Anodic Bonding for MEMS (invited)

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As the complexity of the micromachined structures increases, wafer bonding often becomes a necessity for their fabrication. It is thus not surprising that a lot of effort is spent nowadays for the development of different wafer bonding techniques, searching for the most suitable one to each application. This paper reviews the results related to the anodic bonding, a technique that has become a major technological tool employed in the MEMS industry. The technique is also referred to as electrochemical bonding or field assisted bonding.

In its most used form, this technique consists in joining a silicon wafer with a borosilicate glass wafer, but ceramics can also be used instead of glass. It was reported for the first time more than 30 years ago [1] and since then, many authors have investigated different aspects of this process for a better understanding of its mechanism and of the influence of different process parameters on the seal quality. It relies on the attraction electrostatic forces that develop between the two smooth and clean wafers at elevated temperatures (300°-450°C), when a high DC voltage is applied to the pair (500-1000 V), such that the glass is negative with respect to the silicon. The wafers are brought into intimate contact and chemical reactions take place at the interface, resulting in the oxidation of the silicon substrate and, hence, in permanent bonds between silicon and glass.

Although it seems a fairly simple process, there is a long way from the experimental set-up that can demonstrate the method to a reliable and fast industrial tool used for the mass production. As the device density and complexity increase, the requirements that must be fulfilled by the anodic bonding equipment are more and more severe. Accurate alignment requires tolerances in the μm range. The bonding yield depends on the ability to assure a uniform heating and voltage distribution over the wafers. The necessity to bond in controlled environments adds up to the challenges. A high speed of the process is required for profitable production.

A high quality seal, high hermeticity and mechanical strength must be ensured. These parameters are rather difficult, or even impossible, to measure quantitatively as 100% sampling on product dice. We have found the best method for screening the dice with faulty bonding areas to be the visual inspection (microscopy) after dicing the wafer into individual dice. Bonding defects on a die will appear as voids or areas with deviating appearance. Typically this will show up as areas with significantly lighter grey colour or if the separation between glass and silicon is very large it will be visible as coloured interference fringes. A bonded interface which appears visually to be fully bonded is also an interface which can be considered as giving a perfect hermetic seal and with sufficient mechanical strength. Statistical analysis of the bonded devices, performed in production, is a valuable tool for process and quality control.

Many micromechanical devices need hermetic vacuum sealing of their cavities or well controlled pressures. It has been observed that the residual gas pressure in the cavities after bonding in vacuum is higher than the pressure in the bonding chamber. The gases released from the inner surfaces of the cavities and those generated in the reactions which lead to bonding are trapped in the cavities and influence the performance of the sealed devices. The typical residual gas pressure must be evaluated or verified to be below significant values during process and/or product development. Innovative techniques are required in order to solve the problems of residual gasses, examples being the use of getter materials and diffusion barriers to gas atoms.

An important issue for the design of the micromechanical structures to be electrostatically bonded is how to avoid the sticking/bonding of the flexible silicon parts to the glass. For the usual dimensions of the micromachined devices, the electrostatic attraction forces are high enough to produce the collapse of the mobile parts onto the glass. Therefore, special precautions must to be taken to avoid the problems and the choice depends on the application. The alternatives include the increase of the gaps between the silicon and the glass to values for which the electrostatic attraction decreases to safe values, the selective use of intermediate layers that prevent the bonding and the use of a shield electrode that keeps the silicon and the glass at the same potential in the regions not to be bonded.

The effects of the anodic bonding on the electrical characteristics of the active silicon devices is another important issue. The breakdown voltages of the surface *p-n* junctions and their leakage currents can be negatively affected. For aluminium-gate MOS-transistors located close to the anodic bonded area, the drain-current/gate-voltage characteristics of MOS transistors shift towards more negative threshold voltages, indicating a higher positive surface charge in the gate oxide. A bonding induced increase of the oxide charge is also suggested by the shift of the flat-band voltage of MOS capacitors.

In conclusion, the anodic bonding is by its physical and chemical nature a method with a very good potential of resulting in close to perfect hermetic seals. There are adverse effects that can act on the bonded structures, which must be taken into account and dealt with during the process and product development. This technique becomes then a reliable tool for the wafer-level bonding of MEMS and similar devices (OptoMEMS, fluidics, BioMEMS), used more and more extensively.

Reference:

[1] G. Wallis and D.I. Pomerantz, Field assisted glass-metal sealing, *J. Applied Physics,* 40 (1969), p.3946.