SELECTION CRITERIA FOR THE DISCRIMINATING RTP USER ©

By

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Abstract

The process engineer who has been assigned the responsibility of selecting new semiconductor fabrication equipment is not always given the luxury of using a time-tested set of guidelines with which to make an intelligent choice. The following discussion attempts to set that disadvantage aside by providing a substantial check-list with which to evaluate rapid thermal processing (RTP) equipment. Although the subjects of system architecture and temperature are RTP specific, most of the general guidelines provided herein can be used to evaluate virtually any type of equipment found in the wafer fab.

Introduction

Even for the most experienced process or equipment engineer, the task of choosing fabrication equipment in the semiconductor industry is not always a pleasant one. In some cases, the buyer is not always the user; in others, financial restraints dictate a choice which is not necessarily a sound engineering decision. Either one of these scenarios present a different set of difficulties.

It is generally accepted that the equipment purchasing process is an on-going task that becomes more difficult with the ever-increasing demands of technology. As the semiconductor manufacturing industry continues to follow the International Technology Roadmap for Semiconductors (ITRS) [1] and progresses steadily towards the sixteen billion transistor dynamic random access memory chip (16 Gigabit DRAM), hard choices for semiconductor equipment are being forced upon the process engineer. This is especially true when it becomes time to transfer a manufacturing process developed in the R & D laboratory to the wafer fab.

When saddled with the responsibility of evaluating semiconductor manufacturing equipment, the wise process engineer will review a set of practical considerations before making a final choice. If the engineer is lucky, a previously-available tabulated list of key factors to guide them in this evaluation process has been made available to them from another engineer in the fab. Unfortunately, it is more likely that the engineer must create one from scratch. Whereas the topics on such a list may be used as a sign-off checklist of newly-purchased equipment during factory acceptance, it becomes more valuable when used during the decision making process. Indeed, the process engineer will find such a list quite useful when making a one-to-one comparison of different suppliers and their competing models of equipment.

Our equipment review list in Table 1, “Practical Considerations For The RTP User” [2], are meaningful topics which together may be considered to be a process or equpment engineer’s selection guide for rapid thermal processing (RTP) equipment. Although the first two topics on this list, system architecture and temperature, are equipment-specific to RTP, the remaining topics are generic and can actually be used to evaluate most semiconductor capital equipment. It should be noted that this discussion is directed towards selection of stand-alone RTP systems only and that the topics will be discussed more or less in order of priority. In addition, this paper assumes that the reader is knowledgeable enough to know what a rapid thermal processor tool is and what it can do.

System Architecture

As a first step in the selection of RTP equipment, particular processes furnished by the RTP system may dictate at the beginning of the decision-making process which particular make or model of equipment will be purchased. If this is the case, the architecture of the RTP system (i.e., hot, warm, or cold wall - see Figure 1) may not be a selection criteria at all. For example, rapid thermal chemical-vapor-deposition (RT-CVD) is accomplished only in a cold-wall system. On the other hand, implant anneal may be accomplished by either of the three available architectures. Thus you may have some flexibility in the choice of equipment architecture for a particular process.

The source of thermal energy and how it is distributed (be it single lamp, single or dual banks of tungsten-halogen lamps, or the multi-lamp systems with associated reflector surrounding each lamp) may provide process-specific advantages for the user. While novel lamp architectures are being proposed and developed by educational and research institutions, there are few commercial models of equipment available at this time. However, there is built-in flexibility to an RTP system which has two banks of tungsten-halogen lamps if the manufacturer allows a user to switch off the bottom bank of lamps. This type of versatility would be advantageous in the manufacture of solar cell thin films.

Vacuum is clearly an advantage when processing thin films such as titanium silicide and nitride, although many present-day users are quite satisfied with an RTP system that incorporates a pre-process nitrogen or argon purge prior to wafer processing. Indeed, the availability of vacuum plays an important role in achieving low thermal budget processing of CVD films [3]. Vacuum has also been shown to be useful in reducing the diffusion of impurities in As+ implanted silicon [4]. Partial pressure is most common with RT-

Table 1: Practical Considerations for the RTP User

System Architecture
- chamber wall design (hot, warm, or cold)
- radiation source and reflector design
- single lamp
- one or more linear lamp arrays or multi-lamp
- novel designs
- vacuum or overpressure capability
- options such as deuterium or uv lamps
- method of gas injection
- wafer size

Temperature
- range (150° - 1200°C)
- measurement technique
  - pyrometer
  - emissivity control
  - end-point detection
- accuracy
- uniformity
- repeatability

Process
- time and sequence variability
- reproducibility
- damage & defects
- particulates
- ambient environment
- process control
  - time and sequence variability
  - ramp-up and cool-down rates
  - interface protocol

Equipment
- single wafer vs batch or small batch
- complexity
- wafer rotation
- options
- automation
- throughput
- flexibility and adaptability of control system (S/W driven vs PID controller);
- recipe driven and/or recipe storage; expansion card
- # gases and gas control
- facilities requirements
- size ($ value in cleanroom floor space)
- recommended preventive maintenance procedures
- particles
- availability of manuals (operator and application)

Company
- number of years in business
- # systems in field
- customer recommendations
- on-time delivery
- service
- applications assistance
- local sales representative
- if a new company, who are the players? Are they well-known?
- marketing hype

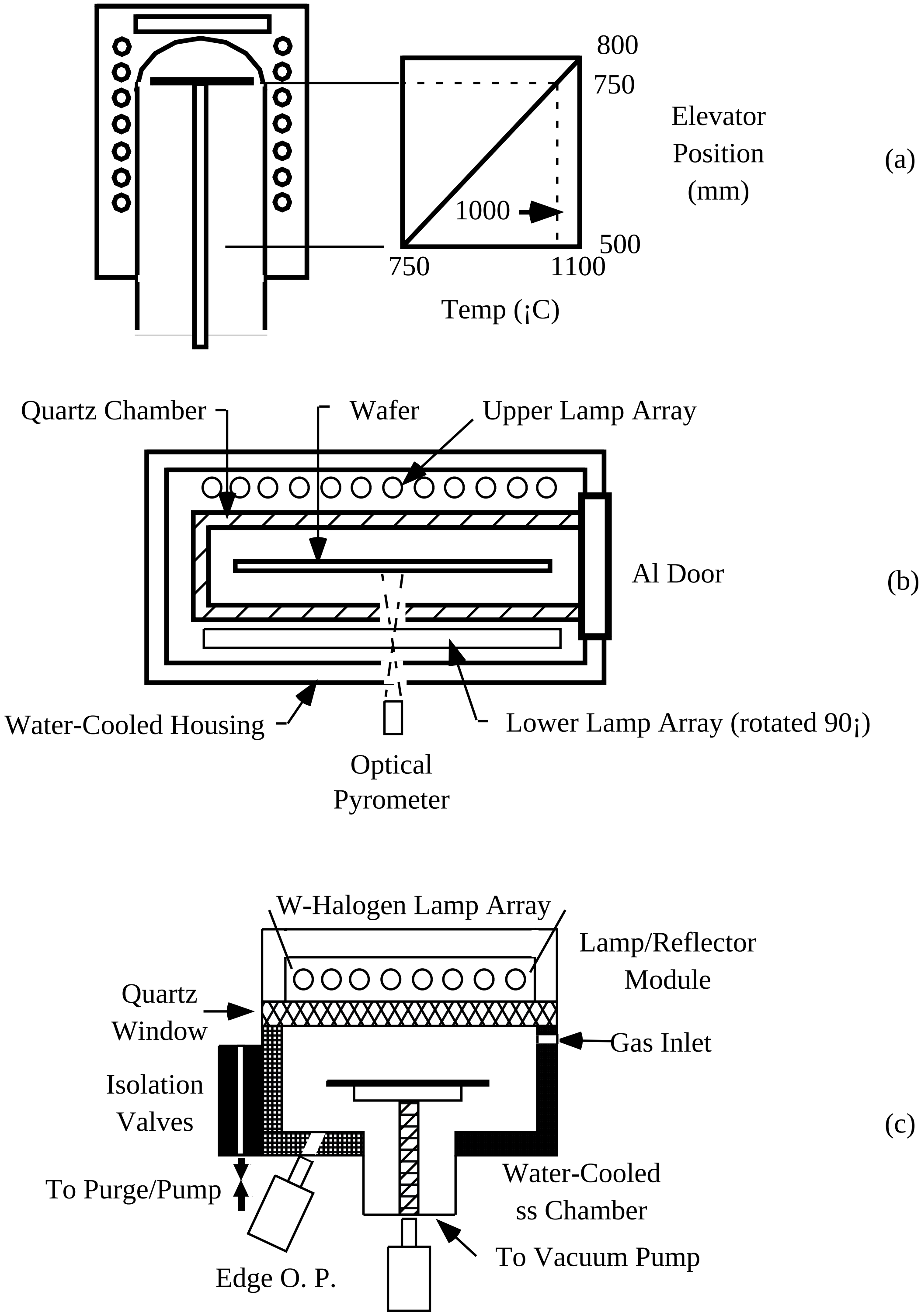


Figure 1: Examples of three RTP system architectures;
(a) hot wall; (b) warm wall; (c) cold wall

CVD processing [5-6]. Overpressure is usually associated with RTP processing of III-V compound substrates [7], but it may not be a requirement in the silicon fab until sometime in the near future where speed of film growth may be enhanced by such capability. In addition, an option such as a deuterium lamp may enhance some RTP processes [8]. However, whether vacuum is or is not available, either standard or as an option, could be an issue. Since many wafer fabs are unsure about future processes, it might be preferable to have the capability of processing with vacuum when the system is purchased, rather than be saddled with a future dilemma of needing the capability and not having it available, thus necessitating another round of equipment selection.

High gas flow rates will affect the uniformity of some processes [9-10], which implies that the method of gas injection will most likely be a concern. A single injection port is more likely to affect wafer process uniformity than will a manifold that disperses gas over a very large area. The ability to process the next wafer size may be a cost-of-ownership issue. With the impending requirement of processing 300mm wafers, the immediate purchase of an RTP system may be influenced by the need for flexibility to process the next generation of wafer sizes.

Temperature

The topic of temperature is a major consideration in the selection of an RTP system. Many equipment suppliers today specify the same approximate range of temperature (150°-1200°C) but may have different ramp rates (i.e., ramp-up and ramp-down rates, usually in °C/sec) or other process specifics. Indeed, one manufacturer presently specifies a low temperature option, 0°-900°C, which brings to mind an obvious question: how does one measure accurately measure temperature below 250°C? In the long run, though, actual in-fab RTP processes will determine the required temperature range on RTP equipment. For example: sol gel film anneal ~ 250° - 300°C; aluminum sinter ~ 400°- 600°; Titanium silicide ~ 550°- 900°C; and implant anneal ~ 900°-1200°C.

The method of temperature measurement in an RTP system is a big concern, of course. The thermocouple was the first method used to measure and monitor the temperature in a commercial RTP system. The effectiveness of optical pyrometers, which have been generally replaced thermocouples, will clearly depend upon several factors, including what wavelength is being monitored as well as their placement within the body of the RTP system. In addition, as identified in Figure 2, other problems exist: variation in emissivity resulting from differing surface texture on the backside surface of the wafer as well as variations in the planar surface of the frontside of the wafer [11-12] due to the die. But other methods of temperature measurement such as optical fiber thermometry (OFT) [13-15] and the potential forthcoming laser interferometry method foresee the near-term ability to measure the real-time, in-situ temperature and emissivity of the sample during processing. Of course, if end-point detection was presently available, accuracy in temperature measurement could become a moot point since all processing would cease once the desired thickness or resistivity and possibly their associated uniformity is achieved.

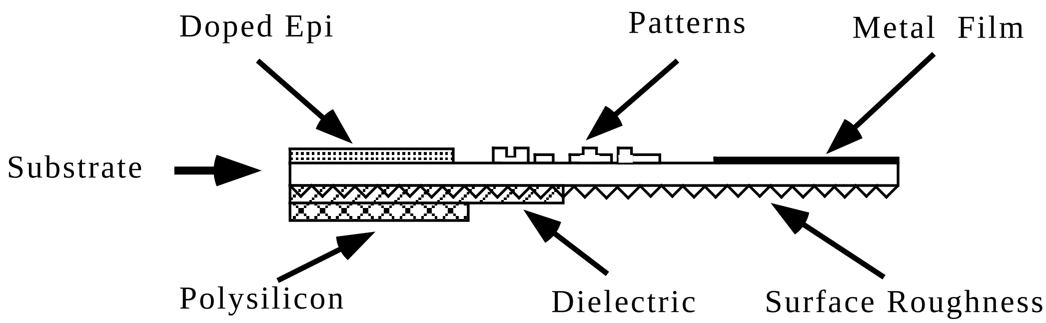
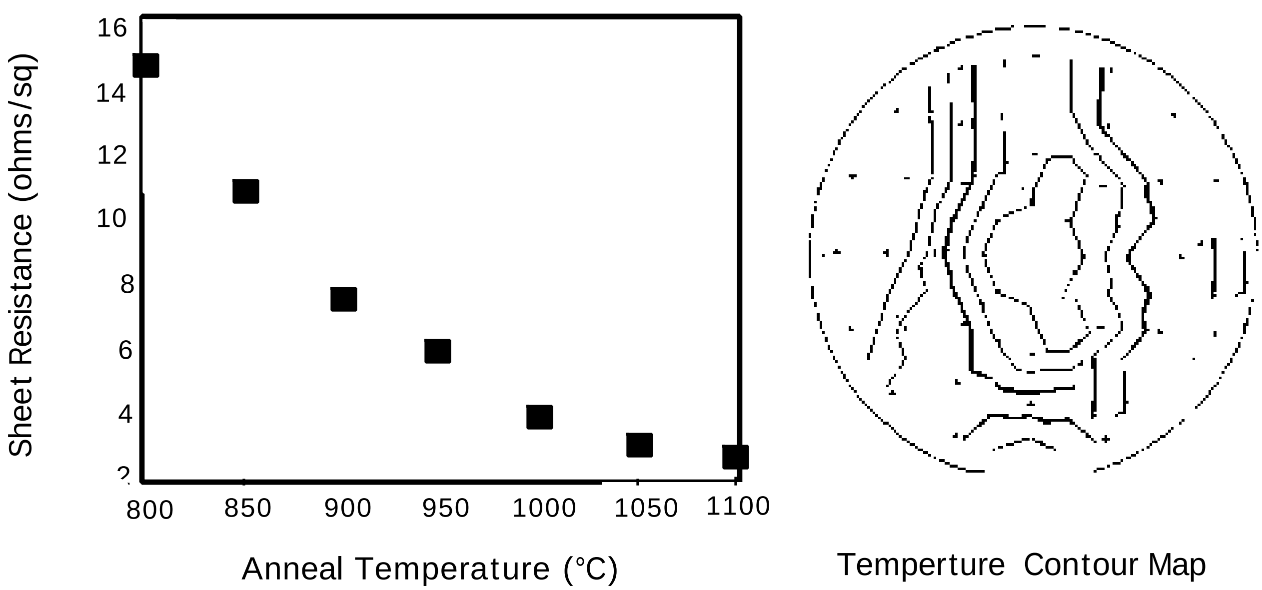


Figure 2: Process issues that will affect temperature [11-12]



(a) (b)

Figure 3: How to convert a sheet resistance contour map into a wafer temperature map: (a) Sheet resistance (Rs) vs RTP anneal temperature. The average Rs of a CVD WSi film after an RTP sintering cycle is plotted; (b) temperature uniformity of the CVD WSi film sintered at 850°C on a 125mm wafer; (b)The average contour is 855 °C (4°C one sigma) and the contour interval is 2°C. The test diameter is 4.5 inches. Both figures are from Varian Technical Report #117, "Dynamic Temperature Control: Key To Process Uniformity in Rapid Thermal Processing (RTP)".

The accuracy, uniformity, and repeatability of temperature in an RTP system are also relevant issues [16]. Accuracy and repeatability are dependent upon the choice of temperature measurement system; but, unfortunately, temperature uniformity is not a viable quantity to be measured in situ at this time. Therefore, temperature uniformity is usually inferred from process uniformity by measurement of some variable such as film growth thickness uniformity or sheet resistance uniformity [17] as shown in Figure 3.

Needless to say, the subject of temperature measurement in RTP is clearly an interesting and "hot" topic. Indeed, the process engineer is certainly likely to elicit "volatile" remarks when discussions are held with the various RTP suppliers on this issue.

Process

Process is concerned with the accuracy, uniformity, and repeatability of rapid thermal processing of wafers. As such, recipe management of time, temperature, ramp-up, and ramp-down (also called cool-down) versatility may or may not be a concern. Some systems may be completely programmable while others may be limited to a lookup table whose parameters have been previously determined. Reproducibility is measured by wafer-to-wafer variation in some parameter such film thickness or sheet resistance. In conjunction with a properly designed chamber and sample holder, if the process recipe has been properly optimized and control of the ambient environment has been achieved, a minimum of damage and defects will result [18-19]. Flexibility of the recipe and repeatable control of the process will be readily available with the presence of multiple ambient gases and an appropriate type of gas control (e.g., mass flow controller) .

Equipment

There are several key equipment issues with an RTP system. Complexity is not a big concern until overall system capabilities are examined. One manufacturer may provide a simple system with an appropriately reduced price but have available a large number of options. This may actually be more beneficial to the process engineer than their being forced to accept a fully loaded system with capabilities that will never be used. Automation and its associated throughput are important issues in the production environment, but are not a big concern to the research and development or implant engineer. The choice of a batch or small batch RTP system is rather limited at the present time; however, the International Technology Roadmap for Semiconductors (ITRS) does predict the imminent requirement of such capability.

Table 2: Recommended Preventive Maintenance Procedures For RTP Equipment [20]

- Process Monitors - once per lot
- Particle Check - once per week
- C-V Check - once per week
- Oxide Growth - once per week
- Temperature Calibration - once per week
- Chamber Wet Etch - once per month
- Machine Clean/Inspection - once per month
- Leak Check - once per month

Flexibility of the software to adapt to either type of engineer may be as important as its interface protocol. In other words, is the system software driven or does it have a PID controller? Is it recipe driven or does the system have simple recipe storage capability? The condition of the operator's manual (i.e., how well it is written), the availability of other documentation and application notes, and the identification of appropriate preventive maintenance procedures are also important. [see Table 2: Recommended Preventive Maintenance Procedures For RTP Equipment]

Facilities requirements should certainly be reviewed, since they are considered as an extension of the system's capability. The size of the system will most likely be a factor in determining the cost of cleanroom floor space. Particulates are always a concern in semiconductor processing. but will most likely be an issue in RTP systems only where wafer handling is an issue (manually loading versus robot or other means.

Company

Now comes the choice of supplier or manufacturer. With the present business climate in the semiconductor industry, one factor that may affect the purchase of a system is the number of years the RTP company has been in business. This is especially true with RTP equipment where recent changes in the supplier community should warrant closer inspection of the companies under consideration. In other words, will the RTP supplier be in business in five years or will a future merger result in the elimination of some products? Past performance can be used to determine the history of on-time delivery, service, and the capability to provide applications assistance. One excellent way to measure the performance of any supplier can be ascertained by obtaining the answers to two questions: (1) what are the number of systems a company has in the field?; and (2) who are their satisfied customers? Any supplier worth his salt will be happy to provide such a list. And don't forget the all important consideration of applications assistance.

On the other hand, however, there is the case where a new supplier has opened its doors for business and launched a new product. Many of the previously mentioned factors do not now play a role in the selection process and new questions must be asked: Who are the people who make up the company? Are they well-known players in the RTP community or do they have a long history in the RTP business? Are their new ideas sound ones and represent a true technical advancement in either equipment design or technology? Remember that many companies have a resident NIH (not invented here) atmosphere and may not be able to pursue intelligent alternatives to their existing technologies. (Note: even if such a technology was known to be better does not mean it was possible for a particular company to develop it). Thus, process results from a new, technologically superior concept or design is as important as the location of their beta-sites (i.e, who had the guts to put time into evaluation of a new company's product). By all means, there is no need to automatically eliminate a company just because they have a new RTP product and/or technology. Just make sure that all of the right questions are asked (which is your job) and satisfactorily answered (which is their job)!

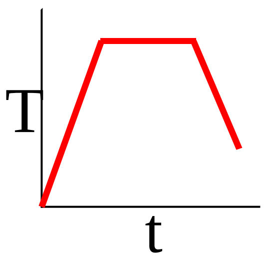
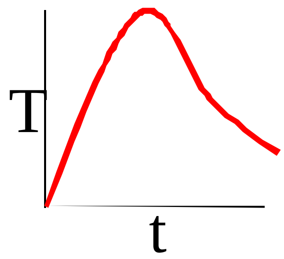
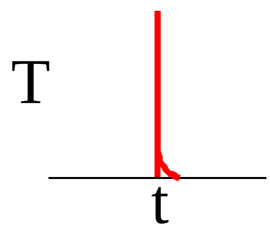
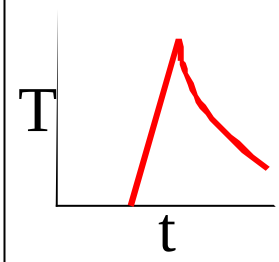
(a) Soak	(b) Spike	(c) Laser	(d) Impulse
			
Wafer is near thermal equilibrium with radiation. Thermal profile is flat during dwell.	Wafer response similar to heating source. Characterized by a rounded thermal profile.	Heat source acts much faster than the wafer. Only surface layer is heated. Thermal profile is sharply peaked.	Heat source is faster than the wafer but bulk is kept relatively uniform. Thermal profile is peaked.

Figure 4: Comparison of four temperature profiles: [21]
(a) Soak; (b) Spike; (d) Laser; and (d) Impulse

An excellent example of a new RTP supplier developing new technology is the "impulse anneal" [21] shown in Figure 4 compared to three other anneal profiles. A quick glance shows that the company has developed something no other company has available. Therefore, just because they are new does not mean that their tool should automatically be dis-regarded. Indeed, it might be worthwhile to take the next step and inquire if they have any "prominent" key players well-known within the RTP community.

The local sales representative may be a concern. Is the 'rep' a direct employee of the supplier or is it an independent sales representative who has a well-established reputation within the immediate community - one who has a known history in your area and may be counted upon to provide maximum representation for the supplier? Of course, with reference to the discussion on a new company, does a well-known, local sales rep handle the new product or is it someone you don't know? The answers to these questions may well determine the direction you may take when selecting your next RTP system.

Marketing Hype

And finally, a word to the wise process engineer: beware of all marketing hype! In other words, do not be totally accepting at face value all of the technical material and specifications provided by the supplier and their marketing department. Hidden within the depths of the information provided to you may be mis-leading, mis-directing, or non-factual information. In other words, your supplier may not always be telling you the truth!

For example, all specifications of RTP equipment by any supplier should be questioned and some even verified. Although the days of old where equipment makers could not be trusted because of their reputation to continually provide marketing hype are long gone, it is still a wise to be up-front with the supplier and demand that they stand by their specifications. Indeed, some years back, one semiconductor equipment manufacturer specified their system was “capable” of processing 200mm wafers, implying that you could buy one immediately. However, upon further investigation, it turned out that they had not even developed such a system! In fact, the specification only meant that the system was designed to process 200mm wafers - not that it had been built or tested yet!

Another example involves a fairly new concept called “spike anneal” [22], first described in 1997and illustrated in Figure 4. Basically, this is an anneal condition where the temperature of the wafer is similar to that of the heating source that is characterized by increasing the temperature ramp-up rate (up to 400°C/sec) while simultaneously decreasing the annealing time such that there is no anneal soak [23]. Therefore, since the spike anneal is directly tied to the maximum ramp-rate of a specific RTP tool and there is no available industry definition or standard, any supplier marketing guru can define a spike anneal for their equipment - any way they want. And guess what? A spike anneal for one supplier will NOT necessarily be the same spike anneal for another. Bottom line? Get a definition from each supplier and compare them carefully when you are evaluating RTP equipment.

Summary

The topics discussed in this paper and summarized in Table 1 are necessary for you to intelligently evaluate and compare rapid thermal processing systems. Now you are armed with enough knowledge to intelligently discuss the performance of each RTP product with their respective manufacturer. This advances you to the forefront of the equipment engineering evaluation team and entitles you to be called a "discriminating user"!

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