Ensuring safety and uptime by managing condensable gases

The need to safely exhaust CVD reaction by-products is increasing as complex device structures gain prominence in microelectronic manufacturing. Edwards Vacuum has applied novel solutions to increase safety, reduce downtime and control costs.

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THE RANGE OF CVD process precursor materials and associated reaction by-products susceptible to condensation in dry-pump foreline and exhaust systems continues to grow as the scope of new materials incorporated into emerging device structures expands. To a limited extent, the tendency for materials to condense in pipe-work can be reduced by diluting the exhaust with inert gas, a technique also widely used to control flammability in process exhausts. However, in the face of ever-increasing flow rates of flammable precursor gases in a number of CVD processes, dilution flow rates are increasing at a correspondingly high rate. As a result there is a strong motivation to reduce dilution rates to lower cost and improve abatement efficiency.

An alternative and more cost-effective strategy is needed to control condensation of liquids and solids in the process exhaust stream. Clearly, the major perceived risk associated with condensation is blockage of the exhaust pipe and a consequent process interruption caused by excessive dry-pump exhaust pressure or breach of seal integrity due to high pipe internal pressure. However, there are also other serious hazards that may result from condensed materials in exhaust pipes. For example, if partly reacted silicon compounds condense in exhaust pipes during a deposition process, and are subsequently exposed to fluorine during the following chamber-cleaning process, an exhaust fire is likely to occur, resulting in a serious risk to equipment and personnel. Similarly, condensed materials which incorporate fluorine may release HF vapour when the exhaust system is dismantled for cleaning and the condensate exposed to atmospheric water vapour.

To counter the condensation threat and improve system safety and productivity, thermal management systems are widely employed to control operating temperatures of forelines and exhaust pipes. These systems typically comprise electrical heater mats in close contact with the foreline or exhaust pipe wall, enclosed by high-efficiency thermal insulation material. However, these systems are really only fully effective if they are carefully installed on the pipes to avoid cold spots, and their operation controlled in real time to ensure correct pipe operating temperature at all times. Furthermore, when designing pipe thermal management systems, care has to be taken that introduction of diluting gases into the exhaust system, or introduction of reactive gases such as oxygen or natural gas into the point-of-use abatement system,

Process type	Exhaust challenge
Low-K CVD	Complete abatement of complex and condensable low-k precursors
SACVD	Safe and effective abatement of high flows of TEOS, mixing with F_2
LPCVD Nitride	Safe handling of high flows of easily condensable materials
LPCVD Poly	High silane flow, associated solid reaction products (powder)
Epitaxy	Condensation of reactive (explosive) polysiloxane reaction products
Metal Etch	Control of condensable and corrosive gases and liquids
W-CVD	Control of H_2 flammability, control of solid reaction products (powder)
HDPCVD	Abatement of high F_2 flows
PECVD Nitride	Condensation of ammonium hexafluorosilicate
Poly Etch	Abatement of PFC gases and control of corrosive gas condensation
Implant	Safe removal of highly toxic hydrides at sub-atmospheric pressure

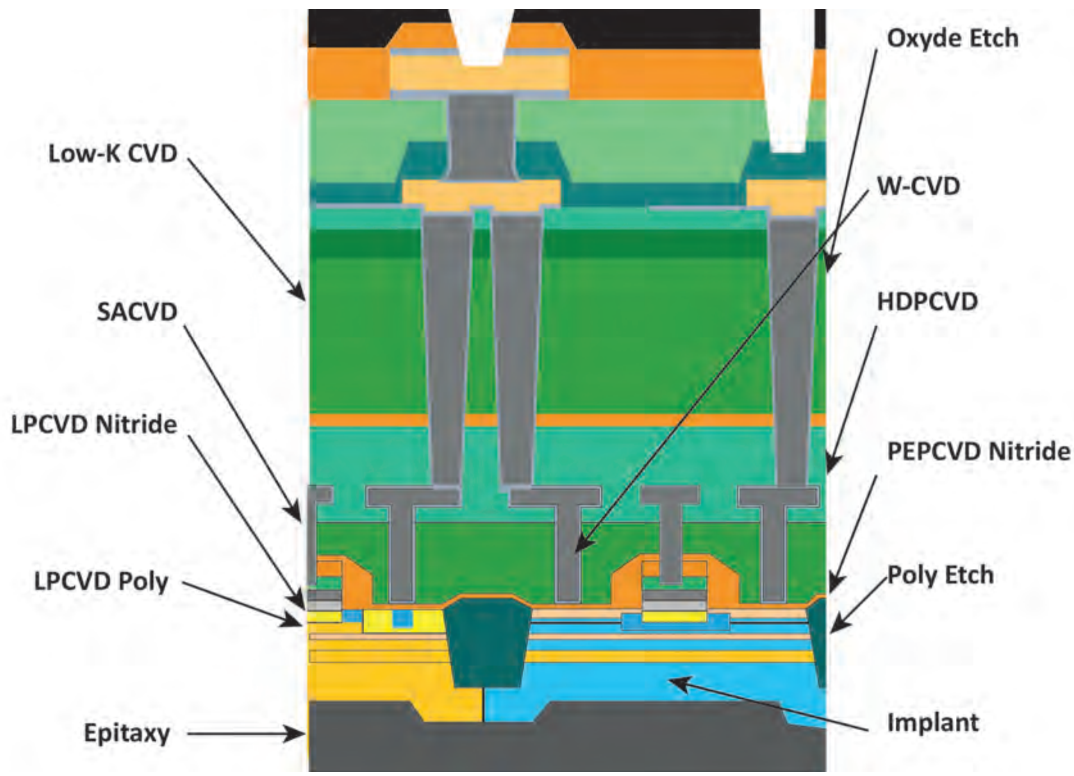

Figure 1: Many semiconductor manufacturing processes have the potential to cause condensation of liquids or solids in the exhaust gas stream, resulting in equipment down-time and lost production.

does not promote local exhaust gas cooling and condensation. This specific consideration requires that the temperature of injected gases and all other factors that can affect the exhaust gas temperature are controlled as part of a total process solution.

Typical applications of exhaust pipe temperature management systems

Many semiconductor manufacturing processes and their related exhaust management challenges are known to have potential to cause condensation of liquids or solids in exhaust gas pipes (see Figure 1).

There are many common examples of exhaust pipe blockage by condensable materials. For example, ammonium chloride (NH_4Cl) is formed in LPCVD nitride processes and condenses readily in exhaust pipes to form solids which can block the exhaust pipe and stop the process. This is particularly bad news if the process tool is a batch-type system (vertical furnace) – in this case an entire batch of wafers is put at risk.

Similarly, ammonium hexafluorosilicate ($(NH_4)_2SiF_6$), very fine white powder, can form during a silicon nitride PECVD process when ammonia comes into contact with fluorine-containing species generated during a chamber cleaning step from nitrogen trifluoride gas (NF_3). The resulting powder can very quickly block down-stream pipework, associated vacuum pumps and point-of-use abatement systems, causing equipment downtime and presenting a health and safety hazard for operating and service personnel (see Figure 2).

In principal, the solution is straightforward: maintaining exhaust/abatement system components above a critical temperature to prevent condensation, as shown in Fig. 3 below.

However, in practice there is a great deal of complexity and know-how involved in designing, installing and operating an effective exhaust temperature management system. It has now become vital that the installer has a detailed understanding of the process, its reaction products and their impact on the reliability and robustness of the sub-fab equipment. Furthermore, in addition to the more familiar condensation-prone process exhausts, epitaxy processes and emerging ALD processes now pose serious exhaust management issues as they migrate into high volume manufacturing.

Epi process exhausts have become notorious for their tendency to accumulate condensed highly reactive polysiloxane materials. These pose a particular hazard for service personnel since they have a tendency to react violently or even explosively when mechanically disturbed or exposed to air, and unfortunately, some emerging ALD processes have shown similar tendencies. The result is to put pressure on sub-fab equipment manufacturers to develop suitable best-known methods (BKMs) for setting up their products, including vacuum pumps, point-of-use abatement systems and the associated forelines and exhaust pipes, to provide safe and reliable operation. The requirement to continuously develop an understanding of emerging new processes now extends to designers of pipeline temperature management systems so that they are able to develop product solutions that deliver consistent, uniform and reliable pipeline temperature control.

Legacy thermal management systems

Vacuum pumps and point-of-use abatement systems intended for use in high-volume manufacturing fabs are typically designed to conform to specific process BKMs, ensuring that the gases are maintained at an

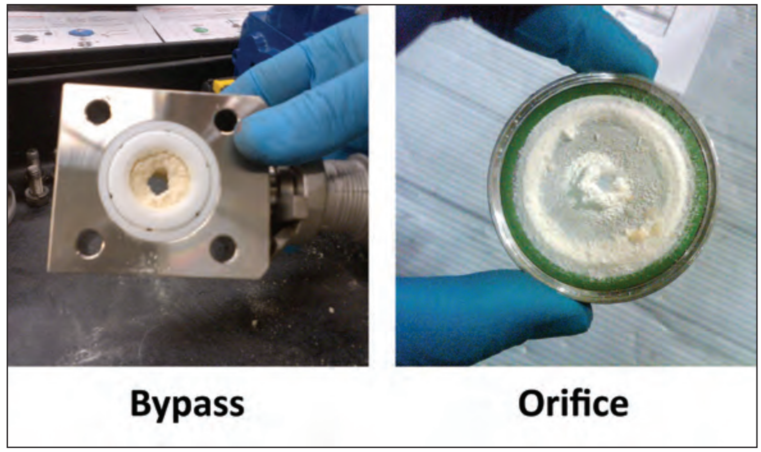

Figure 2: Ammonium hexafluorosilicate ($(NH_4)_2SiF_6$) build-up in downstream pipework and associated equipment can result in pipe blockage and lost production time

appropriate temperature throughout each piece of equipment. This might be achieved by incorporating heated elements at each vulnerable point, such as the flow control orifice shown in Figure 3. Equally important, and in some ways more challenging, is controlling temperature throughout the forelines, which connect the process equipment to the pump, and the pump exhaust lines, which connect the pump to the point-of-use abatement system. These pipe systems are invariably configured on a case-by-case basis to fit the location of the equipment or the available space and therefore require equally flexible and configurable pipeline heating solutions.

Early generations of pipeline temperature control systems aimed for flexibility by simply wrapping the pipes with an electrically powered heating element (such as a tape-heater) and enclosing it with an insulating material such as fiberglass. They usually included a simple local control mechanism typically comprising a temperature-sensitive switch to interrupt electrical power to the heater element above a certain

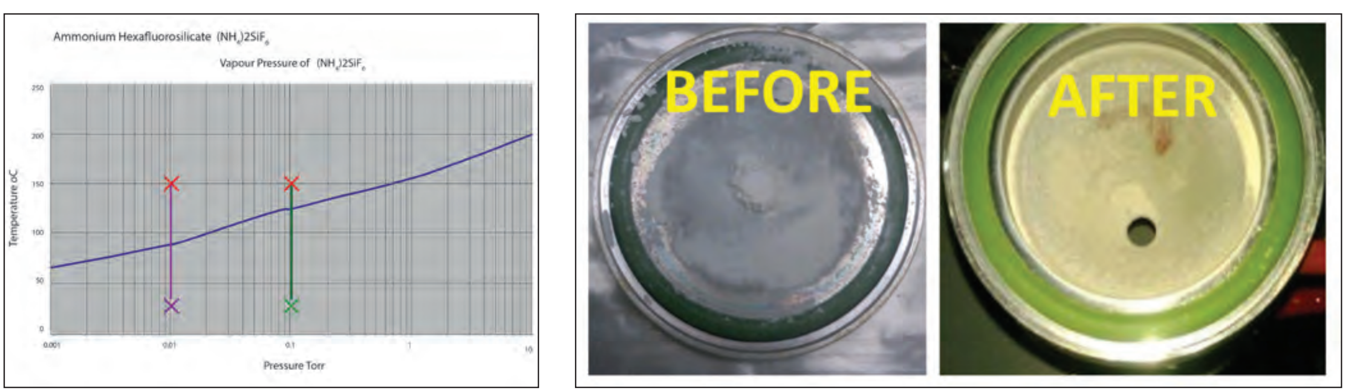

Figure 3: As the phase diagram on the left shows, maintaining the temperature of the gas above a critical temperature / pressure will prevent condensation of ammonium hexafluorosilicate. The before and after photos show a blocked orifice plate on the left and a completely clear heated conical orifice on the right.

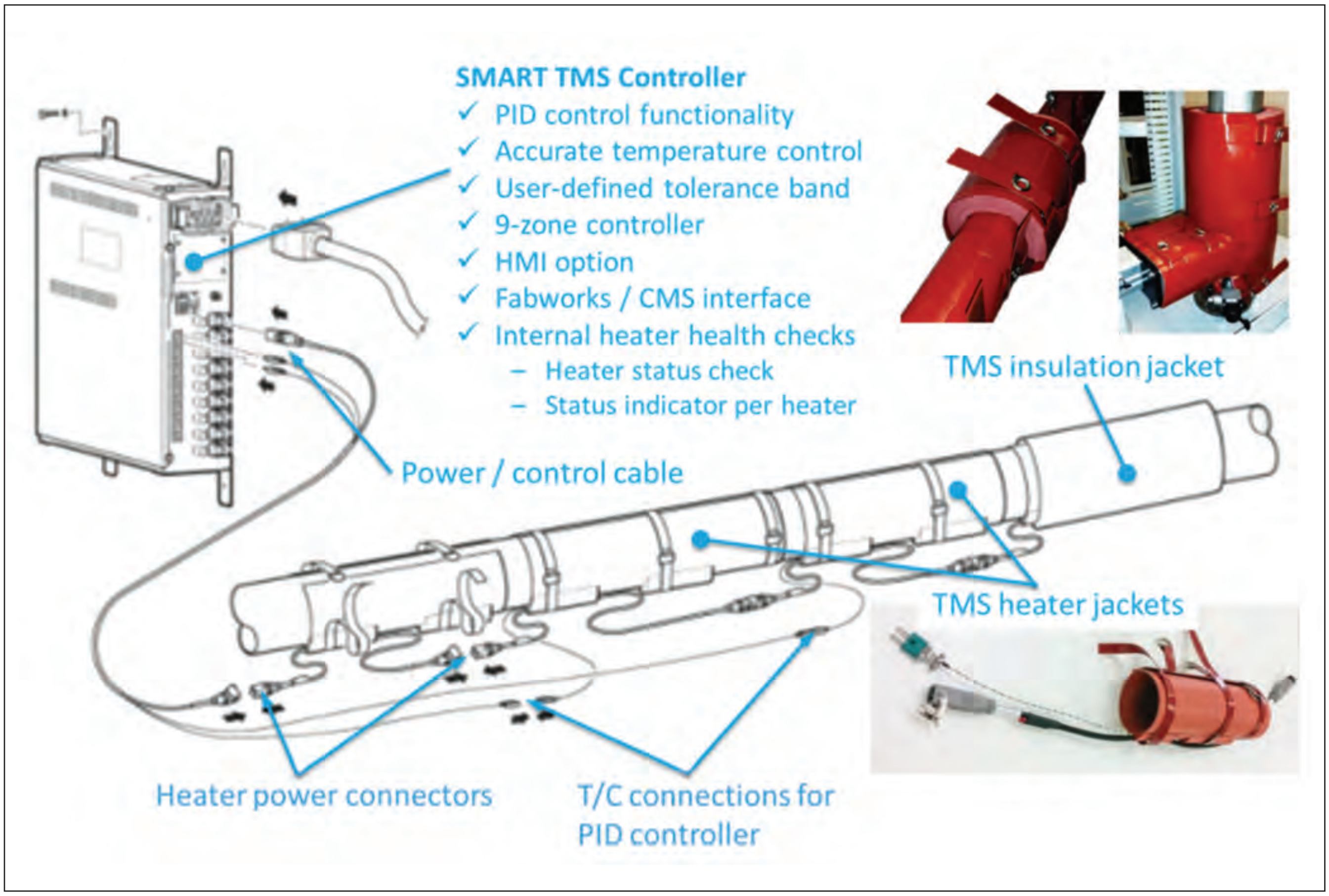

Figure 4: A state-or-the-art intelligent temperature management system can manage multiple heaters from a single remote location, providing visual indictor lights for each. Insulation is precisely sized and designed to allow consistent, one-handed installation on hard-to-access pipe runs to ensure temperature uniformity.

temperature set-point (typically 180°C). A safety fuse set at a higher temperature than the set-point was incorporated to prevent damage to the system in the event of a thermal switch problem. A monitor light was occasionally included to provide visual indication if temperatures fell below an acceptable level. The power supplied to the system was set to a constant level intended to maintain the temperature somewhere just below the switch set point.

However, in practice several problems were encountered with this simple control technique that seriously impacted its reliability. Firstly, on start-up from cold, the temperature could over-shoot the switch set-point causing the fuse to blow, with consequent system downtime for fuse replacement. Secondly, if the heating element temperature approached and remained close to the set-point, the switch would cycle rapidly, gradually changing its operating characteristics and ultimately resulting in complete failure of the switch.

Finally, the monitor lights proved to be unreliable over time and depending on the configuration of the pipe heating system, were not always readily observable by the operator.

Whilst legacy pipe heating systems suffered a number of intrinsic component reliability issues, a far larger problem centered on the configuration and installation of the system.

It is relatively easy to wrap a straight pipe run with a temperature control element and heat it effectively. However, pipe bends, mitred joints and elbows present a more difficult temperature management challenge, as do gate valves, purge ports, bellows, flanges, test ports, support brackets and all the essential components of a process exhaust system. In practice a section of uncontrolled pipe as short as 5 cm can cause a cold spot that results in unacceptable condensation of solids in the exhaust pipe, leading to unplanned system downtime whilst the blockage is cleared. A further challenge to control of exhaust gas temperature is presented by the introduction of purge gas used to reduce the concentration of flammable gas to a safe level.
If the temperature of the injected gas is not controlled at its point of introduction, it can cause a reduction in temperature of the process exhaust gas flow resulting in local condensation despite the installation of a temperature management system on the rest of the exhaust system.

The evolution of intelligent thermal management systems

These problems have been comprehensively addressed in the most recent generation of intelligent thermal management systems. A typical state-of-the-art intelligent pipeline temperature management system is shown in Figure 4. Advances in the technology can be conveniently categorised in five general areas.

Development of comprehensive process BKMs

The onus is now on the supplier of the pipeline temperature management system to ensure that its product provides a level of performance suitable for the target process that ensures maximum personnel safety and process reliability.

Functionality

Temperature can be controlled precisely at any set-point between ambient and some maximum, typically 180°C. "Fail On" technology ensures maximum protection from condensation in the case of a component failure; an intelligent controller enables configurable alarms and temperature to be set through a single remote interface.

The temperature management control system can also be integrated with sub-fab equipment and fab monitoring and control software to provide alerts, health checks, temperature readouts and data analysis. Although materials of construction are selected to permit onsite modification to accommodate changes in pipe configuration with minimal dust and particulate creation, availability of a wide selection of heater and insulation jacket sizes can reduce the need for onsite modifications.

Simplicity

Components are designed for easy installation in tight or confined spaces to improve the consistency and reliability of pipe temperature management installations and to save time and effort on difficult-to-reach pipe runs. Reliable electrical connectors are easy to access and manipulate. Each component incorporates an automatic internal health check capability, including a local indicator light to assist during installation and troubleshooting.

Reliability

Solid state relays rated for long life (over 50 million cycles) have replaced mechanical thermal switches as the primary temperature control mechanism. A selection of shaped heating and insulation components ensures complete coverage of elbows, joints and other challenging features and provides a uniform temperature throughout the exhaust system. Materials of construction are designed for repeated use with improved longevity, enabling their re-use when process tools are upgraded, moved or replaced. Appropriate materials flammability ratings provide assurance against component fires in case of accidents (such as a fire caused by ignition of flammable gas mixtures in the exhaust pipe).

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Efficiency

Efficient insulation and configurable operating temperatures provide better thermal control, improved temperature uniformity throughout the exhaust system, and reduced energy consumption.

Conclusion

Temperature management of forelines and exhaust pipes is critical to prevent condensation of hazardous process materials and byproducts throughout the vacuum and abatement sub-system. New intelligent thermal management systems address many of the shortcomings of previous generations. They can reduce equipment downtime and minimise health and safety risks to operating and service personnel. These systems also provide flexibility, ease of installation, consistency of operation, improved energy efficiency and increased functionality with programmable remote controllers that interface readily with sub-fab equipment, process tools and fab control software.