Al-Al Wafer-Level Thermocompression Bonding applied for MEMS

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***Abstract*—Wafer-level thermocompression bonding (TCB) using aluminum (Al) is presented as a hermetic sealing method for MEMS. The process is a CMOS compatible alternative to TCB using metals like gold (Au) and copper (Cu), which are problematic with respect to cross contamination in labs. Au and Cu are commonly used for TCB and the oxidation of these metals is limited (Au) or easily controlled (Cu). However, despite Al oxidation, our experimental results and theoretical considerations show that TCB using Al is feasible even at temperatures down to 300−350 °C using a commercial bonder without *in-situ* surface treatment capability.**

I. Introduction And Background

As commercial bonders with higher tool forces emerged, SINTEF initiated experiments using bond frames of sputtered pure Al (~1 µm thick, 20−200 µm wide, 99.999%). At the time, bonding temperatures in the range of 450 °C and bonding time above 20 min was state-of-the-art [1,2]. There was no literature on systematic studies of the effect of bonding temperature and time and the Al film quality, on the resulting dicing yield, bond strength and hermeticity. There were concerns that the native oxide on Al, considered challenging to avoid regrowth of in vacuum chambers of traditional commercial bonders ($<1 \times 10^{-3}$ mbar) unless removed *in-situ*, would prevent bonding at lower temperatures, and that islands of Al_2O_3 would remain within the bond frames and result in cracks during thermal cycling.

II. Experimental

A systematic study was made by varying bonding temperature, tool force, bonding time and Al film quality. The applied wafer bonder was an EVG 510 tool with a pressure uniformity within 5%. Wafers with a total thickness variation below 1−2 µm were used to maintain the pressure distribution uniformity. Dicing yields (percentage of samples still bonded after dicing) and bond strengths (measured using pull and shear testing), were compared. Cavities with flexible membranes were sealed in vacuum and exposed to environmental stress. A MEMS infrared thermal emitter was made and sealed applying the developed process. Characterization using AFM, XRD and EBSD was performed on relevant Al surfaces at room temperature of the films as deposited, and at 300 and 400 °C, to explain differences observed in Al film bondability.

III. Results

Bonding Al deposited directly on Si, a dicing yield >80% and >20 MPa bond strength was achieved for TCB at temperatures down to 400 °C using 114 MPa bond tool pressure and 60 min bonding time [3]. When a layer of SiO_2 was present below the Al, the bonding parameters could be reduced to 350 °C, 102 MPa and 15 min without a significant drop in dicing yield or strength [4]. As expected, higher temperatures, higher bond tool pressures or longer bonding times resulted in further increase in dicing yields and/or bond strengths.

The observed difference in bondability for Al on Si vs. Al on SiO_2 became a main research question. For Al deposited directly on Si, grains with primarily (111) orientation were seen, whereas a mix of (111), (200), (220), and (311) oriented grains, typically a bit tilted, were observed for Al on SiO_2 (see Fig. 1). The oxide on the Al must be broken for the Al atoms on the two surfaces to come into contact and form a permanent bond. Less energy should theoretically be demanded to mechanically deform the microstructure of the Al on SiO_2 than the microstructure of the Al on Si. Hence, we suggest that the oxide was broken at lower bond pressures and temperatures for the Al on SiO_2 [5].

Fast rise- and fall times (<8 and 3 ms, respectively) of the MEMS emitter sealed by the technology [6], proved that a hermetic seal was achieved using Al-Al TCB. Reliability studies of mock-ups were promising; cavities bonded with frames of Al on SiO_2 did not degrade in bond strength or became measurably leaky after 1000 h at 150 °C or after 50 thermal shock cycles between -65 and 200 °C [7]. The result undermined reliability concerns related to residues of oxide in the bond frames. A few cavities became leaky after exposure to 5 cycles in 90% RH between -10 and 65 °C, but Al is known to corrode, in the presence of e.g. chloride ions that are challenging to avoid [8].

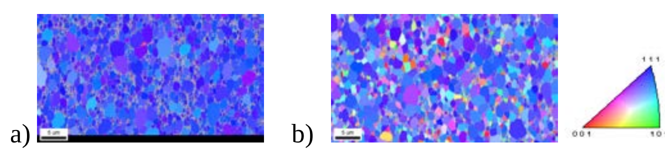

Fig. 1. EBSD images of a) Al on Si, and b) Al on SiO_2, as deposited. The differences in grain orientation remained after exposure to 300 and 400 °C [5].

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