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WHITEPAPER

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OPTIMIZATION OF THE CHAMBER CLEAN CYCLE FOR PECVD PROCESS TOOLS

As semiconductor fabs evaluate their overall productivity, all process steps must be constantly measured and evaluated for potential improvements. One such process step—chamber clean—is used by all chemical vapor deposition (CVD) tools and can be overlooked, because no wafer is actually in the chamber during this step. However, it can prove to increase throughput if properly managed. A fab located in the northeastern U.S. has taken an aggressive approach to improving their CVD process by evaluating the effectiveness of the chamber cleaning step. This step involves using a plasma discharge to periodically clean the chamber to bring it back to an optimum condition. The fab decided that by implementing a more accurate means of determining the end-point of their chamber clean, they could see direct savings from a reduction in gas consumed during the clean process. In addition, higher throughput, and increased yields also result in bottom-line savings. This fab uses a variety of CVD chambers including the Novellus ALTUS™, SEQUEL™, and SPEED™. All these had used C_2F_6 for their chamber clean cycles, but the fab recently converted to NF_6 in order to reduce green-house gas emissions.

IMPROVING THE CHAMBER CLEAN STEP

The fab's process and maintenance engineers took a simple approach to improving their chamber clean step: replace the existing combination of optical emission spectroscopy (OES) and "timed" clean processes with an RF-based system to actively determine end-point under all conditions. OES has been the standard method of determining end-point under high-flow or high-pressure for many years. However, OES proved inadequate for low-flow or low-pressure cleans. In these situations, a "timed" clean step was used. This method allows the plasma chemistry to clean the chamber for a pre-determined amount of time, based on the cumulative deposition of the chamber during wafer processing. No active monitoring occurs after initiation of this clean step.

The new RF-based system operates on the simple principle of actively monitoring the plasma impedance during the clean step and using a change to this impedance to indicate when the clean process has been completed. Depending on the composition of the film being cleaned and its by-products, the impedance can increase or decrease. The RF-based system samples the plasma at 100 millisecond intervals and sends an end-point command back to the tool's controller through its digital communication port precisely when all chamber walls and surfaces have been cleaned. This system utilizes a broad-band RF sensor placed in series with process chamber's RF power path. Locating the sensor as close as possible to the chamber is necessary to produce an RF signal capable of measuring delivered power to the chamber from which plasma impedance can be derived. In turn, the tool's controller communicates important information about the recipe step to the RF-based system. However, prior to allowing the RF-based system to actively command end-point, two issues must be addressed. First, the RF-based system must not cause shifts to any CVD process. Second, all clean processes must be passively monitored to ensure that the RF signature offers a clear and detectable transition which is used to indicate end-point.

SUCCESS ON THE SEQUEL™

The fab decided to begin an evaluation period with their SEQUEL chambers to compare the existing end-pointing methods to Advanced Energy's RF-based system[1]. The RF-based system reliably identified an accurate and repeatable end-point on the SEQUEL CVD tools under all conditions of pressure, flow, process gas type (C_2F_6 or NF_3), and deposited films.

The evaluation process began by installing four RF sensors with their associated electronic modules on four SEQUEL chambers. The electronic module contains a PC with a flat-panel display, keyboard, and semiconductor equipment communications standard (SECS) capability. In addition, the electronics converts all RF data including voltage, current, and phase into a digital format suitable for real-time processing by the PC. The RF-based system passively collected data in the background and stored information on over 200 clean steps. Figure 1 shows a single end-point trace of a high-pressure NF_3 clean of a nitride film. In this situation, the RF-based system demonstrated the potential to eliminate 15% of overall clean time.

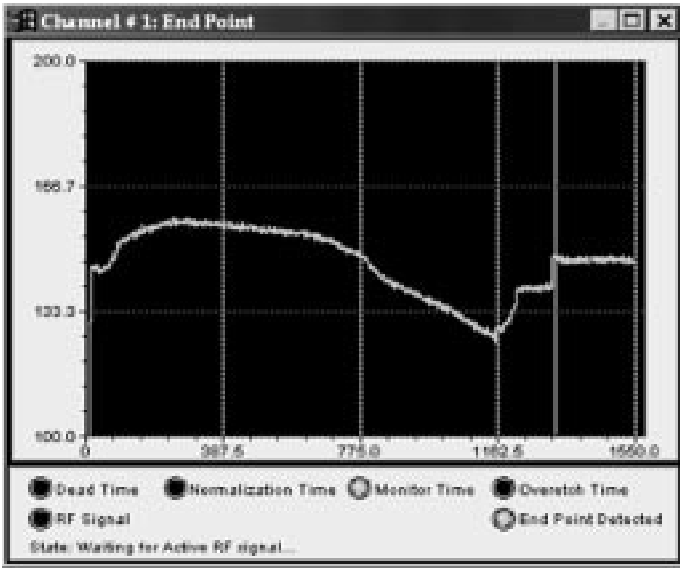

Figure 1. NF3 nitride clean on a SEQUEL™ chamber

This comparison allows the RF-based system to evaluate its potential benefit without any change to the existing configuration. The data collected included both the high-pressure and low-pressure cleans using NF_3 for both nitride and oxide films. After the RF-based system completed the data collection phase, an off-line software program determined the optimum end-point algorithms for the various clean steps. Then an end-point simulation software package allowed the algorithms to be evaluated using the previously collected data. This procedure can be repeated as many times as necessary in a matter of seconds to ensure that all algorithms functions properly. Note in the case of Figure 1, a false end-point could have been detected earlier in the clean step. However, the off-line refinement of the algorithm prevented this. Based on this evaluation, the decision was made to convert 18 chambers to the RF-based system and to eliminate the old OES hardware.

Future efforts on SEQUEL chambers will include testing to reduce the C_2F_6 or NF_3 flow rates. Typically, OES requires a higher flow rate to achieve acceptable end-point detection. The RF-based system has the advantage of viewing the entire plasma discharge—instead of just a small sample—by virtue of measuring all RF power flowing through the chamber. This RF-system has demonstrated requirements of 30% to 40% less gas flow without any degradation of its end-pointing ability[2].

SPEED™ AND ALTUS™

The evaluation of SPEED and ALTUS chambers followed a similar procedure to determine the benefits of converting to an RF-based system.

Figure 2 shows a single trace from high-pressure oxide clean on a SPEED chamber. In this case, the existing timed clean is compared to the RF-based end-point. The RF end-point reached end-point in 30% less time as compared to the timed clean. Even this subtle change in plasma impedance is easily detected. In addition, the low-pressure clean step also utilized a timed clean and achieved a 38% reduction with the RF-based system.

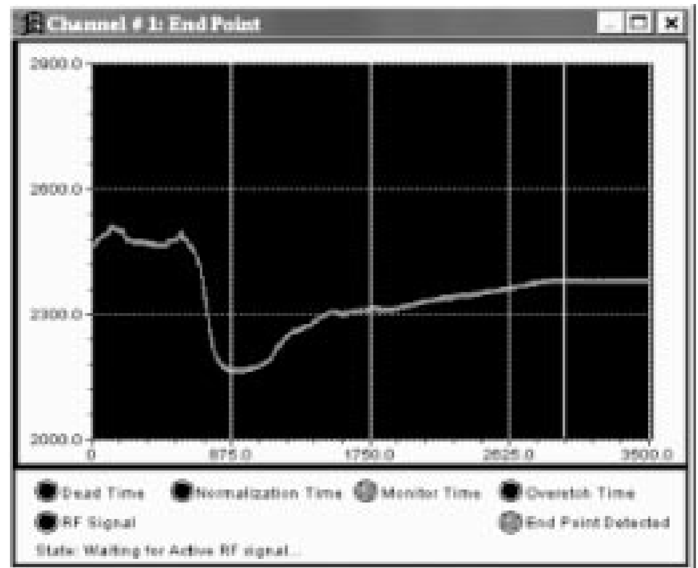

Figure 2. Oxide clean on a SPEED™ chamber

A similar trace from an ALTUS chamber clean is shown in Figure 3. This tungsten clean step also has a subtle change; the trace flattens out just after the chamber has been completely cleaned. A 15% reduction (about nine minutes) in total clean time was achieved with the RF-based system.

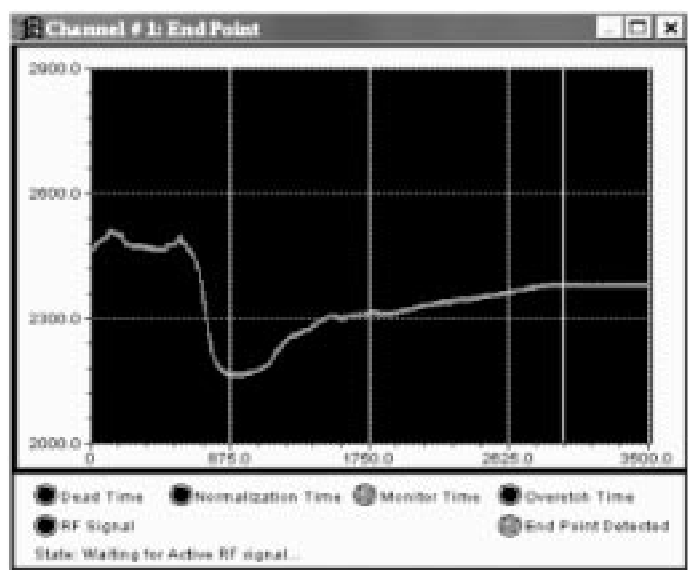

Figure 3. Tungsten clean on an ALTUS™ chamber

SUMMARY

As with most types of CVD chambers, the SEQUEL, SPEED, and ALTUS chambers also achieved significant benefits from replacing their traditional methods of ending the chamber clean step with an RF-based system. The pay-offs are improved tool utilization and less gas consumption. Some additional testing will determine the additional saving by reducing the gas flow during the clean step. Further, as environmental restrictions affect more and more semiconductor fabs, the need to use newer RF-based technology to achieve greater utilization will become even more evident.

FOOTNOTES

1 *RFEP™ (Radio Frequency End-Point System) designed by the Instrumentation Division of Advanced Energy*

2 *AMAT P-5000 CVD-Clean Optimization Project by James N. Pinto of IBM Microelectronics Division, and Michael Triplett of Applied Materials, ACET Division*

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