Precision Passive Mechanical Alignment of Wafers

Personnel

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Sub-micron alignment for wafer bonding applications has become a major limitation in the development of multi-wafer MEMS devices and 3D interconnects [1,2]. Most wafer alignment is done by mechanically positioning one wafer with respect to another using optical measurement techniques, but the large structural loop makes alignment better than one micron difficult, and multi wafer stacks are must be assembled one at a time. Optical alignment techniques are also used for laser diodes with +/- 1 micron accuracy [3]. Passive alignment is used extensively for alignment of optical fibers in MOEMS [4,5,6], but has not been exploited for wafer alignment. Capillary forces at the water-air interface between hydrophobic features patterned on wafers can align two wafers to each other to the micron level [7], but would be impractical for a stack of wafers.

Kinematic couplings [8] and elastically averaged systems [9] are well known to the precision macro world, and hence these principles were applied here [10] to create a passive mechanical alignment technique that make use of matching convex and concave wafer integral features. The concave alignment structures, shown in Figure 45, consist of eight arrays of 22 KOH etched pyramid-struc-tures mounted on the tip of cantilever flexures [11]. The convex structures consist of matching arrays of V-grooves patterned on a boss, as shown in Figure 46. When the two wafers are stacked upon each other, vibrated lightly and preloaded, the interference between the V- groove and the pyramid causes the flexures to bend. The mating structures self-align the wafers achieving an elastic averaging effect. The assembled wafers are shown in Figure 47. Sub-micron repeatability and accuracy in the order of 1 _m were shown through testing. Repeatability and accuracy were measured as a function of the number of engaged features. Sub-micrometer repeatability was achieved with as little as 8 mating features. the wafer-front side (for convex feature wafers) and the wafer back-side (for concave feature wafers) of 4-inch double-sided polished (100) silicon wafers. The convex features are fabricated with a backside KOH etch which creates a pit that defines the cantilever thickness and the pyramid structures. A front-side DRIE releases the cantilevers. The concave features are bulk micromachined through a single KOH etch. Chrome masks made from emulsion transparencies were used to pattern the convex and concave features.

Testing of the passive alignment features was done on an Electronic Vision Group TBM8 wafer alignment inspection system. The two stacked wafers were mounted on the TBM8, aligned roughly and tapped on lightly to enable the wafer alignment features to engage and self-align the wafers. After the top wafer had reached a stable position (i.e. would not move when lightly tapped), the front-to-back side align-ment accuracy was measured. The wafer was then removed and put back on many times so repeatability could be determined. Table 1 shows the results of a 20-cycle assembly and disassembly sequence, where all 96 elements are used. The grooves showed signs of wear after many dozens of couplings, so a second set of wafers was used for experiments where the cantilevers were to be successively broken off. Table 2 shows repeatability and accuracy as a function of the number of engaged features. The offset between repeatability and accuracy is assumed to be caused by misalignment of the masks used to pattern the structures. This misalignment is a fraction of the minimum 20 μm feature size of the masks made from emulsion transparencies.

The data shows that the use of many features does not necessarily provide a great increase in accuracy or repeatability as might be expected, but such increases are only expected when there are random errors in the elements. The accuracy error is hypothesized to be systematic in the alignment fiducials, and the repeatabilit even with only 8 features (two per side) is very good; hence we conclude that wafers can be mechanically aligned to each other using just two of these features per quadrant. This will minimally intrude on the useful wafer surface area. The pyramid structures could also alternatively be formed by appropriate plated metal that would protrude from the surface of a polished wafer, and hence stacks of wafers aligned (coupled) in this manner could then be fusion bonded. In addition, the metal protrusions could be made as surfaces of revolution which should increase accuracy by reducing edge contacts.

This results of this work validate that it is possible to achieve sub-micron alignment of multi-wafer stacks without the need for optical alignment hardware. Thus this technique can have significant impact in multi-wafer MEMS and stacked 3D ICs. The present implementation does not work for anodic or fusion bonding due to the KOH etch roughness, but straight forward process modifications are being pursued that make this possible.

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Fig: 45 Convex features

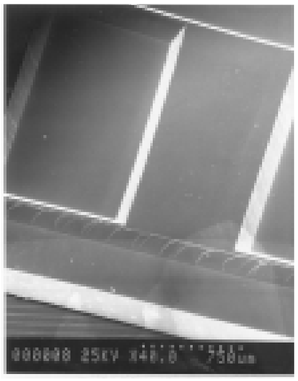

Fig: 46 Concave features

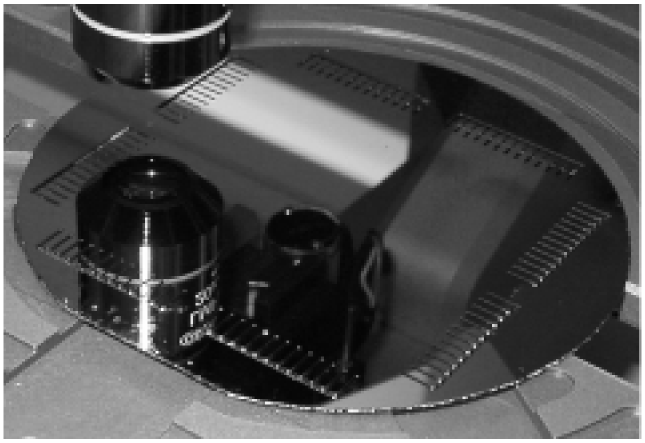

Fig: 47 Assembled wafers during testing

	X [µm]	Y [µm]	Error [µm]	Error angle [deg]
Average accuracy	0.88	-1.08	1.41	-50.2
Repeatability	0.63	1.06	1.06	32.47

Table 1 Test results, wafers M-2 & F-1, all cantilevers with convex features engaging all concave features

	Total number of cantilevers	X [µm]	Y [µm]	Error [µm]	Error angle [deg]
Average accuracy	96	-6.93	1.45	7.07	-11
Repeatability	96	1.09	0.43	1.12	3
Average accuracy	64	-4.3	-5.86	7.22	53
Repeatability	64	0.43	0.42	0.43	3.56
Average accuracy	32	-4.61	-5.43	7.32	49
Repeatability	32	0.63	1.05	0.89	8
Average accuracy	8	-7.51	-4.77	8.89	32
Repeatability	8	0.42	0.89	0.47	6

Table 2 Test results, wafers M-2 & F-2, as cantilevers were broken off