Materials Science in Semiconductor Processing 31 (2015) 84–93

Contents lists available at ScienceDirect

Materials Science in Semiconductor Processing

journal homepage: www.elsevier.com/locate/mssp

Effective cleaning process and its influence on surface roughness in anodic bonding for semiconductor device packaging

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ARTICLE INFO

Available online 3 December 2014

Keywords:
Wafer cleaning
Surface roughness
AFM
SEM
Anodic bonding
Device packaging

ABSTRACT

Wafer cleanliness and surface roughness play a paramount role in an anodic bonding process. Impurities and the roughness on the wafer surface result in unbonded areas which lead to fringes and Newton's rings. With an augment in surface roughness, lesser area will be in stroke thus making more pressure and voltage to be applied onto the wafers for better bonding. Eventually it became mandatory to choose the best cleaning process for the bonding technology that can substantially reduce the impurities and surface roughness. In this paper, we investigate the bonding of silicon/oxidized silicon on Pyrex (CORNING 7740) glass with respect to surface roughness and cleanliness of the wafers by performing three renowned cleaning processes such as degreasing, piranha, RCA 1& 2 (SC-Standard Cleaning 1 and 2) and found that RCA compromises the best between the roughness and cleanliness. Studies were also extended to find out the effects of applied voltage and load on the bonded surface. It was observed for samples cleaned with RCA, an increase of 45% in maximum current and decrease of 75% in total bonding time with the applied load and voltage among all the cleaning techniques used. Three dimensional structures for pressure sensor application were successfully bonded by selecting the appropriate load and cleaning process. Atomic force microscopy analysis was done to investigate the surface roughness on silicon/oxidized silicon and Pyrex glass for different cleaning processes. Scanning electron microscopy and optical imaging were performed on the interface for the surface integrity of the bonded samples.

1. Introduction

Anodic bonding process was first performed by G.Wallis and D.I. Pomerantz in 1969 [1]. Since then, advances in the area of microelectronics, optoelectronics, and microelectromechanical systems (MEMS) packaging and encapsulation made the technology to look ahead of the existing ones [2–4]. In this race, wafer bonding technology turned out to be a premier candidate for packaging industry [5–7]. Bonding for MEMS level packaging requires high quality, precision, low cost and human skill for its success [8]. Various bonding techniques like fusion bonding, anodic bonding, eutectic bonding, and solder bonding have conquered the IC packaging industry where anodic bonding is considered to be an outrunner in packaging of wafers. This is considered to be the foremost primary level wafer packaging method because of its low temperature (250–400 °C) requirement [9–12].

Pyrex glasses are specially doped sodium glasses with 3.5% of the total contents that play a major role in bonding. It is

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http://dx.doi.org/10.1016/j.mssp.2014.11.002
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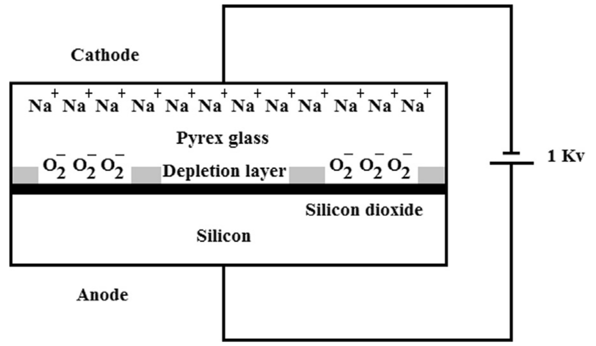

Fig. 1. A cross sectional view of silicon glass anodic bonding detailing the charge distribution.

doped with potassium and calcium too. Pyrex glass and silicon wafer are placed one over the other and are heated. At these elevated temperatures, the viscosity of the glass decreases and the doped sodium, potassium and calcium atoms break down into ions and become mobile [13,14]. When an electric voltage is applied onto the wafers as shown in Fig. 1, these sodium ions that are itinerant in glass are attracted towards the cathode and neutralize them, leaving behind the permanent negative ions. These negative ions form a depletion region very near to the silicon glass interface which means that the area is depleted of sodium ions that will give rise to a large electric field. Due to this large electric field, an electrostatic force of attraction is created at the junction that pulls the two wafers to initiate a bond. In addition, this large electric field pushes oxygen from the glass to the interface where it combines with silicon to form silicon dioxide, establishing a permanent bond between them [15].

More than three decades of its beginning, MEMS devices such as pressure sensors, RF switches, accelerometers, gyroscopes are still under the control of packaging related parasites. It is also known that these devices are more prone to contamination from all levels of fabrication until it is completely packaged. MEMS devices are more concentrated on moving elements than what we see in integrated circuits; thus particles can easily tamper these devices by stimulating stiction. The reliability of device is greatly influenced by the cleanliness of the wafers. Efficiency of bonding mainly depends upon both the cleanliness and surface roughness of the wafer surface [16,17]. Contaminants such as organic particles, inorganic particles that are adsorbed and thin oxide films that are grown over the surface of the wafers can hamper the performance of devices by shorting the circuit. The objective of wafer cleaning is to remove these particulates and chemical impurities from the silicon surface without any detriment or alteration of the substrate surface [18].

The objective of this article is to study the wafer surface roughness and cleanliness that influence anodic bonding of silicon/silicon dioxide wafers with Pyrex glass that has been cleaned with both acid and alkaline solutions which are employed in wet cleaning technology for pursuing high level of pattern resolution and integration. It has been demonstrated that bonded wafers pre-cleaned with piranha solution had limited the current flow and took maximum time to bond when compared to other cleaning processes. The surface roughness was found to be increased while cleaning in piranha solution than with degreasing, RCA methods.

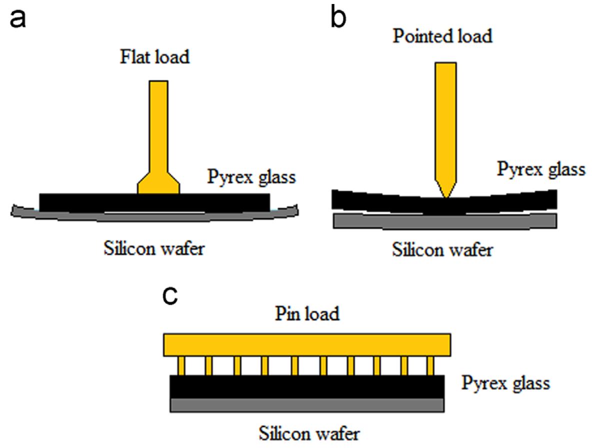

Fig. 2. Bonding of wafers with (a) flat load, (b) pointed load, and (c) pin load.

Ever since its inception, the power of knowledge, visualization and experience made people to bring out the best from the processes by simple modification on the machine. The objective of the study was also extended by modifying the electrode (cathode) on the anodic bonding machine which utilizes the properties of the sodium doped borosilicate glass to bond over processed silicon wafer. After the successful implementation of the objectives, these processes were used for fabricating a MEMS device and the fabrication sequence is elaborated in Section 2. Fig. 2(a) and (b) shows the diversity in electrode community commonly used for bonding. These designs do have problems associated with non-uniformity in contact between the two surfaces like gap formation and bowing effect of wafers. Since the silicon wafers are cleaned with various cleaning processes, the surface obviously become spiky/thorny in nature with various step heights. When two surfaces are in contact, it is not necessary for each and every spike to touch each other as shown in Fig. 3(a). Redefining the electrode (pin electrode) as shown in Fig. 2(c) could waft away the problems associated with the bonding. The probability of these surfaces being in touch would be high with the new load as shown in Fig. 3(b). Anodic bonding is occasionally defined as an electrochemical process and we define this modification on cathode as the catalyst for faster bonding. We have noted an amplified current flow and plummeting bonding time with this new method.

2. Fabrication sequence

From the knowledge acquired from the processes, a fabrication sequence was formulated and a pressure sensor device was fabricated which will be detailed in the following sections. The silicon, silicon dioxide (1 μm grown over the silicon wafer through a thermal oxidation method) and the Pyrex glasses were diced into pieces to study the optimal cleaning process and how it affects bonding. Then the same techniques were then introduced for bonding of 2 in. silicon/silicon dioxide and Pyrex glass. The fabrication process is listed below with substantiating schematics from Fig. 4(a)–(f).