithography techniques. In this paper, a novel method to realize 3D feed-horn MEMS antenna arrays by using mirror-reflected parallel-beam illuminator (MRPBI) system is presented.

2 CONCEPTS AND IMPLEMENTATION OF MRPBI SYSTEM

The most difficult problem in the fabrication of high aspect ratio structures (HARS) and 3D feed-horn-shaped

MEMS antenna arrays is how to achieve a parallel beam when using the UV lithography apparatus. A UV light propagation longer than 6m would be required for a 4-inch^2 exposure area. According to the CODE V optical simulator, However, since a typical laboratory height is less than 6m, it is almost impossible to set up the apparatus in a typical laboratory.

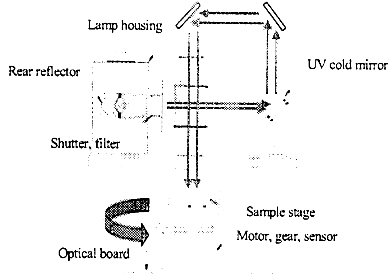


Figure 2: Schematic drawing of the MRPBI system

As an alternative, reflecting the light from several cold mirrors can generate a long propagation path when using UV light. Figure, 2 present schematic drawings of the MRPBI system and the configuration of the MRPBI system, respectively. A conventional UV lithography apparatus is needed to expose the planar stage, but the MRPBI system exposure method is different. For fabrication of higher aspect-ratio 3D structure arrays, the stage has an x-y-z tilt 360° automatic rotation control and simultaneous exposure. Because more parallel UV light is available, the MRPBI system exposure area is smaller than that for conventional UV-lithography.

A mask coupled with a wafer can be employed in a 2-way fixed vacuum, and the stage can be controlled to select hard contact, soft contact, and several other contact conditions. Figure, 3 shows a photograph of the inside of the MRPBI system. Its rotational axis can be controlled two ways: manually and by computer controlled using RS-232C communication port. Thus, we can change two experiment parameters: the rotation time and the exposure time. The MRPBI's wavelength is 365 nm for a 1 kW SHP Hg lamp, and its radiation intensity can be changed to a maximum of 10 mW/ Cm^2.

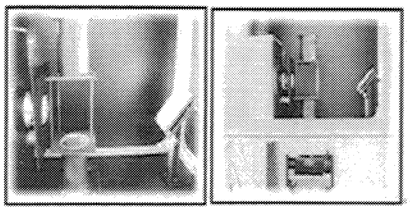


Figure 3: Inside photograph of MRPBI system

3 OPTIMAL DESIGN OF 3D MEMS ANTENNA USING HIGH FREQUENCY STRUCTURE SIMULATOR

The thermal or blackbody radiation emitted by all objects of a given temperature that generate infrared light becomes a maximum in the wavelength range from 8 to 12 μm. Thus, we considered the 3D antenna dimensions in relation to the development of a new form of IR imaging array that used 3D feed-horn MEMS antenna technology to couple the incident thermal radiation into an individual array element or pixel. Figure 8 shows the optimal design parameters and the incident light radiation pattern obtained for a 3D feed horn MEMS antenna by using a high-frequency structure simulator (HFSS). The HFSS uses the following equations for the optimal design and simulation of a conical feed-horn antenna [7]:

$$D_c(dB) = 10\log_{10}\left[\varepsilon_{ap}\frac{4\pi}{\lambda^2}(\pi a)^2\right] - 10\log_{10}\left(\frac{C}{\lambda}\right)^2 - L(s) \tag{1}$$

$$L(s) = -10\log_{10}(\varepsilon_{ap}) \cong (0.8 - 1.71s + 26.25s^2 - 17.79s^3) \tag{2}$$

$$s = \frac{{d_m}^2}{8\lambda l} \tag{3}$$

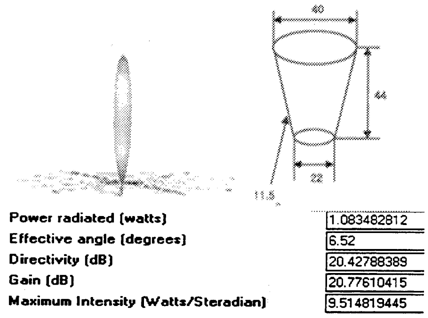
Where D_c is the directivity of conical horn, a is the Radius of horn at the aperture, L(s) is the directivity loss of aperture efficiency, C is the aperture circumference, s is the maximum phase deviation, and ε_{ap} is the aperture efficiency. The Following three equations are used for a feed-horn antenna [7]:

$$\frac{L}{\lambda} = \frac{0.3\times\cos\theta}{1-\cos\theta} \tag{4}$$

$$\frac{d_m}{\lambda} = \frac{0.6\times\sin\theta\times\cos\theta}{1-\cos\theta} \tag{5}$$

$$L = \frac{d_m}{2\times\sin\theta} \tag{6}$$

Where L is the Feed-horn length and dm is the Feed-horn diameter. Figure 4 shows the dimensions of the optimal feed-horn 3D MEMS antenna and its characteristics simulated using a high-frequency structure simulator. The feed-horn angle parameter is 11.5°, and feed-horn diameter is 22 μm. The results indicated a directivity of 20.42 dB and a gain of 20.77 dB.



Power radiated (watts)	1.083482812
Effective angle (degrees)	6.52
Directivity (dB)	20.42788389
Gain (dB)	20.77610415
Maximum Intensity (Watts/Steradian)	9.514819445

Figure 4: Optimal design of a 3D feed-horn MEMS antenna using HFSS(High frequency structure simulator).

Table 1 shows a summary of the dependence of the gain of the 3D feed-horn MEMS antenna on its diameter and length obtained by using HFSS.

Diameter (μm)	70	75	80	85	90	95
Length (μm)	145.23	169.35	195.05	224.48	251.58	282.35
Gain (dB)	16.83	18.76	19.40	17.36	12	14.43
Diameter (μm)	100	105	110	115	120	
Length (μm)	314.79	314.79	384.69	422.15	461.27	
Gain (dB)	13.82	13.50	10.05	9.51	12.31	

Table. 1 Simulated values for a 3D feed-horn MEMS antenna design using HFSS.

Figure 5 shows a comparison of the directivity gain of variously shaped 3D MEMS antenna cylinder, conical horn and feed-horn. Among them, the directivity gain of the feed-horn-shaped antennas is highest at 22dB.

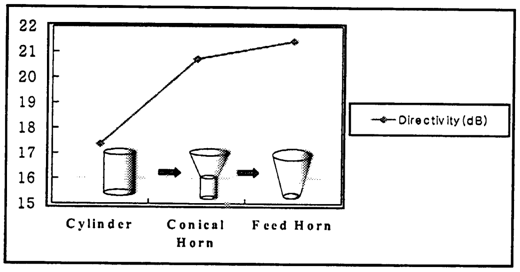


Fig.5 Comparison of 3D MEMS antenna directivity.

4 EXPERIMENTS AND RESULTS

We tried two experiment methods for fabricating a 3D feed-horn-shaped mold structure array using conventional precision machining and UV-photolithography. Figure 6 shows that SEM images of 3D antenna mold fabrication results obtained by conventional precision machining. These experiment results show a rough surface.

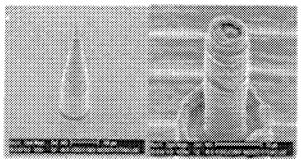


Fig.6 SEM images of conventional machining results for a 3D antenna mold structure.

Figure 7 shows a vertical sidewall structure array, which is over a 100-μm high and which was fabricated using a negative photoresist, PMER, and a MRPBI system. The fabrication steps for the high vertical sidewall are a 2-step spin coating (500 rpm/s, 600 rpm/s) for a stabilization condition of 5 min, prebake at 110°C/25 min, post-exposure bake (PEB) at 100 °C/15 min and exposure for 1800 sec. When exposure time is over 2400 sec a very strong hard reflection and it becomes very difficult to obtain a vertical sidewall.

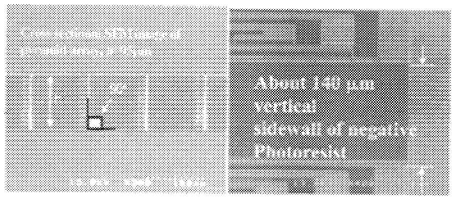


Fig.7 SEM images of a vertical sidewall array using a negative photoresist PMER, fabricate by MRPBI system

The inclined sidewall array using negative SU-8 photoresist an the MRPBI system is shown in Fig. 8. The SEM images in Figs. 9(a) and 9(b) show what look like quadruple shape array while images (c) and (d) show a teapot-shaped array with serious hard reflections. The experimental parameters are a 20° inclined stage with the y-axis direction rotated 360° and an exposure time of 1800 sec. The exposure time is the most important factor in this experiment

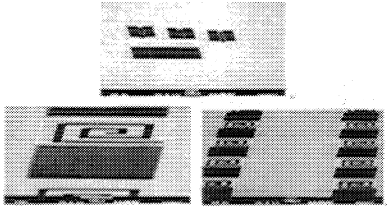


Fig.8 SEM images of an inclined sidewall array using a negative photoresist SU-8 fabricated by MRPBI system

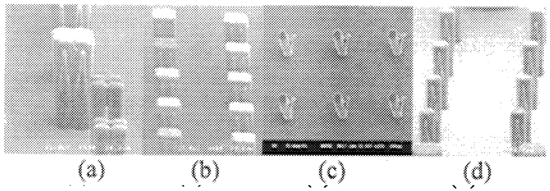
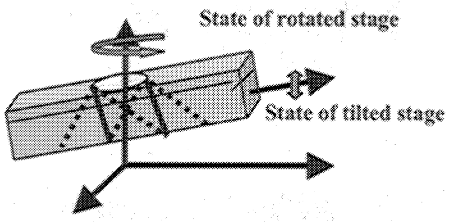


Fig.9 SEM image of quadruple shape arrays and teapot shaped arrays using negative PMER photoresist fabricated using the MRPBI system.

Figure 10 shows the schematic drawing of the 3D feed-horn-shaped array fabricated by UV exposure while rotating the substrate with a tilt.



Developed area of photoresist

Fig.10 Schematic drawing of the 3D feed-horn mold fabrication

We fabricated the 3D feed-horn-shaped mold structure array using a negative photoresist in the MRPBI system. The optimal fabrication step for making a 3D feed-horn-shaped mold structure array is a 2-step spin coating (500 rpm/s, 1600 rpm/s) under a stabilization condition of 6 min, prebake at 110°C/25 min, post-exposure bake at 100°C/15 min: Figs. 11(a), (b), and (c) are for a 35°, 30°, and 25°tilted stage, respectively. The exposure time was 250 s. In this experiment, it is necessary to control the 3D feed-horn antenna angle, hence, several experiments with mold structure of various angles were performed by controlling X-Y-Z stage and protecting it against UV reflection with a bottom anti-reflection coating (BARC).

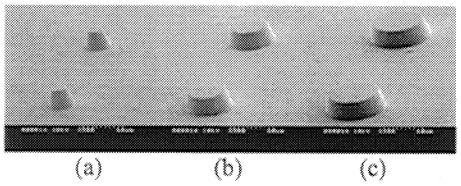

(a) (b) (c)

Fig.11 SEM images of feed-horn mold array.

Figure 12 shows that fabricated 3D MEMS antenna array plate using plastic micromachining. It's thickness of about 30-40μm using Polydimethylsiloxane(PDMS) by capillary filling with clamping technique.

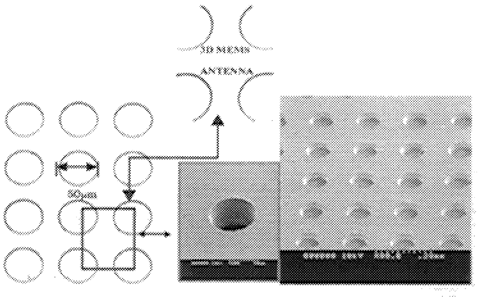


Fig.12 SEM images of 3D MEMS Antenna

Micro assembly of 3D MEMS antenna array and IR detector array have many difficult to conventional MEMS bonding process. That is reason of IR detector array were 2.5 μm floated onto substrate, therefore thickness bonding material required under 2.5 μm for optimization of contact gap and all of IR detector array were bonded with 3D MEMS antenna at low temperature process. To overcome those limitations, the proposed to novel 3D MEMS bonding technique that is mesh structure bonding (MSB) using Microchannel. This MSB technique can be used to produce low temperature bonding, thickness control of bonding material and detail bonding at mesh structure. Figure 13, 14 show that Method of Mesh structure bonding (MSB) using Microchannel with PDMS injection and experimental result of Micro assemblies for 3D MEMS antenna with IR detector using mesh structure bonding (MSB) technique respectively.

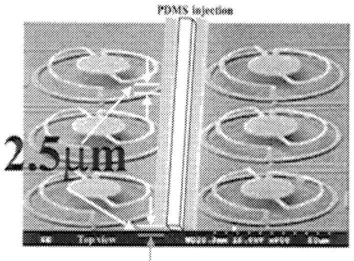


Fig.13 Mesh structure bonding(MSB) using Microchannel with PDMS.

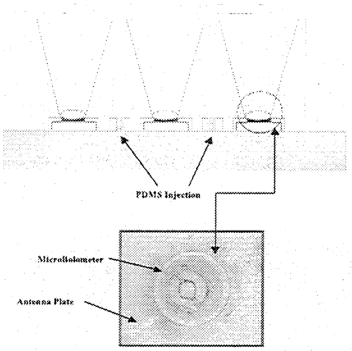


Fig.14 Micro assembly for 3D MEMS antenna with IR detector using mesh structure bonding (MSB) technique.

5 CONCLUSION

In this paper, novel techniques and methods have been described to fabricate a 3D feed-horn MEMS antenna by using a new UV lithography apparatus called the mirror reflected parallel beam illuminator (MRPBI) system 3D MEMS antenna design was optimized for an enhanced performance microbolometer using HFSS.

ACKNOWLEDGMENTS

The authors wish to acknowledge that this paper is the result of research accomplished with the financial support of the Intelligent Microsystem Center, Seoul, Korea, which is carrying out one of the 21st century's New Frontier R&D Projects sponsored by the Korea Ministry of Science & Technology.

REFERENCES

[1] R. A. Wood, "Uncooled thermal imaging with monolithic silicon focal plane," SPIE Vol. 2020 Infrared Technology, pp. 322 - 329, 1993.
[2] Peter L. Marasco and Eustace L. Dereniak, "Uncooled Infrared Sensor Performance" SPIE Vol.2020 Infrared Technology, pp. 363 - 378, 1993.