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Ensuring safety in the sub-fab

Problems frequently arise as a result of an incomplete or absent formal risk assessment when processes are modified or new materials introduced.

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The sub-fab is home to the many pumps and abatement systems that not only help to create the pristine environments required in the process chambers of the numerous tools in the cleanroom, but also handle the exhaust gases and by-products generated by the manufacturing process. In this respect, the efficiency and efficacy of sub-fab operations directly affect the availability, productivity, total operating cost and yield of the manufacturing fab above. Perhaps more importantly, in addition to supporting the process vacuum, equipment in the sub-fab is designed to render cleanroom process wastes harmless and ready for safe disposal or, if appropriate, release into the environment. As such, they are vital to protecting the safety of the people working in the fab as well as those living and working in the surrounding community, and ultimately, all of us who share that environment. The very nature of the process materials and reaction byproducts handled in the sub fab, which may be variously corrosive, toxic, pyrophoric, flammable or environmentally damaging, creates significant risks, especially for those who must operate and maintain the equipment located there. Moreover, as device manufacturing becomes more complex, with the introduction of new materials, new precursors and new processes, the risk of mistakes with potentially catastrophic consequences in both human and financial terms will only increase.

While ultimate responsibility for personnel safety in the sub-fab lies with the fab operator, equipment manufac- turers have a part to play by optimizing their products not only for efficient, effective and reliable operation, but also by ensuring any risks associated with operation, maintenance and repair are assessed and minimised to the greatest extent possible.

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There is often a strong focus on technical performance and cost attributes when selecting sub-fab equipment. However, processes and procedures to ensure optimum operation and continuous mitigation of risks to service personnel are equally critical; these demand the devel- opment of clear and effective operating procedures and guidelines – in industry jargon “best known methods” or BKMs – to ensure the equipment achieves its full performance potential and safety integrity maintained. The manufacturers of sub-fab equipment are perhaps in the best position to define these guidelines since they will typically have acquired an understanding of the risks posed by hazardous materials on a case-by-case basis during the course of system optimization. Frequent development of BKMs is undertaken in collaboration with the process tool manufacturer or early adopters of the process. However, defining operating and maintenance methods and procedures that are truly the best known requires a commitment to doing so at the highest levels of corporate management, and a formal process of reporting, analysis, synthesis and dissemination throughout the equipment support community.

A key component of any BKM program is the active participation of the equipment manufacturer’s service personnel who are responsible for installing, commissioning and maintaining the equipment and are also likely to have first- hand knowledge and experience of the potential hazards. Since service personnel are invariably in the front-line when safety incidents occur, they are well motivated to contribute since they themselves are often at greatest risk, and it is essential that their contribution is incorporated into product development programs to complement the technical performance with assured safety and reliability.

Even a cursory search of the internet will quickly reveal numerous examples of fab and sub-fab incidents. Amongst the lessons that can be taken from these events is that the risk management process and the resulting controls have to cover every foreseeable circumstance across the equipment lifecycle: installation, commissioning, operation, servicing and maintenance. Notable recent serious accidents include:

– March 2014 – A fab worker dies after a carbon dioxide leak

– January 2013 – One worker dies and four others are hospitalized after a hydrofluoric acid leak at a manufacturing facility

– September 2013 – A fire at major memory fab results in the closure of the facility with losses estimated in the range of $1 billion and a measurable impact on global DRAM pricing

– August 2012 – A security guard and 3 firefighters are hospitalized when a fire occurs in the exhaust ducts of a photovoltaic manufacturing laboratory in Singapore. The entire facility is shut down for weeks and 35 workers are laid off

These were events with consequences visible and far-reaching enough to make the national and international news. However, experience indicates that smaller events, often with narrowly-averted disastrous consequences, occur on a much more frequent basis with adverse impacts on fab productivity. These events are typically not widely broadcast, thereby limiting the community learning that might otherwise take place.

In respect of process exhausts, three types of hazard recur repeatedly as manufacturing processes evolve and new process materials are introduced: condensation of reactive chemical precursors or reaction products, corrosion due to condensation of acidic materials, and pipe blockage due to accumulation of condensate in significant volume. The images in **FIGURES 1-3** show a few examples.

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FIGURE 1. (left) Condensed explosive polysiloxane material in an epitaxial deposition system process foreline, (middle and right) CVD exhaust pipe destroyed by explosion of condensed process by-product.

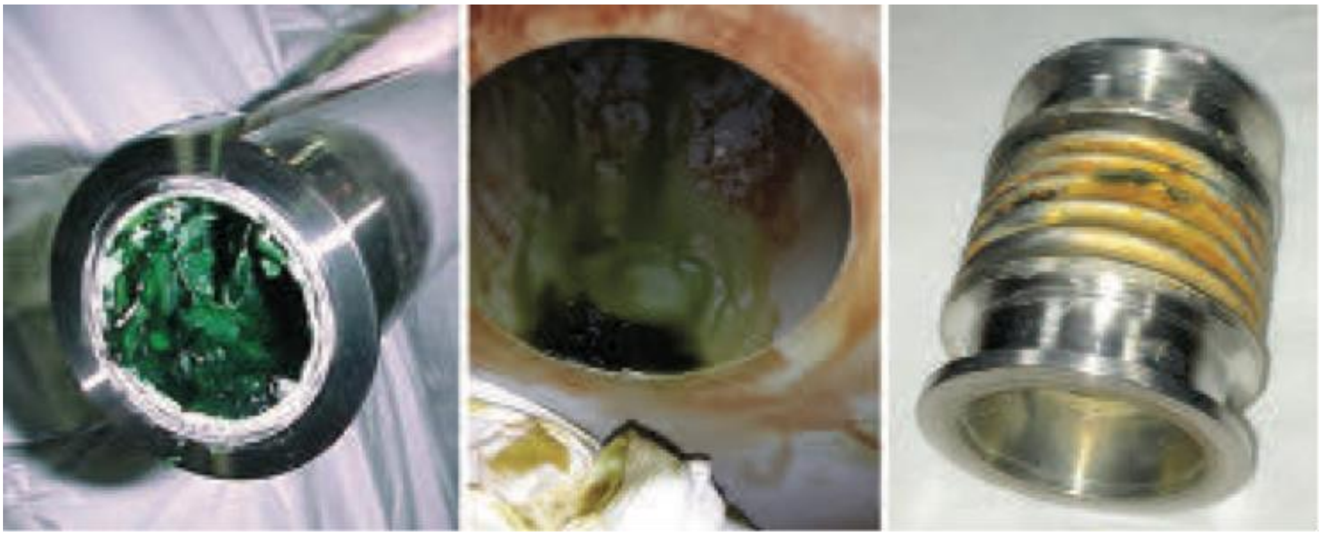

FIGURE 2. (left) Acidic TEOS-based polymer with a pH of approximately 1, (middle) Condensed corrosive Br2-based liquid, (right) Exhaust pipe damaged by exposure to condensed acidic material.

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FIGURE 3. Exhaust blockage caused by various materials (left) $AlCl_3$ from a metal etch process, (middle) NH_4Cl from an LPCVD process, (right) Unknown material deposited in the exhaust of a metal carbide CVD process.

In many cases, the cause of the risk is understood and solutions exist, but problems frequently arise as a result of an incomplete or absent formal risk assessment when processes are modified or new materials introduced. For example, condensation of potentially dangerous or explosive materials can usually be prevented by carefully controlling the temperature of the exhaust gas through the pipework and pumps. Pipe heating systems are widely available for forelines and exhaust pipes, and pumps can be designed with internal thermal management, but if the risk is not properly assessed, the appropriate controls will not be put in place. Furthermore, while a risk analysis may conclude that exhaust pipe heating is required in a specific case, it should also recognize that key to its effective implementation is the avoidance of cool spots, particularly at bends and junctions. Even a small local drop in temperature can create a hazardous situation despite the application of what is widely perceived as an effective protective measure – a subtle effect, but one with which field service personnel have become familiar through hard-won experience. At a practical level, if each process exhaust is designed in isolation, such considerations make their design and implementation a time-consuming and labor-intensive process. However, as noted in a previous publication [1] the ability to maintain effective thermal control throughout the exhaust stream can be enhanced by integrating the vacuum pumping and point- of-use abatement functions together with the interconnecting exhaust pipes into a single unified system. In this way the pipe routing can be standardized to permit optimization of the exhaust pipe heating installation for each specific process and to avoid the need for customization in the field.

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Integration and standardization also permits careful optimization of pump capacities and pipe diameters and routing to minimize power consumption and maximize destruction or removal efficiency (DRE). Finally, whether considering an integrated system or not, secondary enclosures for pumps, abatement and exhaust pipes provide an additional layer of protection by permitting hazardous materials to be routed away from personnel in the event of an unintended release.

In some cases, it is not possible to prevent the accumu- lation of hazardous materials. It then becomes essential to monitor the deposition and remove it through periodic maintenance procedures. For example, blockage can be monitored by measuring the pressure drop over the length of the exhaust pipe – as material accumulates in the pipe the pressure drop increases. By monitoring for blockage, operators can ensure that the system is cleaned before its performance impacts production and at the same time avoid cleaning more frequently than required. Integrated vacuum and abatement systems often combine monitoring capabilities with automated software to alert operators of the need for maintenance.

While problems associated with accumulation of materials in process exhausts is arguably the most frequently encountered hazard faced by sub-fab maintenance personnel, another widely applied risk mitigation strategy, particularly for flammable process materials, is dilution below their lower flammability limit (LFL) with an inert gas such as nitrogen. However, it is important to understand the nature of the chemical processes occurring in the deposition chamber and to base the dilution calculation on the composition and volume of the effluent gas rather than the precursor. For example, TEOS is a precursor gas widely used in the chemical vapor deposition of silicon oxide films. The lower temperature needed for the CVD process and the absence of aggressive reaction products are the main advan- tages of using TEOS compared with traditional precursors such as silane and the mechanical and electrical properties of Si02 films deposited from TEOS are also very good. The decomposition products of TEOS in the gas phase in the absence of oxygen include organic fragments (ethanol, ethanal, ethene, methane, carbon monoxide), and in the presence of oxygen include water vapour, carbon dioxide, ethanal and methanol [2], many of which are flammable. A dilution calculation based on the amount of TEOS entering the chamber rather than the volume of decompo- sition products exiting the chamber could easily lead to an underestimate of the required volume of diluent and the presence of a flammable mixture in the exhaust pipe in some circumstances. Once again, a rigorous risk assessment is required to identify such potential hazards and put corrective measures in place where needed.

Risk assessment and communication

It should be clear from the preceding discussion that a detailed technical understanding of semiconductor manufacturing processes and materials and their impact on sub-fab equipment is a prerequisite for safe and efficient pumping and abatement of process exhaust. In particular, ensuring the safety of sub fab operations requires a formal process for risk assessment. Once determined, safe operating proce- dures must be codified and effectively communicated to field personnel, and a mechanism must exist to update procedures based on feed-back from the field. FIGURE 4 is taken from the Risk Assessment Procedure [3] used at Edwards (adapted from Semi S10) and illustrates the Risk Rating Table, a matrix by which risks are evaluated and appropriate responses determined.

Once risks are assessed the information must be effec- tively communicated to users and field service personnel. To ensure appropriate dissemination of required information, Edwards publishes Application Notes for equipment users and Safety Application Procedures (SAP) for service engineers.

Conclusion

The hazardous nature of many of the materials present in the semiconductor manufacturing process creates significant safety risks for fab personnel and others living or working near the fab, and financial risks for manufacturers and investors. Managing those risks takes more than good intentions and common sense precautions. It requires a detailed and continuously updated technical understanding of the processes and materials based on broad experience across many different types of applications, and ideally, partnership with process tool manufacturers during development and optimization of new

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processes. As in other high risk industries – nuclear, aviation, automotive, healthcare, oil, rail and military – best practice safety and risk management is heavily influ- enced by equipment manufacturers, who are in the best position to understand the capabil-
ities of their products across a wide range of applications.

Ultimately the fab management team own the responsibility for managing risk and safety with the highest levels of corporate respon- sibility. Semiconductor equipment manufacturers, and in particular, manufacturers of pumping and abatement systems that handle and safely dispose of hazardous materials, have an invaluable supporting role to play with their continuous accumulation of know-how and formal processes for risk assessment, including a mechanism for distributing safety information to, and incorporating feedback from, the field.

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