Silicon Lens Arrays for Wafer Level Packaging of IR-Sensors

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ABSTRACT

A new process technology has been developed for a cost efficient production of refractive convex lenses made of silicon. These lenses are produced as lens arrays on standard eight inch Si-wafers to allow the optical capping of IR sensors in a wafer level packaging (WLP) process. A manufacturing process is described using a glass forming process with thin (50µm) AF32® glass wafers. Si-spheres of well-defined diameter are transferred to a thin glass membrane on top of a Si-wafer with prefabricated cylindrical openings. In a thermal bonding process, the lens part of the Si-spheres sinks into the cavities while the outer part is grinded away. The resulting plano-convex lens calottes remain firmly embedded in the wafer surface. In this manner an array of Si-lenses on a Si-wafer is realized to be used as cover wafer for wafer level packaging of IR-sensor devices. First designs of Si-lens arrays have been fabricated. Starting with Si-spheres of radius of curvature 0.8 mm convex lenses of 0.82 mm diameter (aperture) and a sagittal height of 0.12 mm were produced.

Keywords: IR-detector, Silicon lens, vacuum packaging, MEMS, Wafer-level packaging

1 INTRODUCTION

Worldwide market volume for uncooled thermal cameras and thermal detectors is at present estimated to between 2 and 3 bil. US$ p.a. [1]. Thermal (IR) detectors for thermography, motion or presence detection use single sensors or a small number of sensor pixels. IR-cameras for imaging use sensor arrays from small resolution (32x32 pixel) up to XVGA resolution (1024x768 pixel). IR-sensors can be fabricated from thermocouples (thermopile), pyroelectric materials, micro-bolometers or suited photodiodes or phototransistors. To improve the sensitivity of the radiation sensors and to shape the field of view of a detector system IR-sensors are usually manufactured with an optical system for concentration of radiation, i.e. one or a combination of several lenses. Lenses for IR-applications can be made of polymers, silicon, germanium or chalcogenide-molded glass. Polymer materials have the lowest costs of these materials but also limited optical properties and they cannot be used in processes at elevated temperatures. While optical elements made of germanium are expensive silicon is an auspicious material for IR optical elements due to its large refractive index of approx. 3.4 in the IR-range and its wide availability.

Sensitivity of an IR-sensor element can be further increased by operating the sensor in vacuum. The absence of convective heat flow in vacuum increases the sensitivity to absorbed heat radiation. Vacuum tight packaging of IR-sensors can be achieved using an IR-transparent window on top of a sensor. If this window can be realized as a collecting lens a further miniaturization of an IR-detector becomes possible. In Fig. 1 a technical realization is shown for an IR-sensor with vacuum package and a concentrator lens.

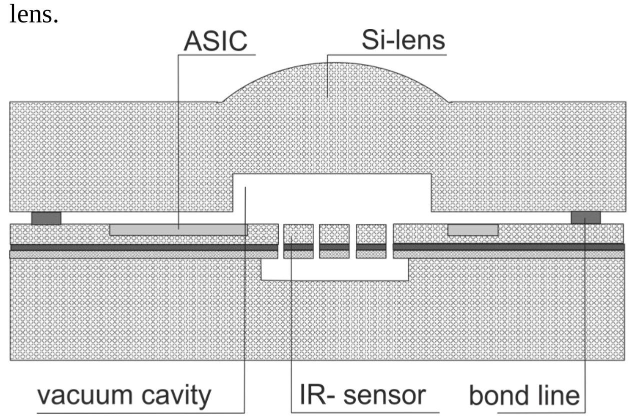


Fig.1: Principal set-up of IR-sensor (e.g. bolometer), read-out circuit and concentrator lens as part of a hermetically tight vacuum chip-size package.

This IR-detector can be manufactured by a wafer bonding process in vacuum forming a tight bond between a bottom wafer with sensor elements and a top wafer with IR lenses. Because wafer bonding is a batch processing technology this is potentially a very cost effective solution for volume production. Generally lens arrays on a Silicon wafer can be manufactured as Fresnel lenses or as convex shaped concentrator lenses. Both lens types can be produced only laboriously with standard Silicon technology. For a Fresnel lens several lithography and dry etch process steps have to be repeated [2]. A convex lens form can be transferred into Silicon by a dry etch process after a lithography and resist forming process. Since the resist shape has to be transferred smoothly into Silicon the dry etch process must not damage the resist too strongly. In Ref. [2] a processing example is described with an etch rate in the range of 0.25 µm/min. Thus a lens of 200 µm height has to be etched for 12 hours [2].

In the following a new technology is described for production of high quality silicon lens arrays on silicon wafers suited for wafer level vacuum packaging.

2 PROCESS FLOW FOR SILICON LENS ARRAYS

The new production process for silicon lens arrays is based on extensive knowledge of glass forming processes in our institute that have been applied to manufacture various optical elements in the past [3], [4]. Here the instance is used that thin glass foils between 20 to 50µm thickness have recently become commercially available. Glass foils from Schott (AF32®)[1] or Planoptik (BF33®) are offered in thicknesses between 20 µm and 50 µm in rectangular or round wafer shapes. The foils are shipped in protective shieldings to avoid damaging of the fragile material. This shielding results in a substantial particle contamination of delivered glass foils. Therefore a suited cleaning process had to be developed before the thin glass foils could be fed into standard silicon micromachining processes. Once the foil is cleaned from particles and contamination it can be handled by attaching the foil on a carrier wafer. In combination with a carrier wafer glass foils can be introduced and machined in a standard silicon processing line.

The process flow is shown in Fig. 2. In a first step to manufacture lens arrays circular holes of 800 µm diameter are etched through a standard 725 µm thick Silicon wafer by a deep reactive ion etch process (DRIE) (a). This wafer will finally become the cover wafer for wafer level packaging of IR-sensors. A thin glass foil of AF32® glass with a thickness of 50 µm is bonded on top of the wafer by an anodic bonding process (b). With this bonding process the holes in the wafer are sealed on one side of the wafer. A second wafer is used as carrier wafer for Silicon spheres. Si-spheres can be procured commercially from Clean Venture 21 Corporation, Japan in diameters from 0.4 mm to 1.9 mm. Cavities in the carrier wafer are adjusted and produced in alignment with the holes in the first wafer. These cavities are filled with Si-spheres by a process that is usually used to adjust soldering balls on bonding pads on chips for chip size assembly processes (wafer level packaging) (c).

The wafer with anodic bonded glass foil is placed and aligned above the Si-spheres in the carrier wafer inside of a vacuum chamber for wafer bonding (d).

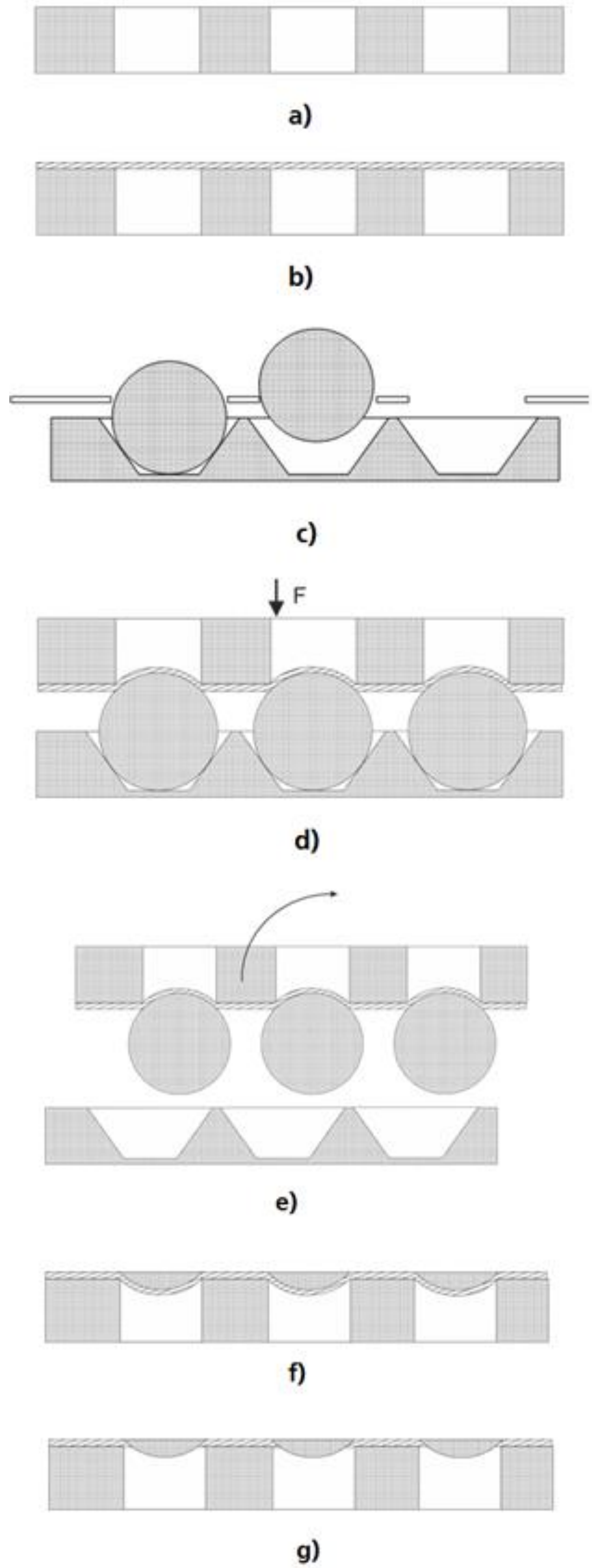


Fig. 2: Process flow for silicon lens arrays.

[1] AF32®, Trademark of Schott Glas, Mainz, D

The chamber is evacuated and a uniform force is applied on the top wafer with glass foil. Temperature in the vacuum chamber is increased up to 800°C. This temperature is above glass transformation temperature of AF32® glass of T_g=722°C. Therefore the glass becomes soft and ductile. The applied force pushes the Si-spheres into the prefabricated holes in the top wafer and the glass foil adapts to the spherical surface. The close contact between the Silicon oxide of the glass foil and the native Silicon oxide on the Si-spheres in vacuum at elevated temperatures creates a tight connection between the Silicon oxides, effectively bonding the spheres to the glass material. Cooled down to room temperature the top wafer with tightly attached Si-spheres is separated from the carrier wafer. The wafer with spheres is transferred into a grinder (Disco). The spheres are grinded until a planar surface is achieved with the glass foil and the remaining Silicon calottes. Bond between the glass foil and the Si-spheres is so strong that the bonding is not loosened by the abrasive force of the grinding process. Up to now no dismantling of a silicon sphere has been observed. With this grinding process the Si-spheres are reduced to plano-convex lenses. The grinding is followed by chemical mechanical polishing (CMP) to produce a planar surface of high optical quality.

Finally the residual glass foil on top of the convex lens surface has to be removed. For this removal a wet etching process with a mixture of HF:HCl is used. Etching time and process parameters have to be adjusted to avoid an under etching of the connection between wafer and lens at the edge of the round cavities that fixes the lenses on the wafer.

3. WAFER PROCESSING

To manufacture Silicon lens arrays on eight inch Silicon wafers Si-spheres of 1.6 mm diameter have been used. According to Clean Venture 21 Corporation, Japan the spheres are produced as follows: Drops of molten Silicon are inserted into a down pipe and solidify in free fall.

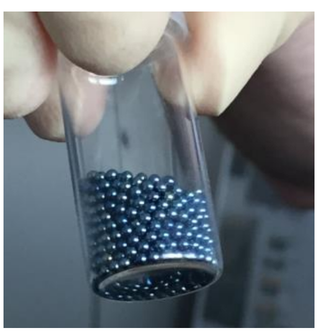


Fig. 3.: Commercially obtained Silicon spheres.

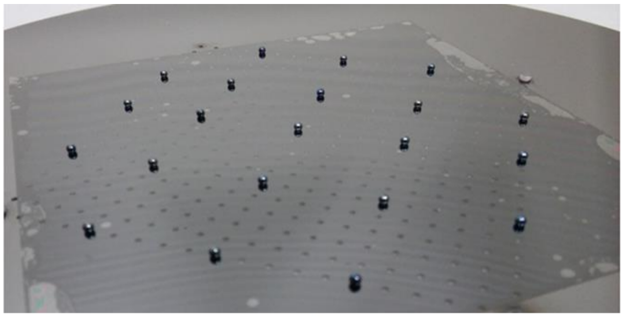
Cohesion forces in the Silicon drop and surface tension produce a spherical form of the free falling and cooling drops. The solidified Si-spheres are polished to reduce deviations from spherical symmetry and sorted by diameter. Spheres are available in diameters 0.4 mm to 1.9 mm specified with +/- 20µm. A sample of delivered spheres is shown in Fig. 3.

The spheres are arranged in cavities on a preprocessed Silicon wafer that is acting as carrier wafer for the further handling of the spheres. The carrier wafer is prepared by a lithography and wet etch process. An arrangement of Si-spheres on a carrier wafer is shown in Fig. 4. The wafer in Fig. 4 is used for process development. The spheres are therefore not arranged in the highest possible density as would be required in a later production process.

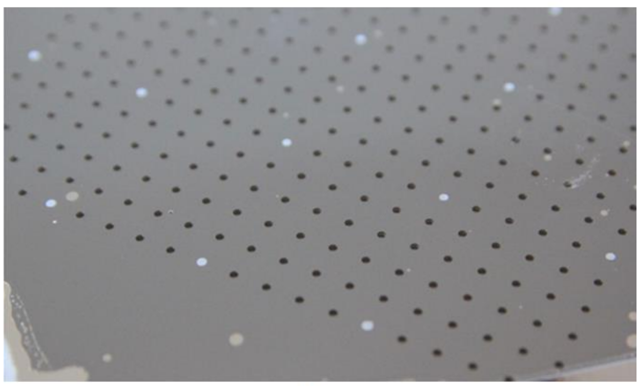
Fig. 4: Silicon spheres placed into a prefabricated Silicon carrier wafer.

In the next step the Si-spheres in the carrier wafer are tightly bonded to a thin glass wafer. For this bonding the effect is utilized that above a glass specific transition temperature viscosity of the glass is greatly reduced and the glass becomes soft and ductile. Other related glass micromachining techniques have been used in the past to create various shapes and microstructures [5], [6], [7], with outer pressure from an inert atmosphere prefabricated forms can be filled with glass or free forms can be blown out with very smooth surfaces. In the process described here mechanical force is used to push the Si-spheres into the thin, ductile glass membrane above the prefabricated wafer holes. During this joining process the glass membrane adapts to the spherical form of the Si-spheres. At the same time pressure and elevated temperature create a tight interconnection between the Silicon oxide in the glass and the nanometer thick native Silicon oxide on the Si-spheres. This bonding is effectively a kind of thermal compression bonding. In Fig. 5a a test wafer is shown with Si-spheres bonded onto a 50 µm thick glass membrane that is anodic bonded onto a Silicon wafer with round wafer cavities below the spheres. These cavities can be seen on several positions that are not covered by spheres. In Fig. 5 a rectangular glass sheet is used on a 200 mm diameter Silicon wafer to demonstrate the technology. By now also 200 mm diameter round glass wafers are in use for the described process.

This rigid wafer-glass-sphere set up is transferred into a Disco grinder. By a grinding process the free standing part of the spheres is removed. Initially material is abraded with a 600 mesh grinding wheel at a removal rate of 1.2-1.4 µm/sec. The final 5 µm are removed with an ultrafine polish at a rate of 100 nm/sec stopping on the glass surface. This grinding will be followed by a standard CMP process to finish the lens surface in optical quality. The successful result of the grinding process is shown in Fig. 5b where the fabricated Silicon lenses are seen from above embedded into the glass membrane bonded on a silicon wafer.



a)



b)

Fig. 5: Silicon spheres bonded onto a glass membrane before (a) and after grinding (b) of the surface.

4. SUMMARY

A new process has been developed to fabricate Si-lens arrays on Si-wafers. The lenses are carved out of Si-spheres by grinding and polishing. To fix the Si-spheres during grinding they are attached to a thin glass membrane by thermal compression bonding. The thermal expansion coefficient of the glass material used has to be adapted to the thermal coefficient of Silicon to allow the thermal variations described. Suitable glass material like borosilicate glasses (BF 33®, AF 32®) is offered commercially in thicknesses down to 20 µm. First examples of Si-lenses have been manufactured on Si-wafers. Starting with Si-spheres of radius 0.8 mm lenses of 0.82 mm diameter and 0.12 mm sagittal height have been fabricated leading to a theoretical focal length of 0.375 mm resulting in a F-number of 0.45. In the next step the residual glass film on the lenses will be removed and the optical properties of the Si-lenses will be determined. In Fig. 6 a detail picture of a lense is shown that was produced by the process described.

Fig. 6: Microscope picture of a Silicon lens embedded in a Silicon wafer. A glass membrane can be seen as a grey cover on top of the lense.

After manufacturing of Si-lens arrays a bond frame will be deposited on the Si-wafer. Bond frames can be made of glass frit material or can be evaporated from suited metals. When a bond frame is produced the lens arrays are available as cover wafers for wafer level optical packaging. Si-sphere diameters and carrier Si-wafers can be designed in a wide variety. Therefore the manufacturing process described here can be adapted to various IR-sensor designs.

ACKNOWLEDGEMENT

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REFERENCES

[1] Yole Development, “Uncooled Infrared Imagers Report, Technology and market trends”, 2017.
[2] E. Logean et al., Proc. SPIE 8550, Optical Systems Design 2012, 85500Q (December 18, 2012).
[3] V. Stenchly et al. “New fabrication method of glass packages with inclined optical windows for micro mirrors on wafer level”, Proc. of SPIE Vol. 8613, 861319-1, 2013.
[4] H.-J. Quenzer et al., US Patent No. 6,951,119 B1, Oct. 4, 2005.
[5] P. Merz et al., “A novel micromachining technology for structuring borosilicate glass substrates”, Transducers 12, Solid State Sensors, Actuators and Microsystems, vol.1, p. 258-261, 2003.
[6] H.-J. Quenzer, V. Stenchly, S. Schwarzelbach, M. Kampmann, B. Wagner, R. Dudde, Proc. Nanotech 2014, Washington 2014.
[7] S. Gu-Stoppel, et al., TechConnect Briefs, Electronics and Microsystems, pp. 87–91, 2016.