WAFER-LEVEL PACKAGING OF THREE-DIMENSIONAL MOEMS DEVICE WITH LENS DIAPHRAGM

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ABSTRACT

This paper presents wafer level packaging of a miniature MOEMS monochromator for biomedical spectroscopy. Optical microlens and piezoelectrically-actuated diffraction grating are fabricated, and packaged at a wafer level into a complete, integrated monochromator with a fiber input. The packaged monochromator is an optical and mechanical system derived from a macroscale Czerny Turner monochromator. It integrates an angled mirror for folding and directing the input light path. A lithographically-defined reflective diffraction grating accepts and spectrally separates the input light from a fiber that is inserted into the built-in groove. The diffracted light is then collected through a diaphragm-suspended microlens and spatially separated on its path towards the output of the system. The packaging, done via encapsulated silicon cavities, provides batch processing and finishing of the complete device. The MLD is characterized with a Gaussian beam propagation model and the SSC packaged device is measured by its resolution and stray light through profiling with a CCD array.

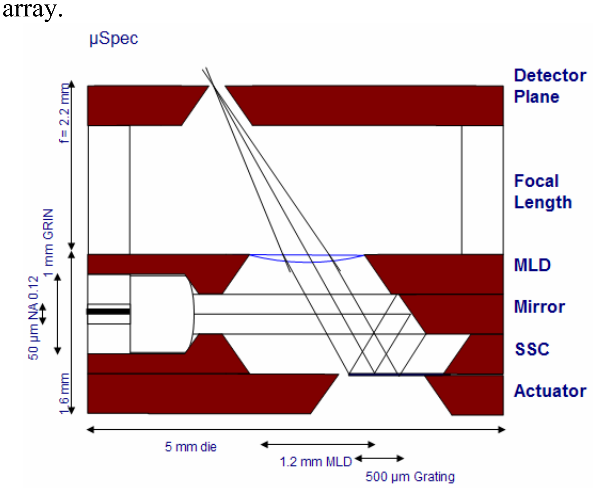


Fig.1. Cross section of the MOEMS spectroscopy system with layers of actuator, optics, and detector labeled.

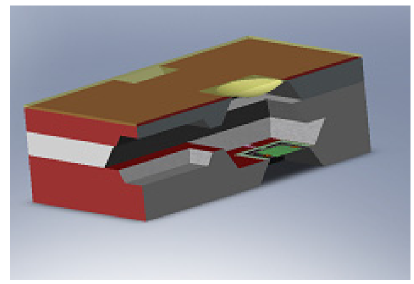


Fig. 2. 3D image of the system package. Cross section is done to expose the cavity and the optical components.

INTRODUCTION

There have been several studies focused on using fluorescence techniques as a bio-detection method to be integrated with miniaturized analysis systems [1-6]. Fluorescence technology and its non-contact probing allow minimally invasive biological and medical procedures to be carried out [7]. It also enables the possibility of portable on-site detection technologies for biological, pathological, and environmental monitoring. In this study a miniaturized spectroscopy system is presented, and specifically its optical packaging technology is shown. Together the wafer level encapsulation and microlens diaphragm provide a compact, integrated package that enables its constituent MEMS components to be realized in a true microdevice.

SCAFFOLD SILICON CAVITY PACKAGING

The proposed complete MOEMS system is shown in Fig. 1 cross section. The cross section shows distinct layers of components that include actuator, mirror, and micro lens diaphragm (MLD). In this system, the wafer level packaging serves the following purposes: 1) align the optical components, 2) protect the MEMS actuator, and 3) allow easy connection of the optical and electrical ports. To achieve all of these, the lithographically defined, batch processed silicon cavity encapsulation is used in the wafer level packaging (Fig. 3). Epoxy bonding (EPO-Tek 301) is used to provide low temperature, simple process for the multi-layer packaging. This wafer level packaging

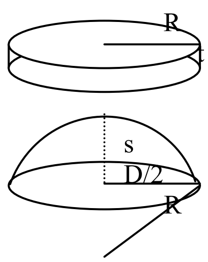
Fig. 3. Process of SSC Package: 3 cavity wafers with the microlens on top are sandwiched for the packaging. Dicing and release of the encapsulated device is done at wafer level at the time of release.

is referred to as Scaffold Silicon Cavity Packaging, or SSC packaging.

For the SSC, the individual package wafers are fabricated by lithographically patterning windows for KOH etching to form the required cavities with front and backside patterns aligned with IR illumination. The patterns on the photoresist are transferred to a SiN (deposited by Low Pressure Chemical Vapor Deposition) etch mask layer, via Reactive Ion Etching. After defining the etch windows, wet etching with KOH is used to form the cavities. The resultant cavity with attached SiN diaphragm is ultrasonicated in water in order to sonically shatter and remove the diaphragm structure. The final pieces are tightly-defined free cavities ready for formation of the three-dimensional system via epoxy bonding. At this point, the top most layer containing the MLD goes through a separate process in the next section. On the other hand, the next two layers containing the mirror and the fiber port go through alignment and epoxy bonding.

MLD DESIGN AND FABRICATION

As we have chosen SU8 with optical index of n=1.6 for the lens material, we can build the microlens geometry by considering the volume before and after reflow. The design of the microlens geometry takes the assumption that a reflown thick photoresist will be able to produce a near spherical profile, providing a good refractive geometry to do focusing or collimation. Simple volumetric equivalence can be used to derive the reflow lens geometry without complex simulation.



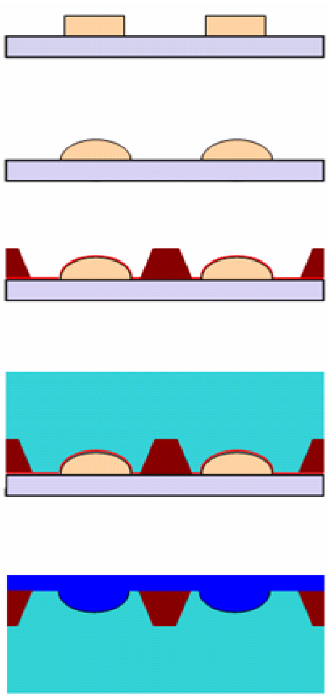


Fig. 4. MLD Process.

The diaphragm-suspended microlens optical element is fabricated via soft lithography using molding technique of PDMS. First, a pattern of circular disks is transfer to the thick, AZ4620 photoresist in preparation for the designed lens reflow (35µm thick). Second, the patterned, thick, dual layered resist is reflown into a semi spherical profile via contact hotplate heating at 145ºC. Third, the lens mount wafer, fabricated earlier, is bonded to the lens substrate via thin coat of AZ5214-E. Next, premixed and degassed (via centrifugation at 3.5 kRPM) PDMS is cured over the wafer complex through gradual curing from 60-90ºC for 30 minutes. The reflow wafer is separated from the rest of the device via ultrasonication in acetone. Finally, 50 µm thick SU8 is spun onto the mold, exposed, and cross-linked slowly from 60-90ºC for 1.5 hrs. The PDMS layer is then subsequently removed. The final structure is now a robust, cured-epoxy-diaphragm suspended, well-controlled MLD wafer.

MEASURED PERFORMANCE OF THE MLD

Two methods are used to characterize the fabricated MLD wafer—profilometry and optical focusing. Contact profilometry is done to verify the reflow geometry on thinner lens sags due the machine range limit. However curvature of the recorded samples shows reflow geometry closely mimicking the trend of a spherical cross section (Fig. 5). On the same graph the theoretical profile of a spherical section is also plotted, which has a 3.05 mm radius that best fit the shape of the reflown cross section.

Typical methods for characterizing high quality normal scale lenses are based on interferometry or physical examination of the surface roughness. For the case of a microfabricated lens, the small size would prove hard for both of these methods to be useful since the size of the lens is on the order of hundreds of micrometers. Although adaptations can and has been done to use microscope aided interferometry and AFM surface analysis of microlenses, a different, and arguably more practical approach was used in this report. Since the microlens is used as a focusing element, we looked at its focusing properties directly through optical means.

One way that a typical lens can be characterized is its ability to focus. Since a positive lens can be considered to be a Fourier transform device for the light (i.e. angular frequency to positional frequency), it should be able to transform a Gaussian input (i.e. nice laser beam) into a Gaussian output Fig. 6a [8-10]. Hence the ability of the lens to maintain a Gaussian focusing is utilized in the characterization of a lens performance.

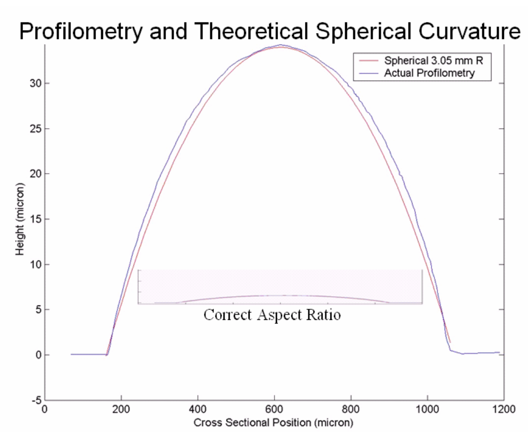


Fig. 5. Reflow of thin lens is compared with spherical profile.

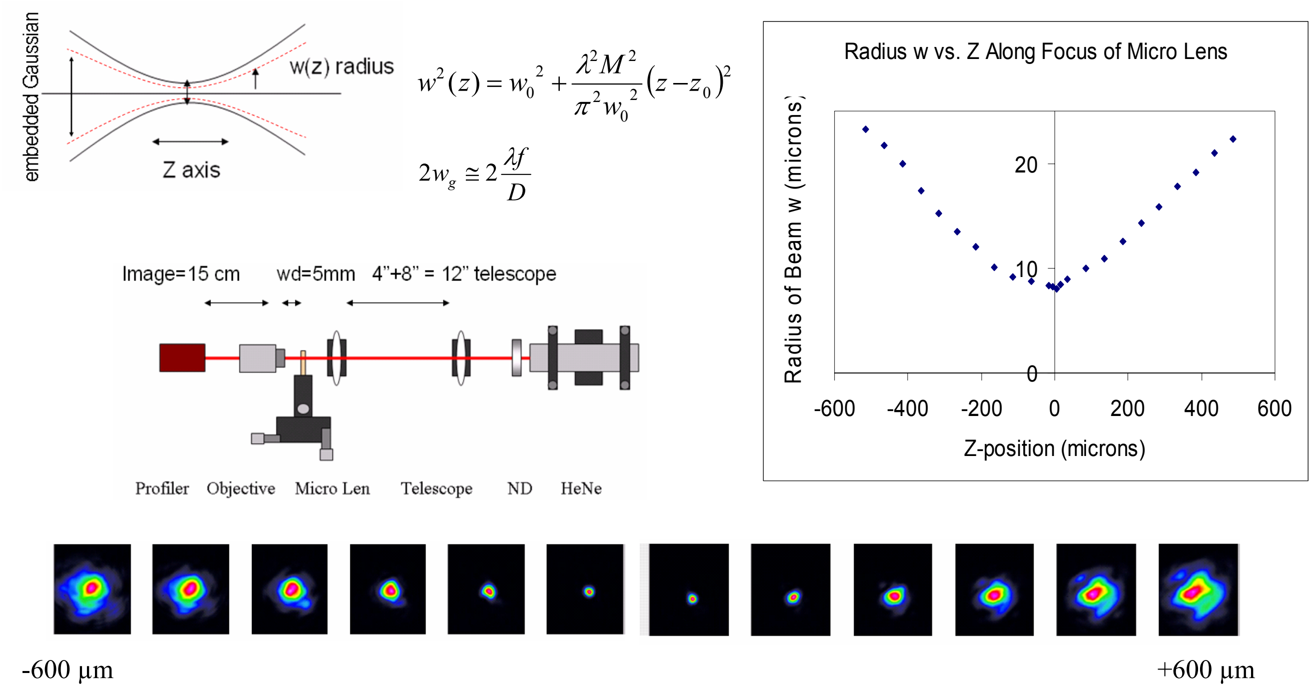


Fig. 6. Gaussian Focusing: a) The measurement is based on Fourier transform of a Gaussian input, with the accompanying equations. b) The setup includes laser source, telescope, the mounted MLD, 25x objective, and beam profiler. c) Plot of the radius along the axis of focus, with 7 µm neck. d) The actual cross sectional images along z-axis.

The second equation from the top in Fig. 6a is the theoretical width of the focus of the Gaussian lens, where w_g is the diffraction limited width of the focus, while λ, f, and D are the wavelength, focal length, and beam aperture that the lens is operating with, respectively. The Gaussian focusing theory expresses the width of the focus as a function of position z along the focal direction as in the top equation in Fig. 6, where w_0 is the minimum focal width and M^2 is a fitting factor that translates into how well the lens is acting as a Gaussian focusing element.

Typical high quality lenses will transform a Gaussian beam and produce a focusing that closely matches the theoretical equation with a M^2 value of 1.2 to 1.3. For the MLD fabricated using the molding process here, we measure a M^2 value of 2.89. This is equivalent to saying that the focusing of our microlens has an envelope that expands Gaussian beam propagation by 2.89 times.

ALIGNMENT, BONDING AND DICING

For the aligned epoxy bonding, the wafers are handled within a Karl-Suss MJB3 contact aligner with visible and IR backside illumination capabilities. One wafer is fixed onto a glass plate by capillary force with controlled amount of water. The other wafer is then spun with premixed epoxy and quickly transferred to the aligner for aligning and contact bonding. Etched holes are used as alignment marks throughout the wafers in order to produce the designed geometry. Backside alignment is used as necessary to improve the process. When the wafers are aligned, they are brought to contact by physical force and securely seated. In the intermediate step involving silicon micromirror, aluminum thin film is deposited to enhance reflectivity and oxygen plasma at 100W, 200 mTorr is applied for 10 minutes to remove excess epoxy.

This bonded optical subsystem is diced to the individual unit dies of 5 mm by 5 mm. However, the dicing is proceeded to leave 80 µm of thickness to allow the wafer handling for the bonding to the actuator wafer before separating into individual devices. The actuator layer also is diced to 5 mm by 5 mm units. The actuator is partially diced like the packaging, released via RIE in CF_4 plasma, and bonded to the SSC encapsulation with epoxy. The resultant sandwich array is separated after bonding by breaking the partially diced wafers by hand.

MEASURMED SYSTEM OUTPUT

For the system that has been built with the MLD and the SSC packaging, the most important performance criteria are its resolution and stray light characteristics. To look at these factors, a dual wavelength collinear HeNe source with 543 nm and 594 nm output is used as the input to the system. In Fig. 7 the input is directed into the system in the red beam shown near the bottom. The diffracted output is then visualized at the detection plane of the same beam profiler as the one utilized in the Gaussian focusing setup.

From Fig. 8 it can be seen that the two wavelengths are clearly separated at the output of the MOEMS system, this demonstrates that the resolution is capable of resolving the 543 nm and the 594 nm laser beam. Based on the diagram of Fig. 7 along with the geometrical dimensions, it can be estimated that the system resolution is around 25 nm. The stray light rejection of the diffracted output is measured at -8 to -15 dB. The optical efficiency of the packaged system is 26% (at 543 nm) compared to 67% for the plain grating. Most of this loss is suspected to be due to the MLD quality and the measurement setup.

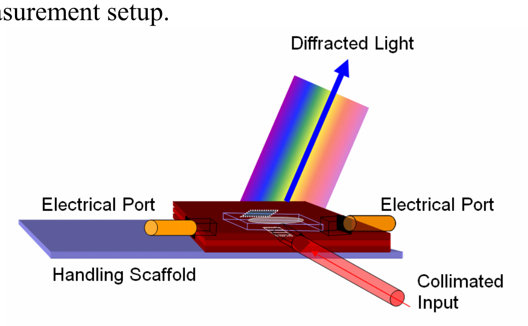


Fig. 7. Diagram of a completed package. The 5 mm by 5 mm unit is a multi-layered wafer level package that is finished with a handling scaffold.

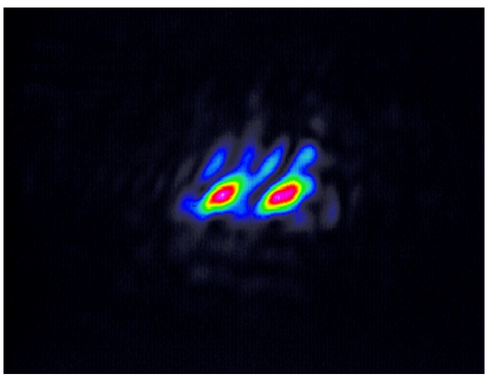


Fig. 8. A packaged device separates dual wavelength HeNe of 543 nm and 594 nm, image taken at far field.

CONCLUSION

A wafer level, silicon cavity structured multi-element micro optical system is constructed with the tools available in microfarbrication. The optical elements included in this packaging system are the aluminum-coated silicon plane mirror and the diaphragm-suspended microlens. This aligned and bonded system is used to encapsulate a MEMS actuator that produces scanning of a diffractive grating. The overall system represents a capable fluorescence detection unit that is demonstrated to separate wavelengths of 543 nm and 594 nm from a collinear laser source.

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