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Wafer-level capping and sealing of heat sensitive substances and liquids with gold gaskets

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ABSTRACT

This paper reports on a novel wafer-level packaging method employing gold gaskets and an epoxy underfill. The packaging is done at room-temperature and atmospheric pressure. The mild packaging conditions allow the encapsulation of sensitive devices. The method is demonstrated for two applications; the wafer-level encapsulation of a liquid and the wafer-level packaging of a photonic gas sensor containing heat sensitive dye-films.

1. Introduction

Several applications require microsystems with encapsulated liquids. Examples are variable focus micro-lenses [1–3], switches and devices based on switches [4–10], drug-delivery devices [11–18], microfluidic electronics [19], tactile displays [20–23], and others [24]. However, the wafer-level integration of liquids or in general sensitive substances is a technological challenge.

Traditional techniques for the fabrication of hermetically sealed micro-cavities, such as thermo-compression bonding [25–30], solder bonding [30–35], glass-frit bonding [25,30,33,36–38], eutectic bonding [30,39–44], and deposition sealing techniques [33,45–59] require elevated temperatures and/or a vacuum atmosphere. They are therefore typically not suitable for the encapsulation of liquids. Some exceptions have been reported, such as the encapsulation of a low vapor pressure liquid under vacuum conditions by parylene deposition [3] or the encapsulation of water by parylene bonding [60] at 220 °C. Here, the bond-tool pressure was maintained higher than the water vapor pressure to confine the water in the cavities. However, these techniques can only be used when the liquid can tolerate these harsh process conditions. When vacuum processes or temperatures much higher than room-temperature cannot be tolerated by the liquid or the device materials, one possible option is the injection of the liquid into the reservoirs with needles after fabrication, as demonstrated in [20]. On wafer-level, adhesive wafer bonding can be used at room temperature and atmospheric pressure [25,30,33,38,61]. A common polymer-based liquid encapsulation technique is based on the use of UV curable epoxy [4,10,20–22,61–64]. Another polymer-based liquid encapsulation at room-temperature and atmospheric pressure utilizes stiction valves made from parylene [23,60,65,66]. However, polymer-based encapsulation approaches are not hermetic and thus the confinement period of the liquid is limited [67], which can be a desired or tolerated feature in some, but not all applications.

A method to encapsulate liquids at ambient conditions is the plugging of the reservoir access ports with gold stud-bumps [68]. This is an elegant and fast solution when the application allows filling thru small holes and the protruding stud-bumps. A hermetic sealing method at room-temperature that is based on cold welding of corresponding and partly overlapping gold rings has been presented in [69]. However, in this method shear forces occur that can break off the sealing rings or induce micro-cracks underneath the gold rings on surfaces with a lower modulus of rupture such as glass. The use of a Teflon gasket to confine a liquid in combination with the application of an epoxy underfill for stabilization has been reported in [62]. This technique however has limited hermeticity, as it is based on polymer seals.

Here, we report on a wafer-level method for encapsulation of liquids or other sensitive substances at ambient temperature and pressure. The method is based on a gold gasket for hermetic sealing

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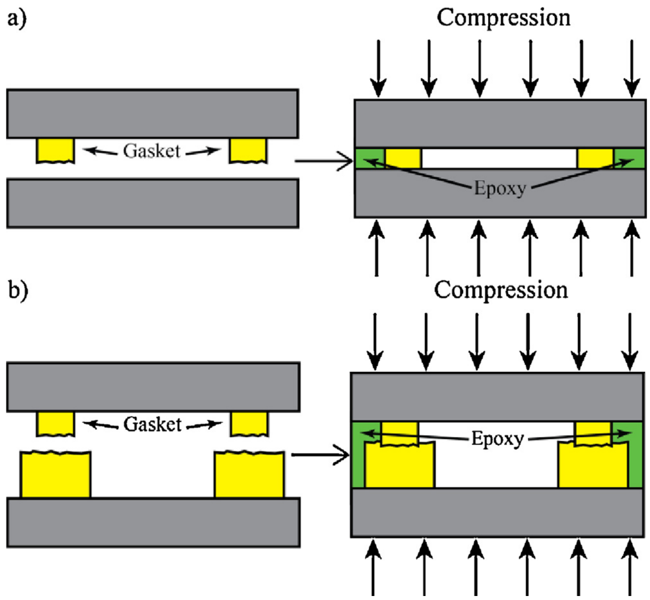

Fig. 1. Schematic drawings of two variants of the sealing process.

and the application of epoxy underfill for stabilization. Bubble-free application of the epoxy underfill is performed at atmospheric pressure using capillary filling microfluidic channels. The method is shown for the hermetic encapsulation of a liquid on a wafer and for the zero level package of a photonic gas sensor that contains heat sensitive dye films as sensing elements.

2. Concept and implementation

The method of encapsulation presented in this paper is an analogy to a method of joining ultra-high vacuum pipes. It is based on the plastic deformation of a gold gasket, as shown in Fig. 1(a). The gasket is very small compared to the package dimensions, so when a sufficiently large bond force is applied, plastic deformation occurs. As a result, the gold adapts to the surface roughness of the mating surface and leaks are thereby sealed. When the mating surface is also made from gold, as shown in Fig. 1(b), the gold structures are cold welded, which results in a seal with improved hermeticity [35,69–72]. Metal cold welding is based on atomic surface migration between surfaces that are brought into intimate contact, which strongly depends on temperature and time. With proceeding time, more atoms migrate in between the surfaces, which results in a stronger bond [70]. Overall mechanical stability of the wafer bond is achieved by an epoxy underfill that is applied to the gap between the surfaces. Heat sensitive materials and liquids can be encapsulated using this method because the encapsulation process takes place at room-temperature and ambient pressure.

In a first development attempt, we demonstrate the method for the encapsulation of heat sensitive liquids on wafer-level. Based on these results, a package for a gas sensor is designed. Common to both applications is that they benefit from the mild processing conditions of the method, although the two applications have different sealing and packaging requirements.

3. Encapsulation of liquids

3.1. Design of the liquid package

The purpose of this proof-of-concept package is to demonstrate that the proposed gold gasket method can be used for sealing of heat sensitive liquids on wafer level. Fig. 2 shows the schematic drawing of the package. The reservoirs are defined by metal walls on the bottom silicon wafer, into which the liquid is dispensed. The lid wafer is equipped with gold gaskets, which hermetically seal the reservoirs after attaching the lid wafer to the reservoir wafer. An epoxy-based underfill is used (not shown in figure) for mechanical stabilization and fixation of the wafer stack. Fig. 3 shows some of the design variations that have been implemented for the reservoir walls on the bottom silicon wafer and the gold gaskets on the lid wafer. Circular reservoirs, square reservoirs with rounded edges, and rectangular reservoirs with rounded edges are implemented. Common for all reservoirs is the 50 μm wall width and 50 μm wall height that forms the cavity. The design variation for the gaskets includes different gasket widths, different amount of gaskets per reservoir, and the use of cross connections between multiple gaskets. Generally, the gasket geometry matches the geometry of the reservoir wall and all geometries have rounded edges. An overview of the design variations is given Table 1.

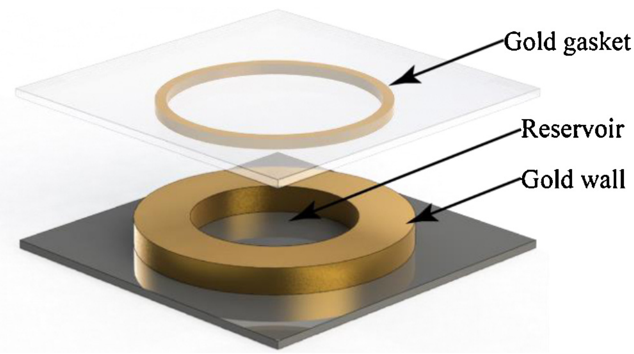

Fig. 2. Schematic drawing of the liquid sealing package.

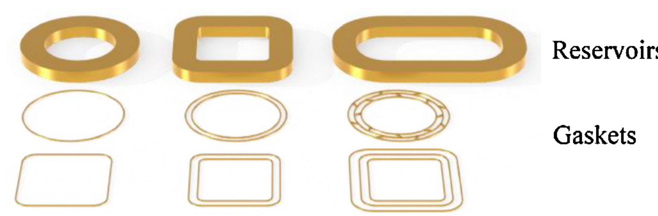

Fig. 3. Subset of gasket and reservoir designs that have been investigated. The larger structures on the top row depict the reservoir walls with different geometries, the tiny structures on the lower two rows show typical gasket variations, in scale with the reservoirs.

3.2. Fabrication of the liquid package

The fabrication of the reservoir and encapsulation of the liquid is depicted in Fig. 4. A gold seed layer from 20/150 nm Ti/Au in combination with a patterned photoresist mold is used to electroplate the gold reservoir walls on a 500 μm thick glass wafer with 100 mm

Table 1
Design variations of reservoirs and gaskets.

Reservoirs	Geometries	Round, square, rectangular
	Wall width	50 μm
	Wall height	50 μm
	Side lengths	2.5–7.5 mm (10 variations)
Gaskets	Geometries	Matches the geometry of reservoir
	Width	2–7 μm (14 variations)
	Height	4 μm
	Gaskets per reservoir	1–3
	Cross connections between multiple gaskets	Only some structures