Direct vs. Indirect Megasonic Tank Cleaning Systems; Uniformity, Cleaning Efficiency and Cost of Ownership

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Introduction

High frequency (1 MHz, megasonic) acoustic enhanced cleaning is a well established method of removing surface particles in semiconductor manufacturing processes. There are two fundamental designs of megasonic batch cleaning systems, indirect and direct.

The indirect megasonic system's acoustic energy is transmitted through a flowing degassed DI water layer and coupled into the process fluid through a sympathetic resonator which forms the bottom of the process vessel. A direct megasonic system transmits acoustic energy directly into the process fluid because the process vessel bottom is the transducer resonator surface.

Here we present comparison data for uniformity, efficiency, particle removal, die reliability and recurring expense of operation; contrasting these two types of megasonic systems. This presentation includes data obtained experimentally in a laboratory and also in a production line.

Problem

High transmission losses inherent to indirect acoustic designs are well studied [1] and are known to be an inefficient method of producing acoustic cavitation in the bath of a batch process tank. Application of indirect technology to hot acoustic assisted cleaning processes is standard practice because there was no available transducer technology tolerant of 60-80^{o}C fluid temperatures.

New direct megasonic technology, able to operate at 80^{o}C, has been compared to legacy indirect systems for acoustic uniformity and electrical/acoustic conversion efficiency. A direct megasonic system was then installed in a tool; replacing an indirect megasonic system. Split lots were run to compare the current (indirect) POR results with the results obtained with the new direct megasonic technology. Both PRE and die reliability were measured. Overall operating costs, principally DI water and AC power consumption, have also been compared.

Experimental Result

Apparatus. [Fig. 1] Two acoustic pressure scans were performed in a laboratory using an x-y-z robotic scanner with 0.001mm resolution to position a ONDA Model SRGH-1000 needle hydrophone. Degassed DI water was re-circulated through the tank as the scans were performed. A Class A/B wide band RF amplifier was pulsed with the output of a HP 22120A arbitrary waveform generator. The hydrophone reading was acquired with a Tektronix RDS-3052 oscilloscope.

Method. [Fig. 2] The oscilloscope was triggered and gated to acquire the acoustic pulse amplitude only, thereby eliminating measurement errors due to echoes within the tank. The field intensity over a 10x20mm section of the transducer was mapped on a square grid at 0.3mm intervals. A first scan was performed along the under surface of the sympathetic resonator (not yet installed). A second scan was performed 1 mm above the upper surface of the sympathetic resonator (installed). Both scanning planes were tilted by 4° to match the incline of the floor of a typical indirect megasonic system. The transducer was a ProSys standard bonded quartz device properly matched to the RF amplifier. No adjustments were made to the RF test signal between the two scanning operations.

Result. [Fig. 3] We observed a pressure loss of -8.2dB (~61%) when transmitting acoustic energy through the angled sympathetic resonator (6mm quartz). The data points of the two lines are obtained by calculating the mean sound field strength along the 10mm axis and plotting is as a single point. The value -8.2dB is the mean pressure difference of the two curves. This agrees well with data presented in Hatano and Kanai [1] for intermediate plates at a 4° tilt.

Note the increased non-uniformity (ripple) due to the lower face of the angled resonator not being at $\lambda/2$ from the driven transducer. This tilt causes an acoustic impedance mis-match between the plate and the fluid. The ripple amplitude exceeds 2dB (20%) peak-to-peak.

Production Results

The direct megasonic system was installed in a wet process station running an NMOS process. A process recipe was developed that applied a theoretical comparable acoustic pressure in the process tank taking into consideration the inherent power loss of indirect systems. [1,Fig.3] Gate oxide capacitors were processed and data was collected for PRE and die reliability. Die life tests were performed on a variety of direct processes and compared to the previous indirect process of record.

A reliability requirement of less than 100ppm cumulative failures after 25 years of use at 125°C and at maximum operating voltage of 3.63V was required. Weibull plots [Fig.4,5] for the split lots were analyzed and the direct megasonic system produced a 50% LPD improvement from 4.8 to 2.7 per wafer and a long term device reliability improvement from 274 days to 825 days.

Split lot analysis resulted in a process with a watt density of 0.55 W/cm^2 for the direct megasonic system. The indirect system POR calls for 2.6 W/cm^2.

Cost Savings

Comparisons are based on the most common OEM indirect megasonic system, and the ProSys direct megasonic system. The overall costs of operation were calculated based on DI water and AC power usage. Eliminating the need for DI water and vacuum (used as the indirect coupling layer), and reduction of AC power consumption (more efficient RF power generation and transmission) to achieve equivalent process conditions in the tank, results in a significant reduction in the costs of operation. Overall cost savings for this application are $15K USD per year.

Conclusion

Direct megasonic systems are more than capable of replacing indirect systems and achieving improved PRE with longer die life and at saving considerable costs on the utilities. The direct system is capable of these improvements because it utilizes a newer array manufacturing technology, a direct coupled acoustic transducer to the process bath chemistry, very efficient RF power generation and an improved RF supply chain.

References

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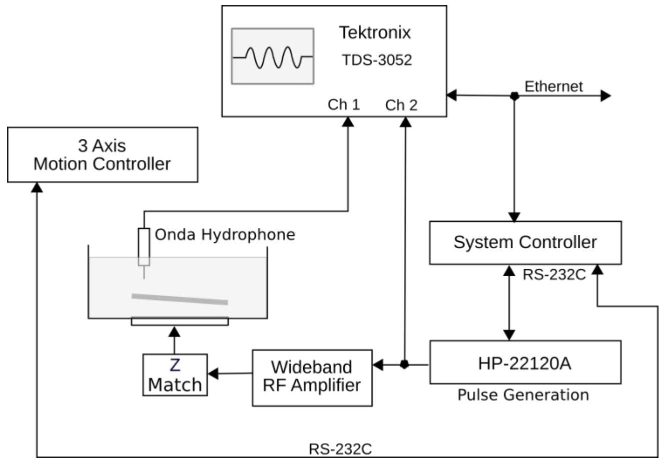

Figure 1: Apparatus

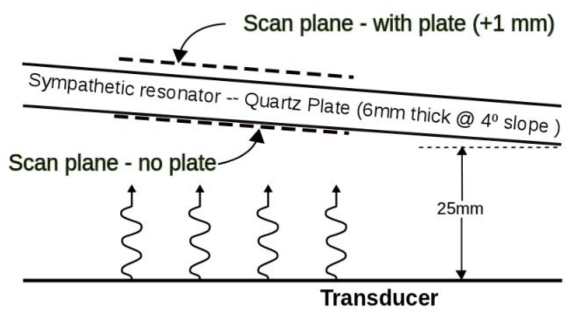

Figure 2: Apparatus Detail - Sympathic Resonator

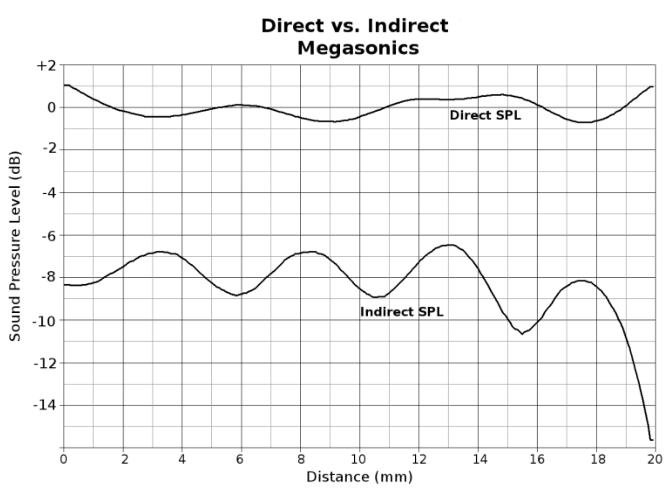

Figure 3: Experimental Results

Fit and extrapolation equation for split 1:

$$Log_{10}\left[-\ln\left(1-F\right)\right] = 2.10362 \quad \left[Log_{10}\left(t\right) - 1.218507 \quad V - 15.749114 \quad\right]$$

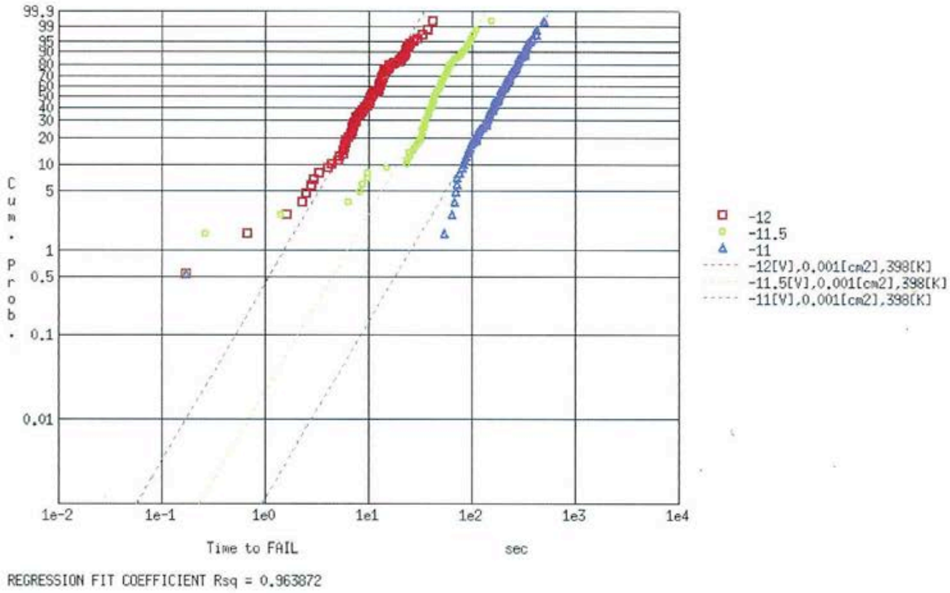

Figure 4: Weibul Plot -Split 1 (POR)

Fit and extrapolation equation for split 3:

$$Log_{10}\left[-\ln\left(1-F\right)\right] = 2.41405 \quad \left[Log_{10}\left(t\right) - 1.270224 \quad V - 16.23088 \quad\right]$$

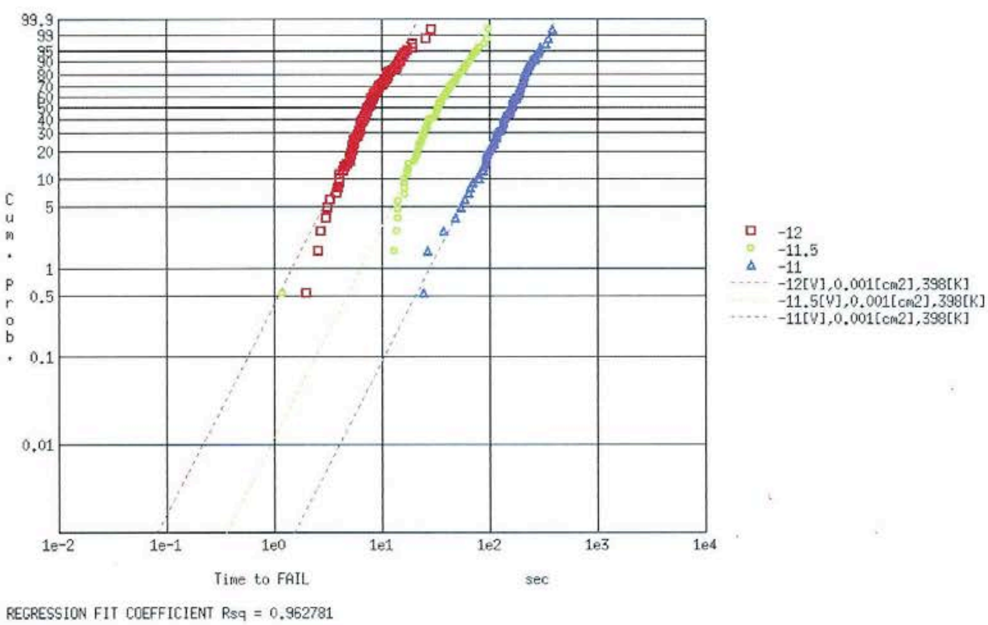

Figure 5: Weibul Plot - Split 3 (Selected)