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ANAB

# Semiconductor Equipment Assessment

# Results Bulletin AML-400 Series

## Assessment of New Wafer Bonder

**Bonder with in-situ alignment demonstrates low cost MST/ MEMs, production capabilities for pressure sensor accelerometer and micropump applications.**

### Equipment description

*The AML-402 Bonder is a flexible production equipment with in-situ alignment for applications in MST and MEMs with a low Cost of Ownership. It produces bonds of high quality that are, thermally matched and low stress in silicon, glass, and other wafer materials. The machine is able to handle a wide variety of bonding processes including, anodic, glass frits, eutectic, adhesive, silicon direct and solder bonding.*

***Features:***

- *In-situ alignment accuracy of <2.5 micron*
- *Selectable preload clamping to ~2000 N*
- *High vacuum or process gas ambient*
- *($2x10^{-6}$ mbar) or up to atmosphere*
- *Bonding temperature range RT to 560°C (dependent on the process being used)*
- *Temperature Uniformity ±2°C (100mm wafers)*
- *Bond cycle time ~20 minutes per bond (standard silicon - glass anodic)*
- *Nitrogen cooling*
- *High strength bond*

*Equipment upgrades implemented for faster heating and bonding and improved process control include:*

- *New platen material*
- *Stiffer compliance plates*
- *IR reflective view port*
- *Higher wattage heater bulbs*
- *Longer piston travel for stack heights of 10 mm*

### Flexible, Low Cost Wafer Bonding

The AML 402 Anodic Bonder has been successfully assessed in manufacturing trials under real production conditions for a high production application and close-to-production conditions for two other industrial applications. Starting with an AML 400 machine, primarily seen as an anodic bonder, the development during the project has added quite a number of functions to the machine. The latest version, the AMLWB04, is suitable for a wide range of wafer bonding techniques, including silicon direct bonding, glass frit bonding, eutectic, adhesive, and solder bonding, including III-IV material.

### In-situ alignment and performance improvements

Alignment requirements vary considerably between applications. The capability of the AML series to align accurately was demonstrated at the first evaluation site OnStream (See Project Factfile). Vernier methods demonstrated that the targeted improvement to better than ±2.5 µm could be maintained for 6” anodic bonding. The largest factor in this misalignment is due to expansion mismatch between the silicon and 7740 glass wafers used, with the machine related factor only ±/-1 µm, showing the low cost microscope/ camera system in the AML 402 to be perfectly adequate. Baseline equipment performance parameters demonstrated are listed in Fig. 1. As can be seen, equipment improvements enabled all targets (set by the Users) to be met or exceeded, except “top wafer thickness” and “platen flatness”. However, methods have now been developed to handle thickness down to 250 µm. The platen flatness achieved is suitable for most applications and can be improved to 1 µm (With an additional machining cost).

| Parameter | Target | Initial | Final |
|---|---|---|---|
| Max. bond temp. (°C) | 550 | 450 | 560 |
| Max. bond force (kN) | 2 | 1 | 2 |
| Align. accuracy (µm) | ±2.5 | 5 | 2.5 |
| Anodic voltage (kV) | 2.5 | 2.5 | 2.5 |
| Th’ness-top wafer (mm) | 0.1 | 0.5 | 0.4 |
| Particulates (/sq.cm) | 0.05 | 0.1 | 0.02 |
| Max. wafer stack (mm) | 10 | 6.5 | 10 |
| Unif. platen temp (%) | ±3.5 | 5 | 3 |
| Cooling Rate (C/sec) | upgrade | 3 | <30 |
| Vacuum (mbar) | 1E-05 | 1E-05 | 1E-05* |
| Platen Flatness (µm) | 5 | 25 | 10 |

**1E-06 overnight*

***Fig.1 AML 402 Performance Improvements***

The low temperature bonding process goes from room temperature up to a maximum bonding temperature of 560°C with a platen temperature uniformity of ±2°C for 4” and ±3°C for 6” platens at 400°C. The anodic bonding voltage can be up to 2.5 kV. The maximum wafer stack thickness can be up to 10 mm – a feature that is useful for microfluidic applications for which multi-stack bonding is often needed. The process induced wafer bow variation was found to within ±7.5 µm.

### Benefits proved for MEMS gyroscope production

**Higher Throughput Anodic Bonding**

As a result of collaborative work with SSP, a volume production client, improvements including enhanced PC control, vacuum system and nitrogen forced cooling have made the bonder more attractive for the production market. These changes along with the faster heating / bonding have significantly improved the throughput as can be clearly seen from Fig. 2 (upgraded tool vs original-AML400). As a result, the cycle time at SSP has been significantly reduced to ~20 minutes per wafer bond giving a throughput of 3 wafers/hour.

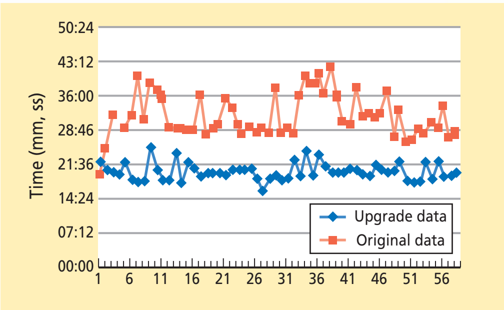


***Fig. 2 Process Time (Combined)***

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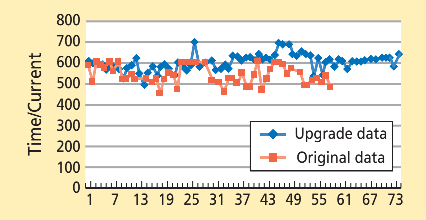


*Fig. 3 Integrated Charge*

As well as higher throughput for the Gyroscope, production control has also been improved. For example, integrated charge, a key bonding control parameter (Fig. 3), is more stable. This has improved gyroscope performance with tighter control of key parameters. This can be seen by the improvements in both the Cp & Cpk for a critical measured output parameter (Figs 4a & 4b), which have increased from 0.65 to 0.97 & 0.47 to 0.6 respectively. Comparing this same key parameter before and after the introduction of the AML bonder, shows an improvement of >20% in its average value compared with devices made with an earlier bonder.

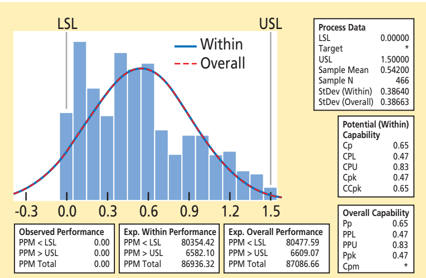


*Fig. 4a Initial gyroscope bias*

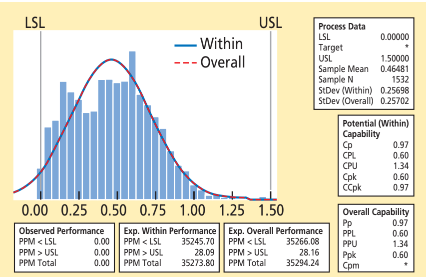


*Fig. 4b Gyroscope bias using AML 402*

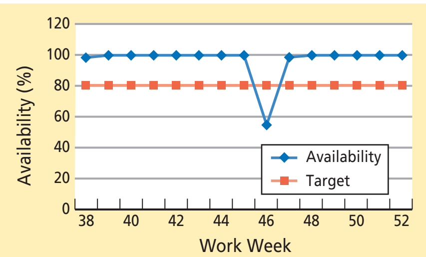


*Fig. 5 Production statistics-Availability*

## Productivity

The AML 402 Anodic Bonder demonstrated excellent stability and reliability in terms of, MTBF MTTR and Uptime (Fig 5), when exercised during a 3 month production period at SSP. Availability was 96% with an MTBF of 168 hours and an MTTR of <1hour. There was no breakage in bonds and the mechanical yield was measured at 99.99%.

## Low Cost of Ownership

The bonder showed a very advantageous Cost Of Ownership (CoO), The main benefits are lower unit cost and in-situ alignment. These benefits together with high reliability, throughput and small footprint lead to a price per bond (amortised over 1 year) of one third compared to a competitor that aligns separately from bonding. For example, for 1 bonder used for 5000 wafers per year, the cost per bond is ~23 euro/bond compared with ~68 euro/bond. For two machines for 12,000 wafers per year it is still < half (<20 cf ~40 euro/bond). Even if a separate aligner is already available, the cost per bond is ~40% less for the AML bonder.

## Other Applications

### Minimal voids – Triple stack anodic bonding of microfluidic devices (C2V)

Throughout the project there has been no evidence of any void presence attributable to the bonder. The AML402 has a bond chamber that can operate at a base pressure in the range of $10^{-6}$ mbar thus helping to reduce voids and allowing the evacuation of cavities prior to bonding. This is advantageous in the fabrication of microfluidic structures as produced by C2V using a triple stack bonding. Test structures (Fig. 6a) evaluated bond strength and voids and their influence on fluidic systems. Suitability of the bonder was demonstrated with 20 µm channel widths, comparable to the smallest channel width in a micro-fluidic device. No leakage was detected. Bond strength was tested on structure Fig. 6b in conjunction with gas pressure in a functional micro-mixer device. Visual inspection before and after testing indicated no difference after pressure testing at 10Bar. Glass staining was minimal due to the ability to run at low current density thus removing the risk of electrical breakdown in the glass.

### Glass frit bonding for high performance pressure sensors (MEMScAP)

The AML bonder has independently controlled ramp rate of both platens so heating and cooling can be optimised for better uniformity and reproducibility of bonds.

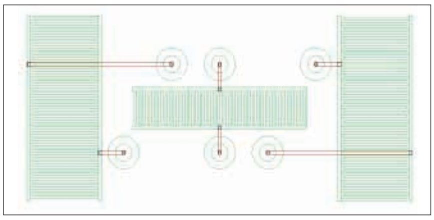

*Fig 6a 20µm Test structures*

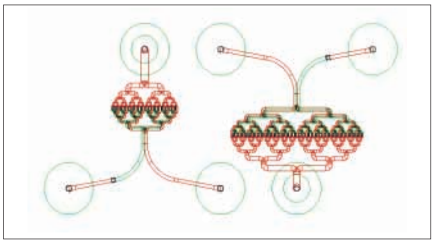

*Fig. 6b Strength test*

Rapidly, customisation of the process by the operator was provided by new hardware and software flexibility. MEMScAP found that set up and process optimisation followed bondings was possible, within a day, for glass frit bonding of a MEMS pressure sensor.

High quality bonds were produced that satisfy gas leakage / hermeticity tests in accordance with MIL STD 883. Leakage current tests indicated that all pn junctions resisted the heat treatments utilised whilst only minor and acceptable variance occurred to parameters compared to die level bonding

MEMScAP's current production uses die level packaging. The AML bonder increased throughput from 4 uph to a potential 100 uph. The combined benefit of wafer level packaging and much higher throughput (<90 min cycle time compared to 2 hours for the current single chip process) has resulted in a vast increase in the number of units per hour (UPH) by a factor of more than 10, lower cost production and therefore a more competitive price. The AML bonder is therefore considered well suited to low and medium volume wafer level glass frit bonding.

## Conclusions

Wafer level packaging processes utilising a variety of bonding methods are essential for the production of many types of Microsystems. The availability of this low cost, versatile bonder will assist in the strategic objective of accelerating the emergence of production for Microsystems.

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SEMICONDUCTOR EQUIPMENT ASSESSMENT

## Further information on Project ANAB

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