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The ubiquitous technology for prototype and disposable bio-chemical sensors packaging

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Abstract:
A new packaging process for silicon-based chemical sensor arrays has been develop using semiconductor, thick film, and flip-chip technologies. Passive sensors are fabricated on silicon in a semiconductor process compatible with the incorporation of on-chip electronics. Sensor-specific polymer membranes are screen-printed directly onto individual electrode sites. Substrates with flow channels are made from glass using semiconductor process technology. Sensor chips are mounted onto the substrate using a flip-chip approach in which the fluid channels are sealed with a polymer gasket. Electrical contacts between the chip and substrate are made through conductive epoxy bumps. Conductors are brought out to the edge of the substrate; where they are accessible to the next level of system interconnect through a standard board-edge connector.

Key words: new packaging process, sensor arrays, partitioning, microfluidics integration.

Introduction

Among the most promising approaches for reducing the cost of chemical sensing instruments is the use of semiconductor processing technology to mass produce microsensors. This technology has proven capable of producing many types of functional solid-state chemical sensors [1,2,3]. Arrays of such sensors are valuable because they can provide multicomponent analysis, interference compensation, redundancy, and extended dynamic range. Disposable sensor arrays will be at the heart of many future biomedical and industrial chemical analysis instruments. Truly cost-effective arrays, however, require both inexpensive sensors and inexpensive (batch-fabricated) packaging. Ideally, these packages should also protect the sensors during handling, allow simple replacement of the sensor array, and have adequate input/output density. For chemical analysis applications, the packaging scheme must include a fluid channel. As the size of this channel is reduced, the required sample size and cost of calibration are reduced

1 Packaging Issues for Sensors

Sensors fabricated on silicon have many advantages, including reproducibility provided by semiconductor process technology, low cost associated with batch fabrication, process support by the electronics industry, and the capability of forming integrated sensors. The integration of such sensors with signal conditioning electronics, micromachined chambers or flow channels, or other types of sensors by the lack of simple and effective encapsulation, interconnection, and packaging technologies.

Sensor system partitioning can be approached in many ways; in choosing a specific level and method of integration, application demands, process compatibility issues, and final lower system cost. A combination of sensors and electronics on monolithic chips are conceptually capable of improved performance, efficiency, and reliability as compared to equivalent systems assembled from multiple components. An alternative is the adaptation of commercial multichip modules (MCMs) for sensor integration. and MCMs interconnect chips through metal lines patterned by thick –or thin – film methods on a suitable substrate, such as ceramic or silicon.

Conventionally, silicon-based sensors are passivated and tested prior to separating them into individual dice. Sensor chips are attached individually or in groups onto a suitable substrate, such as a printed circuit board or header, and wire bonded to the same to provide electrical I/O connections between the chip and the next level of interconnection. In addition, the substrate serves as a package for the sensor by providing it with mechanical and environmental protection and a path for dissipating heat.

1.1 A simple packaging process

The packaging requirements for chemical, biological and biomedical sensors are more complex, since their sensing elements must be in direct contact with the measuring environment, which from an electronic point of view is hostile. Furthermore, most of the processes for chip-to-package attachment are incompatible with chemical sensors. The high temperatures are detrimental to thin film electrode materials, ionophores and biological layers. The fabrication of these sensors must be partitioned so that all processing which follows the formation of these sensitive elements is low temperature (typically below 50^0C) of the attachment possibilities listed previously, epoxy bonding offers the lowest process temperature and the least thermally induced stress [6].

The process presented here packages silicon-based chemical sensor arrays with substrates containing flow channels and the package assembly can be fully automated and manufactured exclusively with batch fabrication technologies

2. Advanced concept of microsensors interconnect technology

The concept of flipping or inverting chips for mounting offers some distinct advantages for integrated circuits in general. Shorter interconnect distances result in lower inductance and faster signal response. Thermal performance is enhanced in two ways: the conductive bumps provide excellent thermal pathways, and the backside of the chip remains accessible for heat sinking. Array bond pad configurations can be used to increase I/O capacity and to provide uniform power and heat distribution. This last point is most important to solid-state sensors. Automated assembly can give sensors packaged an important economic advantage over those packaged in usual more time-consuming and costly process.

As developed last years, flip-chip interconnect technology has traditionally connected dice to a substrate through raised metallic bumps fabricated in the chip pads or on matching pads on the substrate. While these solder bumps provide the lowest inductance and resistance path available between chip and substrate, their formation requires special metallurgy and high temperature processes. A chip is placed face down, aligned to the substrate, and the solder bumps are reflowed at a temperature in the range of 300° C to join the two pads. As mentioned previously, high temperatures are not compatible with many of the polymeric or biological components required by chemical sensors.

Recent advances in the materials used for flip-chip interconnection, however, have made this technology available for chemical sensor design. It is now possible to replace the traditional solder bumps with a conductive polymer, or epoxy. The epoxy can be cured at low temperature, and unlike solder it does not flow when the chip is mated to the substrate, thereby making possible a finer pitch. The polymer flip chip is an efficient, practical, high-volume production method. With conductive polymer interconnect, flip-chip technology can be part of the solution to the packaging challenges of chemical sensor arrays.

The following process uses the flip-chip approach to electrically connect and physically attach a silicon sensor chip and package substrate. A polymer is used to form a seal to contain solution within the channel and protect the rest of the package. Low temperature curing polymers have been used previously to encapsulate silicon sensors and bond them to glass. Attempts at using polymers for encapsulation [9] have shown that, in most cases, poor adhesion to the substrate, rather than polymer permeability, leads to encapsulation failure.

2.1 Silicon Processing

Sensors are fabricated in silicon using a sequence of CMOS-compatible semiconductor process steps and thick film technology, allowing for the future incorporation of on-chip signal conditioning electronics. The basic structure of a solid state electrode, as shown in Fig. 1, is quite simple. Polysilicon leads connect the sensors to silver output pads. Sensors are realized by the formation of various metal sites using a lift-off process. Coatings may be applied to selected sensor sites by a wafer-scale electroplating process using a grid. Following completion of the semiconductor process sequence, all remaining structures are formed using thick-film technology. Precision screen printing is used to deposit sensor-specific polymer structures, silver epoxy flip-chip interconnect bumps, and the channel sealant, as summarized in Table 1:

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Table 1: Thick Film Technology for Chemical Sensors

Structure	Material	Thickness
ISE Contact Layer	Silver Epoxy	50 µm
Ion-Selective Membranes	PVC, Siliconne Rubber	150 µm
Enzyme Immobilization	PVA, Hydrogel	75 µm
Flip-Chip Bond Pads	Silver Epoxy	25 µm
Channel Sealant	Silicone	75 µm

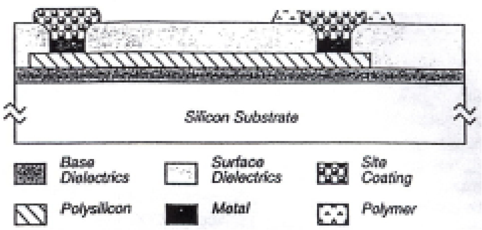


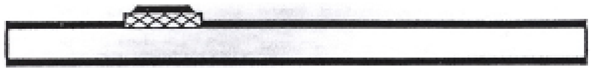
Fig 1: A schematic cross-section of a generic solid state electrode. The site coating may be either silver epoxy or an electroplated material

This example of technology partitioning during sensor fabrication carries over to the proposed package structure. We have used the electrically conductive silver epoxy to make interconnect bumps and to provide a stable connection between the site metal and membrane material which is capable of stenciling 50 micron high bumps with a 304,8 microns pitch, as well as 25 micron high bumps with a 203,2 microns pitch.

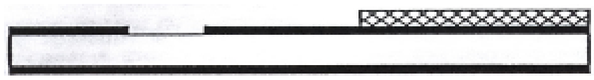
2.2 Substrate Processing

Substrates were made from both soda lime and Pyrex (Dow Corning #7740) glass wafers, 100mm in diameter and microns in thickness. Soda lime was chosen for its low cost, while Pyrex is a well characterized micromachinable material, and its low temperature coefficient of expansion makes it desirable for applications in which the test solution needs to be heated or maintained at an elevated temperature. Glass substrate fabrication, as shown in Fig. 2, requires just two photolithography steps, followed by a single screen printing step. Following semiconductor processing, holes are drilled into each of the flow channel for fluid ports, and the substrates are partially cut with a wafer saw. Silver epoxy is printed to form the other half of the flip-chip interconnect bond, and the substrates are separated from each other. The substrates have arrays of metal leads, each of which is brought out to the substrate edge in a configuration compatible with standard board-edge connectors.

(i.) A clean glass wafer (of thickness compatible with a selected board-edge connector)

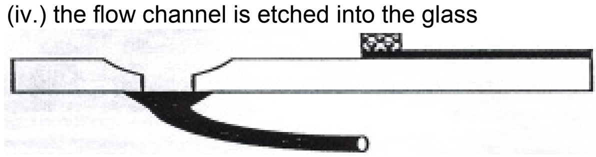


(ii.) The surface is then sputter-coated with silver, and provide substrate interconnect.



(iii.) The wafer is patterned for interconnect

(iv.) the flow channel is etched into the glass



(v.) Finally, all excess silver is etched

Fig 2: Process sequence for glass substrate fabrication.

The two glass materials used etch quite differently, as seen in Fig. 3. The sidewall profile for the Pyrex is straight, at an angle of about 35°, while the soda lime glass profile is rounded. In addition, the etched surface of the soda lime glass channel is uniformly rough, while the floor of the Pyrex channel is almost perfectly smooth. Etching processes and mechanisms for these two materials are still being investigated, along with the suitability of their characteristics for various applications.
For volume production, substrates made by injection - molded plastic substrates more cost-effective and our packaging process easily.

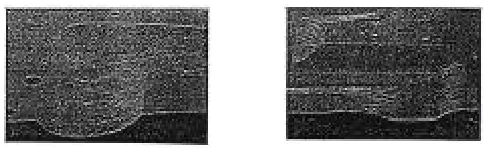


Fig 3: Flow channel etched in (top) soda lime and (bottom) Pyrex glass

3 Packaging sensor assembly, experiments and results

Following fabrication of both the sensor chip and glass substrate, the package is ready for assembly, by either of two methods. In both cases, the silicon chip is inverted over the substrate and mounted over the flow channel, as shown in Fig. 4. A polymer which is screen-printed around the perimeter of the sensor array seals the channel by acting as a gasket at the silicon-substrate interface.

In one method, the silicon is embedded within a recess in another (smaller) piece of glass, shown in Fig. 4 as the top mounting plate. The channel sealant and conductive polymer are printed and cured prior to assembly. The top mounting plate is aligned and secured to the glass substrate by small fasteners which slide through pre-drilled holes in both pieces of glass. This structure allows for separation of the chip from the substrate following testing, allowing either piece to be examined or replaced. The clamping force of the fasteners gives this method the advantage of a longer package lifetime during use. The fasteners also simplify alignment of the chip to the substrate.

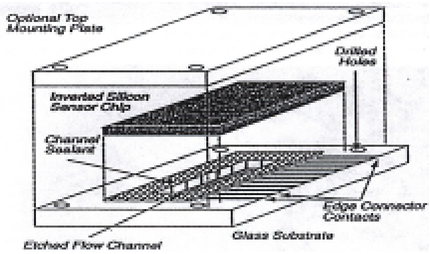


Fig 4: A schematic of each of the package components and the assembly

In an alternative method, the entire package was disposable. The channel sealant and conductive polymer have applied just prior to assembly. After that conductive polymer bumps on both surfaces have aligned through the glass and contacted, the entire package has processed to cure the polymers. For additional protection, the chip may be coated with a moisture resistant encapsulant.

By our flip-mounting procedure for assembly both establishes electrical contact between the silicon and the substrate through the conductive polymer bumps, and aligns the sensing sites inside the flow channel, as shown in Fig. 5. The package sensor is made ready for use following the attachment of tubing over the ports on the back side of the substrate.

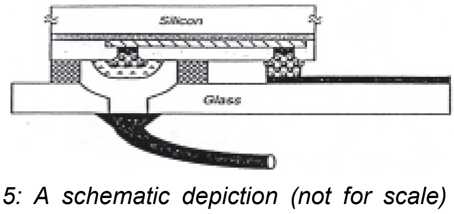


Fig 5: A schematic depiction (not for scale) of the electrical connection and seal between the silicon sensor chip and the glass substrate

3.1 Results

The process has been successfully applied to the packaging of multi-sensor arrays of solid-state potentiometric, amperometric and conductometric sensors fabricated on silicon chips measuring 15mm x 15mm. The glass substrates used contain 1mm wide by 0.25mm deep flow channels. A finished package is shown in Fig. 6. It interfaces to a standard 20 pin board-edge connector with 2,54 mm spaced contacts and shielded ribbon cable interconnect.

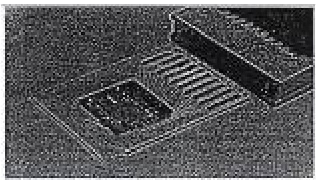


Fig 6: A packed silicon-based sensor chip, assembled without the top mounting plate

Ongoing work is focused on studies of the seal integrity and lifetime in both the disposable and reusable versions of the package. Scaling limitations for the sensor structures and the flow channel will also be determined as a function of detection limit and flow rate.

Summary and conclusions

Chemical sensors have unique packaging, interconnect, and encapsulation requirements. By our technological concept the sensor design demands are simultaneously and cost-effectively met. System-level partitioning for chemical sensors calls for the integration of a sensing structure and packaging that protects the devices without interfering with their operation. The method presented here for achieving this final criterion involves the incorporation of a micromachined channel within the package. By incorporating this element into the packaging design, and using flip-chip technology we could realize devices which meet the both needs of rapid prototyping and disposable chemical sensors manufacturing

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