A CANON COMMUNICATIONS LLC PUBLICATION
OCTOBER/NOVEMBER 2004

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Maximizing tool uptime and process stability through an RF system upgrade

Brent Rosecrans and Gil P. Dorcey, *Agilent Technologies*

A case study from a CMOS and GaAs product line details how a fab team retrofitted a series of etch tools with a new RF subsystem, replacing a system that often failed to ignite the plasma.

L*ike most fabs, the 150-mm wafer* facility run by Agilent Technologies in Fort Collins, CO, has limited toolset capacity to manufacture its high-mix product line of CMOS and gallium arsenide products. Therefore, each tool must be reliable and function at its rated capacity to avoid bottlenecks that can ultimately limit the output of the entire fab. This article describes a successful effort by Agilent personnel to improve the performance of the fab's plasma etchers, which had been experiencing excessive downtime as a result of faulty radio-frequency (RF) subsystems.

RF Subsystem Retrofit

Agilent uses the 590 plasma etcher from Lam Research (Fremont, CA) to etch the final nitride passivation layer. Although not a particularly demanding process, nitride passivation etch requires that the plasma tool process each wafer correctly. In addition, the passivation processing module has very tight wafer output scheduling to meet customer shipments, requiring that the tool achieve the highest uptime rates possible. Since the nitride passivation etch step is a back-end-of-line process, there is no way to make up for time lost because of tool downtime.

For some time, Agilent's RF subsystems were malfunctioning: either they were causing the plasma sporadically to not ignite or the matching network was unable to match the plasma impedance

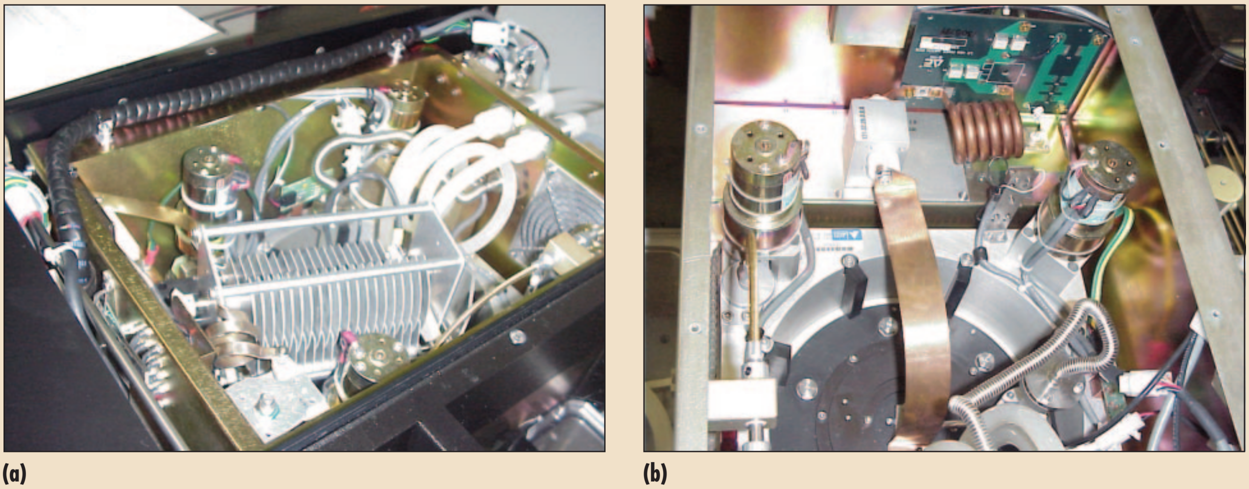

Figure 1: Lam etcher matching network (a) before, and (b) after the retrofit. The matching network is contained on the circuit card next to the Z-Scan RF sensor.

correctly in order to bring reflected power within the range allowed by the tool controller. System experts spent a great deal of time running conventional tests, performing standard fixes, and replacing parts as recommended by the tool manufacturer, but to no avail.

Then the fab stepped outside the box to achieve the needed results. It turned to Advanced Energy Industries (AE; Fort Collins, CO), which had developed a complete RF-system retrofit kit for the Lam plasma etchers that could be installed easily and quickly without altering fundamental tool functionality or requiring a significant tool reconfiguration. The retrofit consisted of a fixed-component RF matching network, AE's RFG 1251 generator designed to deliver power into a non-50-Ω load, and AE's Z-Scan RF impedance sensor.

The sensor is used to monitor and control RF power delivery to the cathode of the etch chamber to guarantee repeatable, point-of-use RF power delivery. This control is crucial, because experience has shown that both the ability of the matching network to match the impedance of a given process and the speed with which it attains a proper match vary. The malfunctioning of the matching network causes variations in the amount of power delivered to the chamber, leading to changes in the etch rate of the nitride film. In some cases, the RF matching was so poor that that film did not etch at all.

An RF matching network consists of a set of capacitors and inductors that are designed to match the impedance of the load to the source impedance of the RF generator (in this and most cases, 50 Ω). The load consists of the plasma chamber with plasma-ignited process gases, the wafer, the RF cable, and RF transfer components. To match the impedance of the process chamber to the source impedance of the generator, the match must be configured to the conjugate of the impedance of the plasma chamber. The conjugate of a load presents the same RF resistance while operating at the opposite reactance. The match transforms the phase angle of the power delivered to the matching network throughout the plasma to 0° and sets the resistance to the generator source impedance of 50 Ω.

The main difference between an automatic matching network (automatch) and a fixed matching network is that the

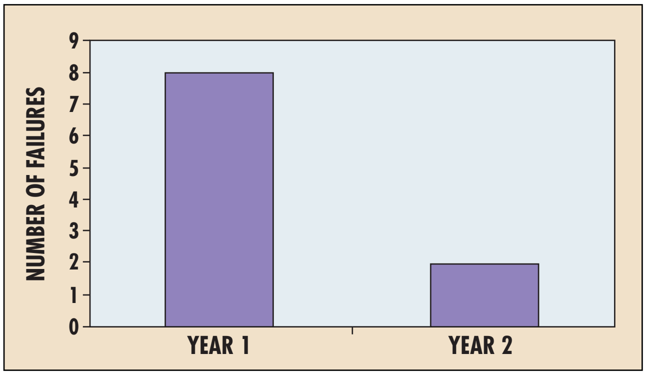

Figure 2: Comparison between the number of equipment failures in the first year (before the retrofit) and the number of failures in the second year (after the retrofit).

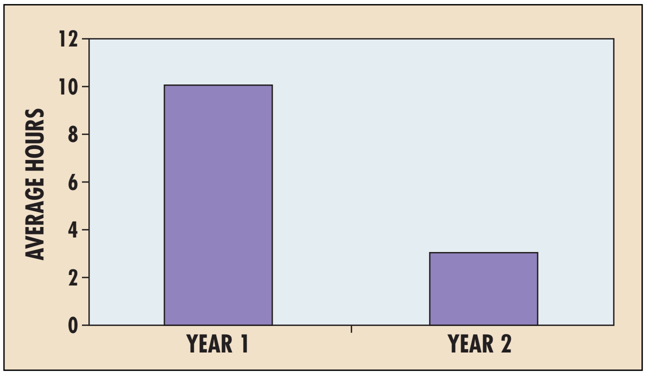

Figure 3: Comparison between the time required to resolve an RF subsystem failure and get the tool back into production before and after the retrofit.

former has sensors and a control loop to vary the value of the series and shunt elements to make a 50-Ω match. While a fine approach for many applications, automatch adds complexity and variation, and it requires periodic setup and maintenance. In contrast, the values of the shunt and series elements in the fixed matching network are set based on process requirements. In addition, the fixed network has no moving parts and does not require adjustments.

When the fixed matching network is used, the input impedance of the matching network is allowed to vary from 50 Ω in response to process conditions. Consequently, the RF generator must be configured so that it can deliver power into a non-50-Ω load. In Agilent's retrofit project, a 1250-W RF generator replaced the existing 650-W generator, providing additional capacity to deliver power into the off-axis load.

After Agilent and AE engineers installed a Z-Scan sensor and ran the tool through the normal processes, they concluded that the impedances and power levels of the processes to be run were within the limits of the fixed-match setup and that the proper shunt and series for all processes existed.

New System Installation and Results

When an Agilent team installed the first RF-subsystem retrofit system on a plasma etcher, they replaced the existing RF generator with an RFG 1251 RF generator and replaced the existing automatic matching network with a fixed matching network that was approximately the size of a deck of playing cards. The team also replaced the Lam phase/mag detector and the capacitor drive motors with sheet-metal parts designed specifically for the Lam AutoEtch match unit. A Z-Scan sensor was mounted where the motors had been. A Z-Scan RF impedance sensor was placed after the matching network. Overall, the quality and fit of the parts was excellent, allowing the team to complete the fairly complex retrofit in just four hours. The photographs in Figures 1a and 1b show the RF matching network area in the etcher before and after the retrofit, respectively.

Since the retrofit was driven primarily by the cost of downtime associated with RF subsystem failures, the question of downtime was scrutinized thoroughly. Figure 2 compares the number of failures in the first year (before the retrofit) with the number of failures in the second year (after the retrofit). Figure 3 shows that the time required to resolve an RF subsystem failure and get the tool back into production decreased markedly after the retrofit. And Figure 4 demonstrates that cumulative RF subsystem downtime was reduced by 92%, from 80 to 6 hours, after the installation of the new RF system. Further education in the use of the system has reduced RF subsystem downtime to nearly zero. Since the last quarter of 2003, no catastrophic failures

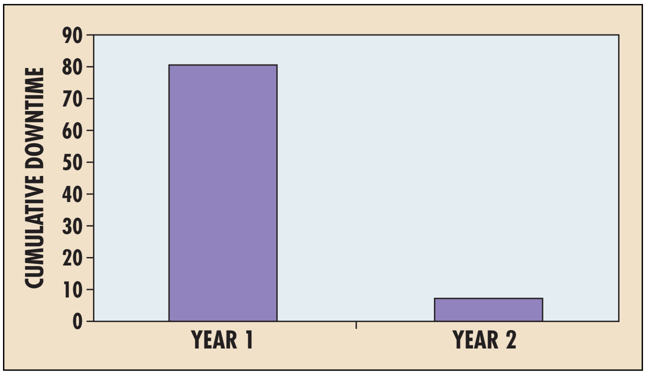

Figure 4: Comparison between cumulative RF subsystem downtime before and after the retrofit. Downtime was reduced by 92% after the installation of the new RF system.

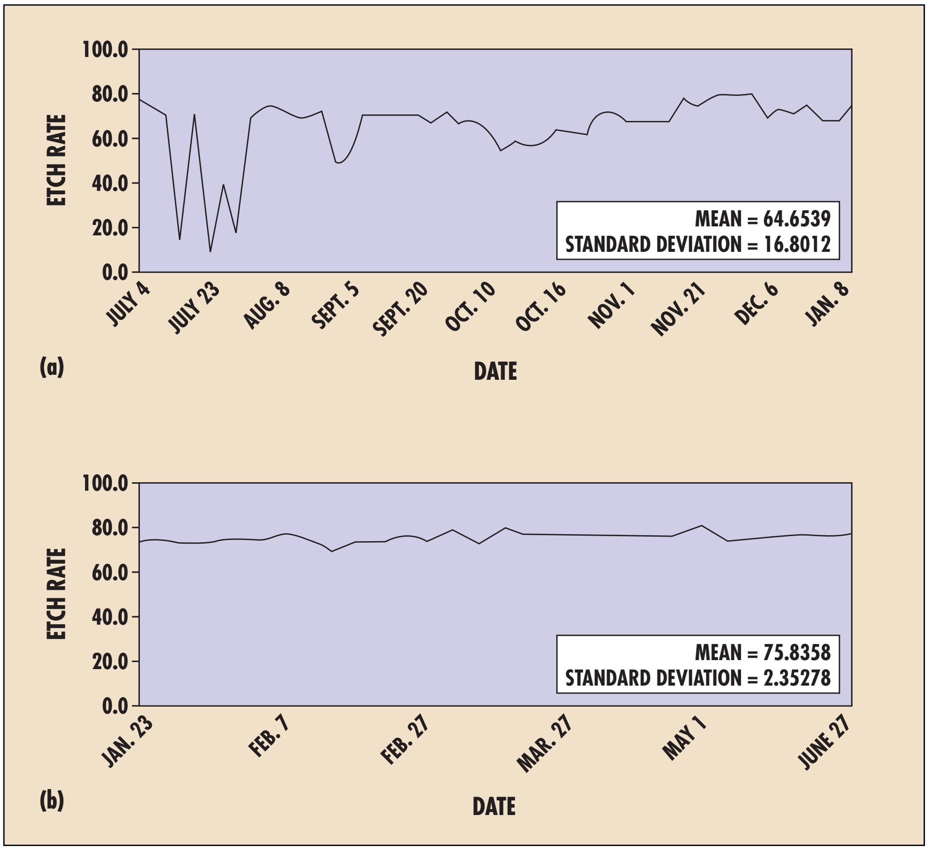

Figure 5: Control charts showing the silicon nitride etch rate (in Å/sec) using (a) the standard RF delivery system, and (b) the new RF delivery system.

requiring the replacement of parts or other system retuning have occurred.

An unexpected benefit of the retrofit was an improvement in process stability. Because delivered power in the new system is measured at the electrode and instant feedback is given directly to the generator, the etch process could be centered immediately after installation and stability could be maintained. The charts in Figures 5a and 5b illustrate the fab's standard process qualification monitor for etch-rate performance six months before and six months after the installation of the new system, respectively.

Using the new RF delivery system, the etch-rate standard deviation was reduced from more than 16 Å/sec to approximately 2 Å/sec. Before the retrofit, there were 13 out-of-control events out of 52 etch tests, compared with 0 such events out of 30 tests after the retrofit. Since out-of-control events require the use of additional test wafers and possible maintenance intervention, their reduction directly reduces downtime and lowers costs.

Conclusion

A fab team at Agilent found that an RF system retrofit increased equipment uptime. In addition, improved process quality has enabled the fab to reduce the consumption of test wafers and focus efforts on more-pressing problems. Increased predictability of critical end-of-line processes has allowed the team to more effectively forecast line wafer outs without uncertainty caused by excessive downtime.

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