IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676,p-ISSN: 2320-3331, Volume 13, Issue 3 Ver. I (May. – June. 2018), PP 69-73
www.iosrjournals.org

Silicon Carbide Structure Material for Optical Communication

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Abstract: *Integration of 3-D devices, IC or MEMS, often requires a handle wafer which is removed before final packaging of the devices. This process usually uses lapping, chemical etch or high temperature heating to de-bond the handle wafer. A new technique to release a Pyrex handle wafer using laser ablation is presented. Pulsed energy, from a 248nm excimer laser is delivered transparently through the Pyrex handle wafer. This causes delamination of the bonded silicon structures from the handle wafer. This technique offers fast throughput at chip and wafer levels and protects the fragile and delicate active devices from harsh physical, chemicals and potential thermal stresses. We present a method wherein the handle wafer used in 3-D assembly of a MEMS device was released using laser micromachining. A Pyrex handle wafer rigidly supports anisotropically etched, through-silicon wafer, vertical mirrors during thermo-compression bonding to active MEMS parts. After this first thermo-compression bond, the Pyrex handle wafer was lifted off using laser ablation, leaving clearance for additional bond steps, which includes additional components and a package frame. Multiple Au-Au thermo-compression bonds of vertical surfaces onto a single MEMS chip were performed, to assemble and package 3-D MEMS devices.*

Keywords: *Optical MEMS, corner cube retroreflector (CCR), hermetic packaging, flip chip bonding*

Date of Submission: 07-05-2018 Date of acceptance: 26-05-2018

I. Introduction

Sands et al. [1] have used the absorption of pulsed laser energy at buried interface to enable the transfer of the thin film heterostructure from its growth substrate to virtually any receptor substrate without significant heating of material outside the interaction zone. A different application for such approach is presented here where instead of transferring a thin film the handle wafer was released using pulsed laser energy. 3-D device was thus assembled using this process.

The packaging of MEMS devices is one of the most difficult and cost sensitive process in product development due to its many requirements [2, 3 and 4]. MEMS packaging techniques are borrowed from IC industry, but the functionality of MEMS devices differ a lot from the IC devices. MEMS packaging presents various challenges which were never faced by the IC packaging industry due to the diversity of MEMS devices and the requirement that many of MEMS devices are in continuous and/or intimate contact with their environment [4] Even though application specific packaging is not an efficient method of sealing MEMS based products, a new and specialized package is designed nearly for each new MEMS device. Consequently, most manufacturers find that packaging is the single most expensive and time-consuming task in a MEMS product development program, and is also often the first to influence the system response.

To package an optical MEMS sensor, a transparent window and electrical connections to the outside world need to be integrated into the design. Processes, which can create a package and simultaneously assist in the fabrication of the needed optical surfaces, will be beneficial toward meeting the growing need for low cost packaging solutions. Past works have presented various methods and approaches to package an optical device with integrated window for optical access [5-8]; however these techniques requires extra complex processes to package 3-D optical structures.

In many devices hermetic sealing is required, allowing only a negligible amount of gas to be, in order to prevent the device from becoming contaminated.[7, 9] Moisture can be readily absorbed by some materials (for example Al) used in MEMS device fabrication. This can cause failure of MEMS devices due to stiction, swelling, stress, and possibly delamination at various stages. To minimize these failure mechanisms, MEMS packages needs to be hermetically sealed. Also low temperature packaging is desired as high temperature can cause thermal stress/mismatch problems. The processes discussed in this paper results in a hermetically sealed package optical device called Corner Cube Retroreflector (CCR). A different method of fabricated CCR was presented before [7 and 8], however when higher range communication (20-50 m) is desired this new method of fabricating CCR was used to get better sidewall profile.

II. Concept Of Corner Cube Retro reflector (Car)

CCRs have been used for a wide range of applications ranging from street signs and road markings to measuring the distance from the earth to the moon. In the last decade, efforts were spent in developing CCRs for data communication from low-power sensors [8]. MEMS optical corner cube retroreflectors (CCR) have been developed over the past decade to realize transmission of data from low power sensors to a base station, via a probing laser beam [8]. They consist of an active mirror surface, and two orthogonal static mirrors. Optical ray tracing analysis shows that an incident optical ray which is thrice reflected by the convex corner defined by the three mirrors exits in the direction of the incident ray. By moving or distorting the active mirror, the returned ray is re-directed away from the incident ray. Moving the mirror in synchrony with information from sensor, one can impart this information onto a probing laser beam using very little power, thus, the sensing signal can be transmitted back into central station to realize remote free space communications.

III. Laser micromachining

Excimer laser micromachining has been used extensively in the manufacture of ink-jet print heads, which are among the most successful MEMS-related products to date [9] Laser micromachining has allowed reduced nozzle spacing (and hence higher print resolution), better control over nozzle shape, and improved yield compared with mechanical drilling or electroforming [9]. The excellent polymer machining characteristics and 3D capabilities of laser processing are also highly relevant to other fluidic devices. Key elements of microfluidic systems, such as channels, filters, mixers and reactors, all require 3D (or at least 2.5D) structuring. Furthermore, polymers are better suited than silicon-based materials in many instances. For example, transport is often based on electrophoresis (rather than hydrostatic pressure), requiring a dielectric channel. Laser processing can also be used for patterning the necessary thin film electrodes, allowing a unified fabrication approach. A particularly good example of the potential of laser machining for bio-MEMS was reported by Pethig et al [10]. Here multilevel metal/polymer structures were built up on glass substrates, with a KrF excimer laser being used to pattern each layer. Using this approach a range of elements for BFC (biofactory-on-chip) was demonstrated, aimed at dielectrophoretic transport, trapping, and mixing of microorganisms. Other examples of laser ablation for direct fabrication of MEMS have been reported recently, including machining of shape bimorph actuators in silicon [10], and patterning of multilayer magnetic materials for actuators [11]. In our application we use the laser micromachining method for releasing the pyrex wafer from silicon, so that the underneath structures made in silicon carbide are not affected by the laser ablation technique. Laser debris can be difficult to remove, hence the structures were covered with photo reactive polymer so that after the laser ablation step the polymer can be removed using photoresist.

IV. Design and Experiment

4.1 Design of the MEMS CCR

Fabrication of our CCR is divided into two parts. The first is the active two-dimensional (2D) micromirror array based on mirror design and using silicon nitride or silicon carbide as the structural material. The second is the fabrication of 3D vertical mirrors using glass as the carrier wafer. The glass wafer acts both as a packaging lid to protect the mirrors and as a transparent window that allows the optical probing signal to pass through and reach the CCR. We will first be discussing the silicon carbide as the structure layer and later illustrate how the vertical mirror was released and packaged finally. Silicon carbide as structure layer is able to withstand higher temperature and can be modulated either electrostatically or using other actuation techniques.

4.2 Silicon Carbide (SiC) as Structure Layer

The etched polycystic 3C-SiC films were grown on silicon dioxide (SiO_2) using low pressure chemical vapor deposition (LPCVD) process [12].The process gases include 0.75sccm SiH_4, 2.25sccm C_2H_4 and 3sccm H_2. The grow process was at 1050°C for 60 min and the work pressure was 40 Torr. The thickness of 3C-SiC was about 2μm.

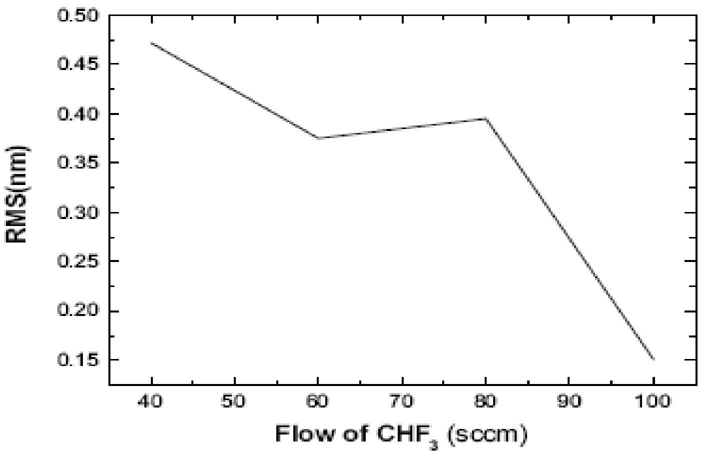

Figure 1: Effect of the flow rate of CHF_3 on the surface roughness of the etched surface.

Following this, 400nm of Aluminum was deposited using evaporation technique and then patterned as etching mask. Figure 1 shows the effect of flow rate of CHF_3 on the roughness of the etched surface. Since we would like to apply the structure for optical application, we wanted to have a low surface roughness, so we characterized the etching of silicon carbide.

The source power, bias power and etching period were set to 500W, 100W and 2 minutes. The etching was performed in ICP etcher. The etch rate of the silicon carbide is plotted as the flow rate of CHF_3. As the flow rate of CHF_3 is increased the chemical etching is enhanced and the physical etching is reduced. But when the CHF_3 gas flow increased from 60sccm to 80sccm, the surface roughness was slightly increased, because the chemic etching and physic bombardment play equivalent role in etching mechanism.

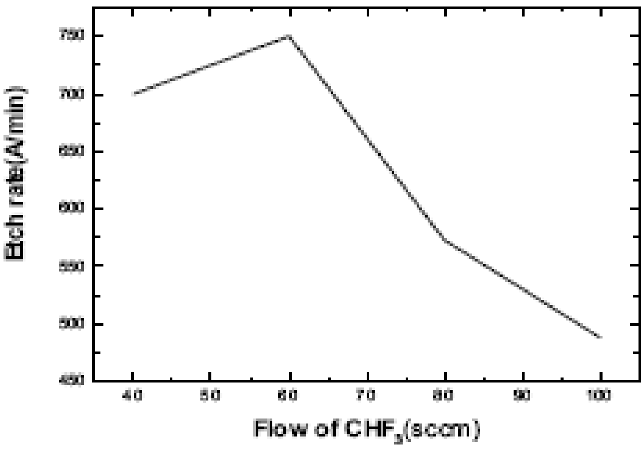

Figure 2: Etch rate of silicon carbide as a function of the CHF_3 flow rate.

Figure 2 shows that the etch rate increases when the flow rate was increased from 40sccm to 60sccm. This suggests that ion bombardment plays an important role in etch mechanism. The etch rate decreases considerably when the flow rate was increased from 60-100sccm.The reason is that when ion flux increased, the ion collision increased while the ion bombardment energy is reduced, then the chemic etching plays a role in the etch mechanism.

When O_2 was added into the etching gas properly, the etch rate was increased evidently, and the etching residual material was reduced. The reason is that O_2 can react with CHF_3 and release more free fluoride (F) ion, at the same time O_2 can react with carbon (C) and produce volatile CO and CO_2 compounds. But once added too much O_2, the etch rate was decreased because the F concentration was diluted so the etching effect was reduced. The effect of the O_2 percentage on the SiC etching was observed, with the etch rate experiencing a maximum of 400 nm/min at around 10% O_2 and then decreasing with increasing O_2 percentage. From graph of figure 1 and 2, the peak etch rates of almost 400nm/min were obtained at 900 W source power, 150 W bias power, the etch gases include 11 sccm CHF_3, 43 sccm SF_6 and 6 sccm O_2.

4.3 Silicon oxide as Structure Material

Silicon oxide can also be used as a structure material for fabrication of the torsion mirrors as the silicon oxide is a strong material and metal like Aluminum or Gold can be deposited on the silicon oxide structure, so that the mirror is reflective in the desired interest of wavelength. Following the method that we mentioned above about using silicon carbide, the same can be used for silicon oxide. The etching of silicon oxide is better known in the reactive ion etching (RIE) tool or silicon oxide can also be etched using buffered oxide. The etching of silicon oxide with 11 sccm CHF_3, and 60 sccm O_2 at 400 W RF power at 50 mT pressure was measured to be 25 nm/min. We deposited 3 µm of silicon oxide and that helped form the structure. Below is table 1 which describes the etch rate that we got for different variations of gas chemistry, RF power for 50 mT pressure.

Table 1: Etch rate of silicon oxide for different parameters

Gas Flow (in sccm)		RF Power (in Watt)	Etch rate (in nm/min)
CHF_3	O_2		
60	11	400	25
60	8	400	22.5
20	11	400	2.5
20	8	400	1.2
60	11	200	8.7
60	8	200	3.2

Table 1 determines the etch rate of silicon oxide for different gas chemistry and RF power using these parameters we were able to fabricate the silicon oxide and etch and pattern it using surface micromachining techniques.

4.4 CCR Surface Improvements and Packaging

To increase the optical range of the CCR smoother and flat surfaces for all the three sides of the CCR are required. The CCR presented earlier had an operating range of 10-15 meters [5 and 7]. There the CCR was assembled using the DRIE mirrors and surface micro machined MEMS mirrors. The DRIE mirrors suffered from scalloping effect even after the wet polishing and the MEMS mirrors had a curvature even after using a sandwiched approach. To overcome these short comings vertical mirrors were etched in (110) Si wafer using KOH etching and MEMS mirrors were fabricated on silicon wafer with either silicon nitride or silicon carbide as the structure material. The KOH etching gives atomically smooth sidewalls and mirrors fabricated on silicon wafer results in stress free mirrors due to the use of single crystal silicon as the device layer. Vertical mirrors in the shape of a cross cannot be etched on a (110) silicon wafer, so two orthogonal mirrors were fabricated separately and were bonded to the silicon chip in different steps unlike single step assembly/packaging.

To ensure that we are able to release the pyrex bonded to the silicon a laser ablation process was used. For, the laser release uses a 248-nm excimer laser with 30 mJ/pulse, a spot size of 162 µm, and fluence of 1.2 W/cm^2 repeated every 5 µm as shown in Figure 3. Next, a slightly taller second pair of vertical mirrors with integrated bond frame is bonded using Au-Au thermal compression to complete the fabrication of the CCR. In this method, photoresist is used to protect the underlying active mirrors during laser ablation, and the resist is stripped off using solvent after bonding. The average surface roughness on these mirrors is around 12 nm.

The alternate process was developed in parallel to the testing and integration effort. The parts made using the first method, though having a slightly rougher surface, were used for sensor integration and testing.

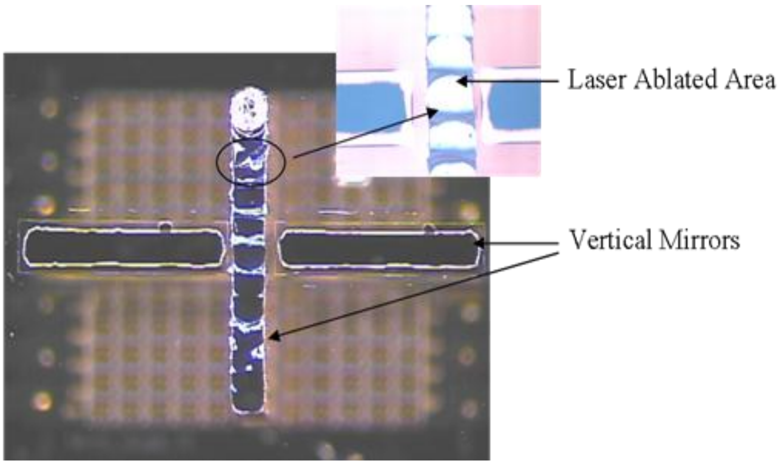

Figure 3: Surface deformation after laser micromachining. The zoom image shows where the laser beams hits to release the pyrex lid.

The vertical mirrors were sputter coated with gold (100 nm Cr, 1000 nm Au) using a back side exposed self-patterning liftoff process [5] to increase reflectivity and allow thermo-compression bonding. Thermo-compression bonding (FineTech Pico5, 320°C, 41 MPa, 2 minutes) was performed, initially using structures without a package frame, to bond the vertical mirrors to the unreleased silicon chip. After the first bonding of one set of vertical mirrors, the handle Pyrex lid was removed using laser micromachining. A 248nm laser with 30 mJ/pulse, 162 µm spot size and fluence of 1.2 m/cm^2 was shot at every 5 µm during the linear move, de-bonding the Pyrex chip from the device chip. During this process the underlying active MEMS devices was protected from laser ablation debris using photoresist. After removing the protective photoresist, silicon chips were released in concentrated hydrofluoric acid. A second thermo-compression bonding of a combined orthogonal vertical mirror and package frame was performed on the same chip to finish the assembly. The glass wafer and package frame serve to protect the MEMS device and allow optical probing of the internal parts.

Optical image of the MEMS chips after laser liftoff process where the MEMS mirrors were not protected using photoresist and the debris can be seen on the active parts Another optical image of the MEMS mirrors were structures were protected using photoresist and after removing the photoresist no debris were found on the mirrors. This method of ensuring that the structures are protected eventually resulted in larger communication range.

V. Conclusion

Corner cube retroreflector are used as free optical communication transmitter and improve the surface roughness of the structure material by covering them with photoresist while doing a laser release of the pyrex lid and then bonding the other mirrors enables us to perform a 3-D microstructures with a unique packaging technique. For our experiments, a 248-nm excimer laser was used a pulse with of 30 mJ/pulse, and fluence of 1.2 W/cm^2. This resulted in improvement of the surface roughness from 40 nm to 10-20 nm on the structure material which resulted in longer communication range of 30-50 m as oppose to 10-20 m earlier.

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IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE) is UGC approved Journal with Sl. No. 4198, Journal no. 45125.

Wang Wei "Silicon Carbide Structure Material for OpticalCommunication ." IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE) 13.3 (2018): 69-73.