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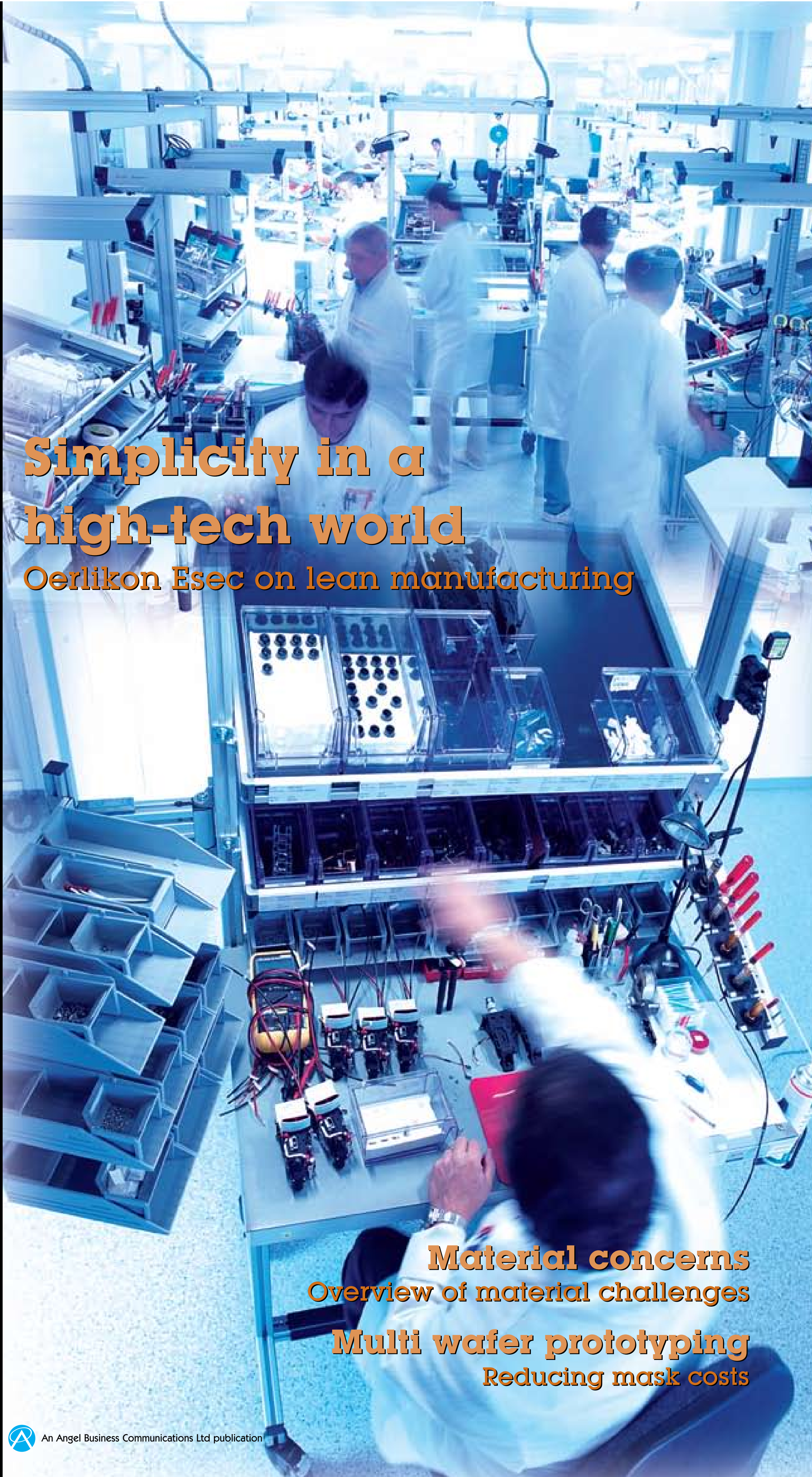


Simplicity in a high-tech world

Oerlikon Esec on lean manufacturing

Material concerns

Overview of material challenges

Multi wafer prototyping

Reducing mask costs

An Angel Business Communications Ltd publication

Optimising performance by integrating RF power and matching technologies

Advanced Energy discusses the importance of accurate delivery of RF power in the semiconductor industry.

As semiconductor film stacks and features become increasing complex the demands placed on plasma processes creating them continues to grow. One of the most essential elements for critical plasma processes is the accurate delivery of RF power. It is now common for processing chambers to be equipped with two or more independently powered electrodes, often operated at different frequencies and in some cases multiple frequencies are mixed on a single electrode. Advanced features such as pulse-modulated power are gaining popularity, as is the use of multi-step or continually cycling process chemistries to further manipulate feature details.

Today, more than ever, RF power delivery systems must offer flexible control while being highly adaptable and agile in order to meet exacting standards. Regulation and control must be accurate across a broad range of operating conditions to accommodate next generation processes and chemistries required by device and process designers.

Advanced power delivery for next generation process technologies

Effective integration of a RF power system with an impedance matching network is essential for optimised power delivery into today's processing systems. Today, the RF generator and match network must work together to provide accurate and repeatable power into increasingly complex and variable plasma conditions.

Essential capabilities now include:

- Extremely accurate power delivery into all load conditions
- Wide impedance range operation
- Real time impedance metrology for accurate tracking and compensation of load conditions
- Highly agile tuning to ensure power delivery into fast transients
- Fast ignition and settling to minimise process overhead
- Advanced features including pulse modulation, pulse synchronisation and phase matching

Only through recent advances in power delivery architecture and intelligent matching capabilities have all these features become available. Still, to effectively utilise such capabilities, a properly integrated solution is necessary. Here we demonstrate such integration of an Advanced Energy Paramount RF Power Delivery System with an Advanced Energy Navigator variable matching network.

For demonstrating the capabilities and attributes of such a combined system, a semiconductor class, dual electrode chamber was used to create 'live' plasma test scenarios. Impedance matching through chemistry transitions were used to compare and contrast different matching methods, while tuning speed

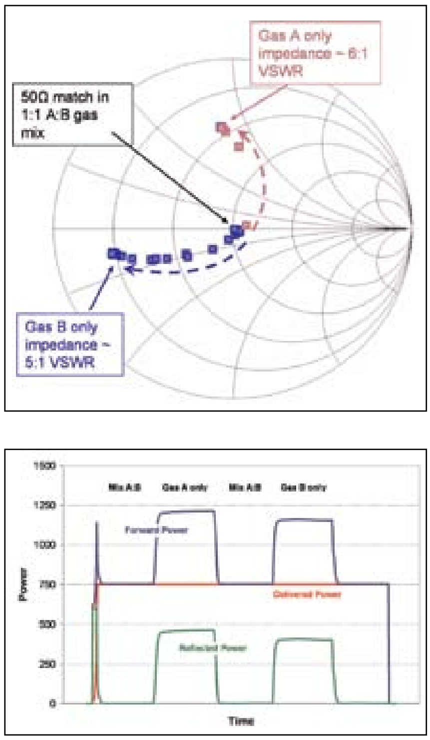


Fig. 1. Gas flow induced impedance changes in an ICP plasma under fixed match conditions

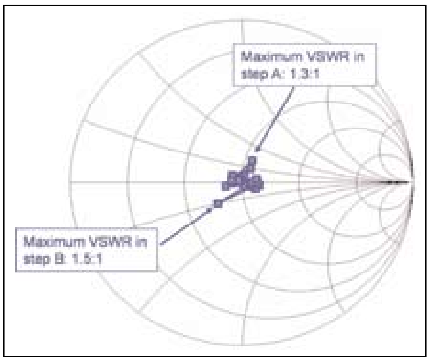
Variable matching networks are relatively slow. Therefore when process transitions become rapid or highly cyclical, alternative methods for tuning are required

was illustrated through power transitions and ignition events. Advanced capabilities combining features such as frequency tuning, load power leveling and pulse modulation are demonstrated to deliver unique capabilities in simulated process runs.

Process results

Transients are increasingly common in multi-step plasma processes. Transients may result from changes in gas flows, chemistries, power levels or any or all of the above simultaneously. Power delivery must remain stable through these events. Fig. 1 uses a Smith Chart to show load impedance changes resulting when an equal mix of two gases transitions to all of one gas and then to the other. The temporal impact to power delivery is also shown.

Through such transitions power to the plasma is maintained using load power regulation. This operating mode is the fastest option for maintaining power through transients. Load power regulation, however can be limited depending on power requirements and the range of impedance change therefore compensation for large changes is traditionally handled using a variable matching network. Fig. 2 shows impedance compensation when a variable match actively retunes through process transitions.



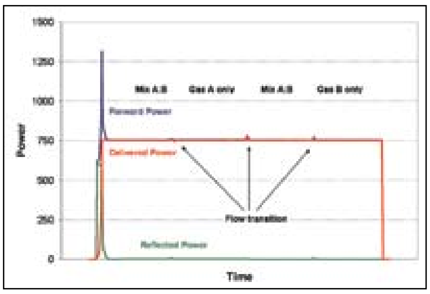
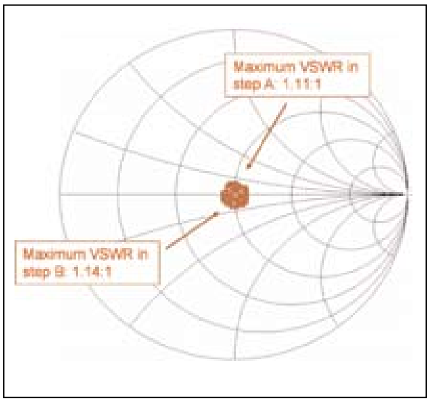


Fig. 2. Active retunes by variable matching network during process transitions



Variable matching networks are relatively slow. Therefore when process transitions become rapid or highly cyclical, alternative methods for tuning are required. Sweep frequency tuning offers extremely fast impedance matching to compensate for rapid process transients and cycles. Fig. 3 shows the Smith Chart impedances and the power delivery trend during sweep frequency tuning during the gas cycling described above.

Fast frequency tuning extends the usable range for load power regulation resulting in broad, yet highly agile operation. For very large impedance changes, a variable matching network may still be required. Proper implementation of each element provides the highest agility with the broadest operating range available (see Table I).

Sweep frequency tuning can be significantly faster than variable match tuning. Tuning speed is best illustrated using fast impedance changes such as those brought on by power transitions.

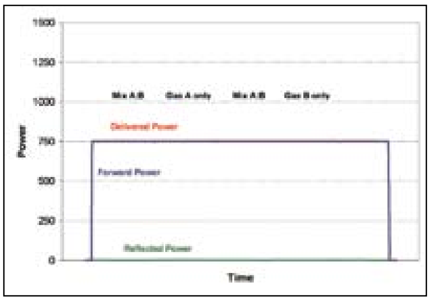


Fig. 3. Sweep Frequency tuning during gas flow transitions provides fast tuning through process transients

In Fig. 4 tuning speed is tested using a 5x change in power to an ICP plasma. The corresponding impedance change occurs over a period of approximately 800 μsec. At that point frequency tuning responds and completes the retune in approximately 232 μsec. A variable matching network required several hundred milliseconds to accomplish a similar retune.

Fast frequency tuning can also decrease settling time at ignition. Fig 5 shows three scenarios for tuning at ignition, a) default match network capacitor positions, b) optimised match network preset positions and c) frequency tuning.

Fast retuning may be most valuable when both rapid and frequent process

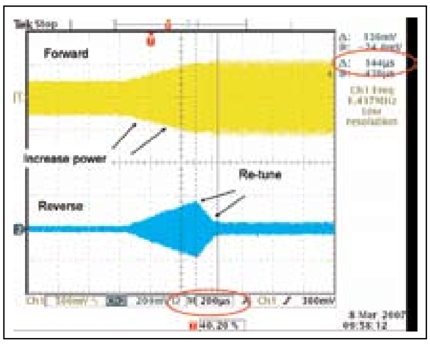


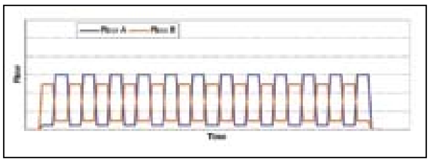
Fig. 4. Power stepped from nominal to 5x nominal creating plasma impedance shift… frequency based retune in less than 250 microseconds

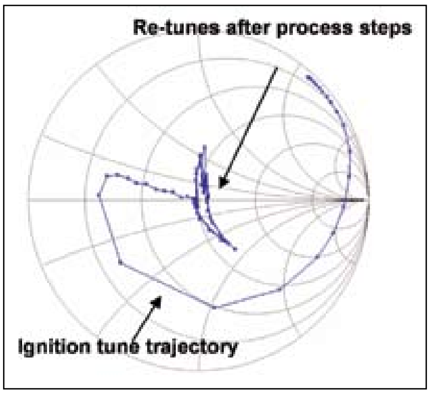
Option	Advantage	Disadvantage
Load Power Regulation	Extremely fast, accurate delivery to into 50 and non-50 Ω loads	Limited range depending on required power or changes in load impedance
Variable Match with autotune	Widest impedance matching range available. Adjustable pre-sets for minimizing time to achieve match.	Relatively slow, mechanical components in match. Subject to wear in highly cyclical processes
Frequency agile tuning	Very fast, broader impedance range for load regulation	Operating range still smaller than variable match
Load power regulation with frequency agile tuning integrated with variable match	Broadest operating range, fastest performance available	None

Table 1. Power Deliver/Impedance Matching Options

cycles are required. Fig. 6a shows impedance results from a process cycled repeatedly between dissimilar gas flows. Fig. 6b and 6c contrast the temporal response of a variable match to a frequency based tuning approach. Impedance excursions are minimised by the more agile frequency based tuning approach.

Pulsed power modulation provides a means for tailoring plasma behaviors but pulsing can create undesirable issues for a variable match network. High speed frequency tuning along with fast impedance measurement (intra-pulse) can address these issues allowing for dynamic tuning, real time, even while RF power is pulsed. Fig. 7 shows an oscilloscope trace of frequency tuned pulsing during plasma ignition.





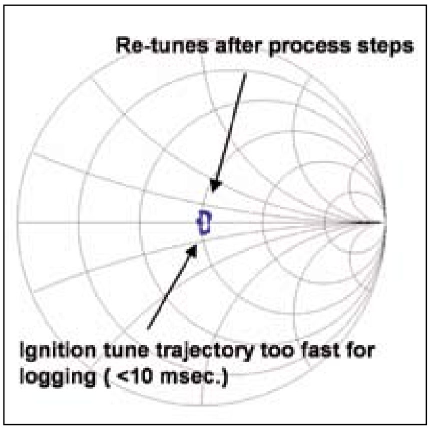


Fig. 6a (Top left). Gas flow cycles for inducing impedance changes. Figs. 6b (Left) and 6c (above). Impedance excursions from gas flow cycling in an ICP plasma (b) using fixed frequency, variable match and (c) using frequency agile tuning.

Summary

Complex film stacks and exacting standards for plasma based thin film processing places unprecedented demands on today's RF power delivery products. Requirements to maintain tight process control on multi-step processes featuring wide ranging plasma impedances demand a highly sophisticated and capable power delivery technology. To take greatest advantage of features like load power leveling, frequency agility, digital impedance matching and pulse modulation, proper integration of power delivery and matching is required. Integration of the Advanced Energy Navigator Digital Matching Network with the advanced Paramount RF Power Delivery System is shown here to offer next generation performance capabilities meeting the future demands of plasma process technologies. The complimentary capabilities of the combined products offers unprecedented flexibility and accuracy opening up new territory for plasma process precision and performance.

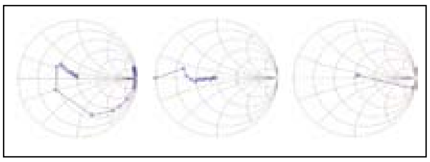


Fig. 5. Tuning trajectory at plasma ignition using (a) no match preset (~ 2.7 second tune time), (b) optimised preset (> 1 second reduction in tune time) and (c) frequency based tuning with fixed match position (~ 0.01 second tune time)

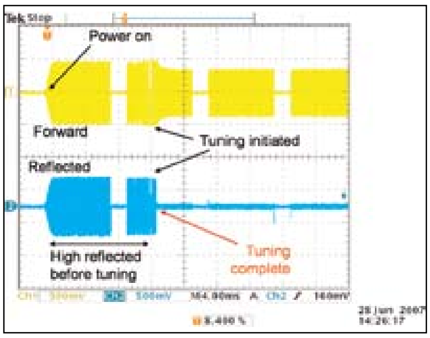


Fig. 7. Frequency tuning while pulsing at ignition. Start frequency was 13.56 MHz; tune frequency 13.81 MHz. Pulse frequency 100 Hz @ 80% duty factor. Time scale: 4 millisecond per division