Conference Paper

Vacuum Coating Processes – recent experiences in increasing process efficiency and reducing environmental impact

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1 ABSTRACT

Coating processes in contemporary solar cell manufacturing generate harmful by-products (both to the environment and health) that cannot be disposed of without appropriate treatment. Edwards can deal with the exhaust gases such that any remaining emissions comply with the stringent environmental legislation. Instead of a 'one fits all' approach behind the processing tool, Edwards provide tailored treatments in a way that:

- also takes care of by-products generated by the gas abatement process
- applies different abatement techniques for the different exhaust gases in order to reduce environmental impact and operating cost.

At the end of the abatement process, any by-products can be safely disposed of into the atmosphere, water drain or at landfills.

2 OVERVIEW

In this presentation I will

- Give a short description of the thin film solar cell manufacturing process at the tool end
- Describe the stages for treating the process gases
- Explain the benefits of 'staying dry' when abating silane
- Talk about the hydrogen fluoride (HF) challenge and its cost effective treatment

3 SHORT DESCRIPTION OF THIN FILM SOLAR CELL COATING MANUFACTURING PROCESS

Solar cells based on thin film technology are manufactured in 'flat panel' type tools such as the Oerlikon KAI 1200 tool through a plasma enhanced chemical vapour deposition process (PECVD). In short, glass substrates of over 1 m^2 in size are held in a plasma environment under vacuum. Gases, in particular silane, are introduced which react in the chamber resulting in the deposition of the active silicon layer. Periodically, and in case of the KAI1200 after every process run, the process chamber has to be cleaned of the unwanted deposits around the substrate. In many cases fluorinated gases like nitrogen triflouride (NF_3) or sulphur hexaflouride (SF_6) are utilised to clean the chamber in a chemical etch process.

Silane is toxic and flammable gas while the global warming potential of SF_6 is more than 23,000 times that of CO_2. It is logical that the excess of both gases plus any other process by-products should not simply be released into the atmosphere without further treatment. This would, among other reasons, destroy the green credentials of the solar industry.

Typical chamber sizes of process tools create an additional challenge for the attached vacuum and abatement systems as they exceed the typical sizes known from semiconductor process tools.

4 STAYING DRY – ABATEMENT OF SILANE

Traditional burner/washer concepts operate on the principal of destroying process gases in a high temperature burner followed by a quench/scrubber operation. The burner uses fuel gases such as methane or propane to be able to create the high temperature conditions to crack the sometimes hard-to-destroy process gases. The introduction of oxygen to achieve higher burn temperatures might be necessary for some gases like SF_6. When these gases have been turned into something less hazardous the task of catching the abated by-products and cooling down the gas stream before the exhaust manifold remains.

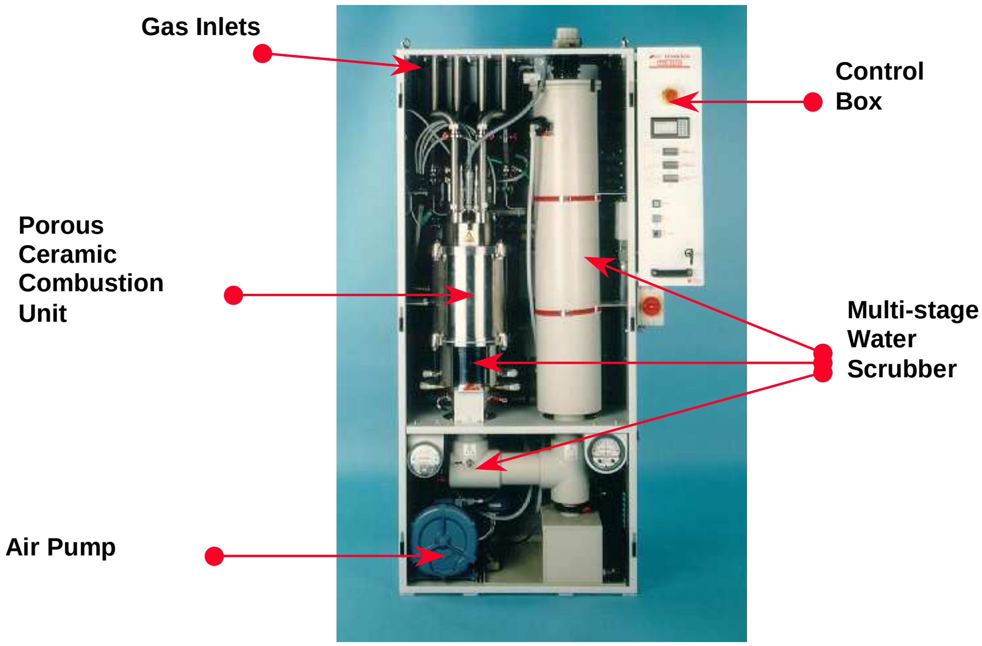

Figure 1 Burner/scrubber system

In burner/washer systems a water quench cools the gas stream coming from the burner and dissolves process and abatement by-products like sulphates in a wet scrubber. By introducing large amounts of water into the abatement process we have just created another problem for ourselves. This water is now contaminated, and though a portion can be circulated inside the scrubber, water that goes to drain needs to be treated further before allowed to be disposed of. Dealing with this waste water requires further investment in water treatment facilities like precipitation plants that also generate significant running costs.

When depositing the active layer in thin film solar cell manufacturing the main gas the abatement system has to deal with is silane. When abated it turns into silicon dioxide, SiO_2, which basically is 'sand'. Edwards offers an abatement tool (SpectraZ) that operates on a 'dry' concept eliminating the use of water altogether – and the costs associated with it. Not only can it deal with high amounts of silane typical for thin film solar manufacture, it is also designed to keep the process inlets and combustion chamber clean of deposits leading to long service intervals. The SpectraZ is a thermal abatement tool utilising fuel gases but no water.

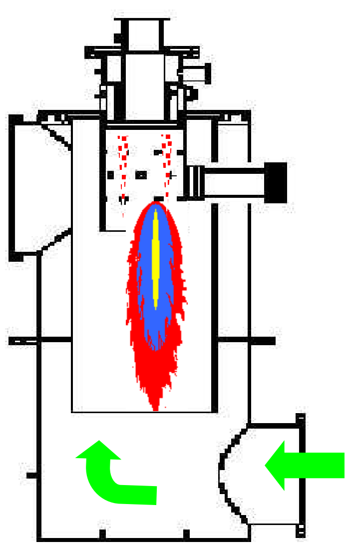

Figure 2 Air cooled 'dry' burner

For example, the abated silane from a thin film process tool can generate more than 6 kg silicon dioxide per day (24h hour operation).

If this amount of SiO_2 was washed out in a wet scrubber it would be reasonable to expect very frequent service intervals apart from high quantities of waste water requiring further treatment. Instead, the dry abatement solution uses a powerful fan and a filter bag downstream to a) cool down the thermally abated process gas stream and b) collect the process by-product silicon dioxide dust. The beauty with this concept is that the SiO_2 dust collected in a filter bag can be easily disposed of at landfills. And commercially, too, it offers great benefits for the solar cell manufacturer. Low maintenance requirements and the elimination of any kind of water treatment facilities deliver an attractive cost of ownership model.

5 HF CHALLENGE – COST EFFECTIVE TREATMENT

From time to time the process chamber requires cleaning from excessive silicon deposits. This could be done through a mechanical method or through a chemical process. A mechanical clean requires tool downtime while a chemical etch process is a more in situ approach that can be integrated into the process run.

One of the gases used for etch cleaning is sulphur hexafluoride (SF_6). While not terribly effective, only about 20 % is broken down and actively "cleaning", it's relatively cheap and allows the chamber cleaning step (like other fluoride based gases) to be carried out fully automatic in sequence with the deposition steps. Another popular etch gas used is NF_3, however, in my example I will concentrate on SF_6.

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During cleaning SF_6 together with oxygen (O_2) is introduced into the process chamber and broken down. The fluoride radicals are a very strong oxidant etching away unwanted deposits from the chamber walls. The sulphur molecules combine with the other species present in the chamber and the process exhaust stream will consist of a mixture of SF_6, silicon tetraflouride, HF and other sulphur oxygen fluorine compounds.

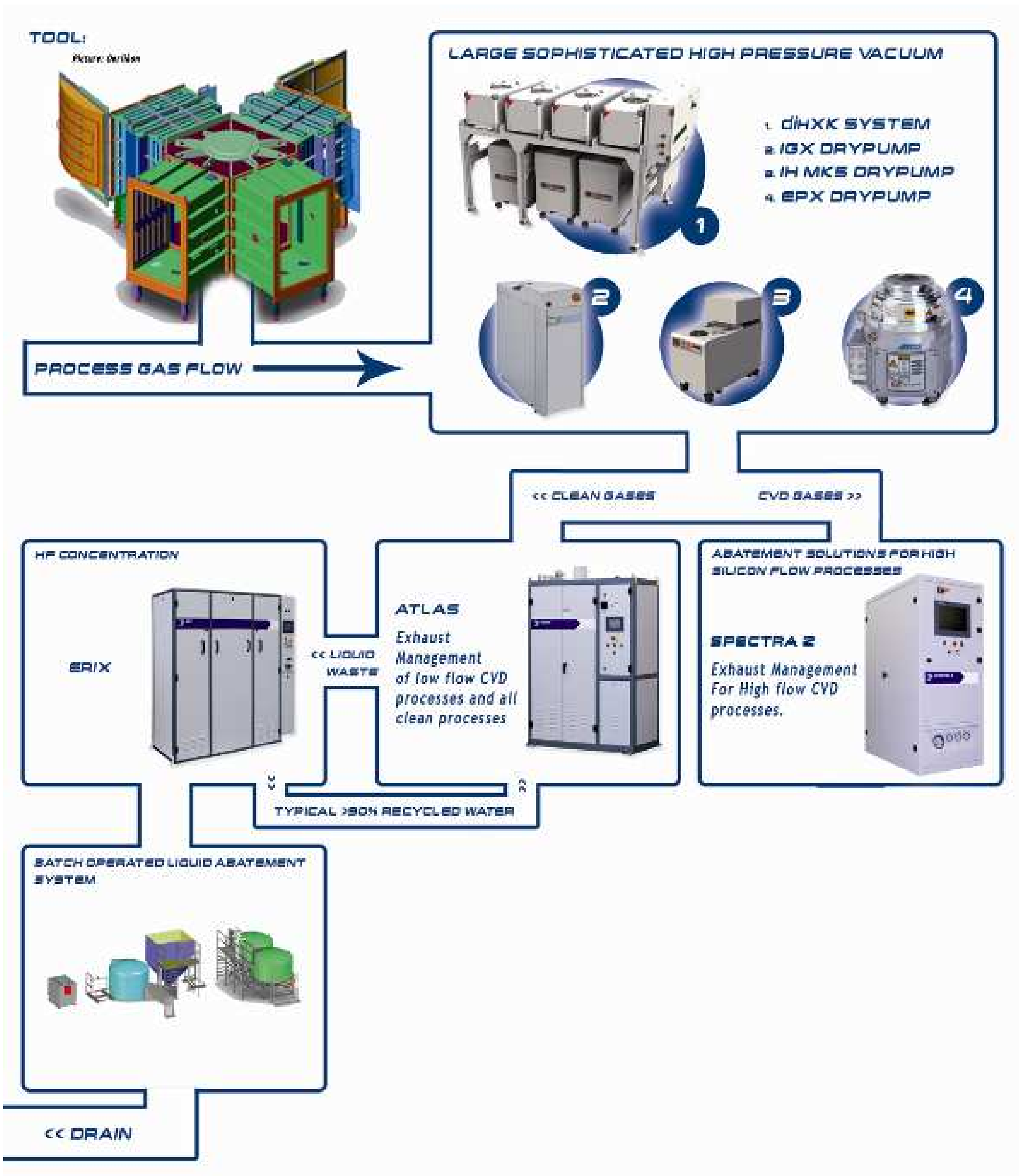

Figure 3 Integrated abatement concept

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Again, this gas stream cannot be released to atmosphere without further treatment for environmental reasons. As discussed SF_6 is a PFC gas, its global warming potential is 23,000 higher than that of CO_2. The remainder is highly acid and demands treatment prior to disposal. Simple thermal abatement, as described for silane, will not be sufficient. For treating SF_6, HF and their by-products a thermal abatement process with a wet scrubbing stage remains the prevailing option to deal with these gases. During this process unused SF_6 from the process chamber is thermally abated into hydrogen fluoride (HF) and sulphur oxides (SO_2, SO_3). Together with the other process by-products (SiF4, HF, etc.) these gases are 'washed out' in the scrubber stage transferring the HF and sulphuric/sulphurous load into the water circuit of the abatement system.

Any wet scrubber system can only tolerate a low maximum concentration of acid to remain effective. This generates a constant stream of acid loaded waste water that needs to be transferred to the next step. Now, even though thin film solar cell manufacturing plants operate semiconductor like processes, their scale and defined steps do not generate the amounts of acid waste streams that would justify investment in full scale water precipitation treatment plants. A more cost effective approach is required.

This approach can be a combination of HF concentration with subsequent small scale batch operated liquid abatement facilities. The waste water stream from the SF_6 abatement is pumped into tools using electrodeionisation technology. Edwards ERIX systems can reduce water consumption by up to 90 %. The acid waste water (acid concentration ~ 500 ppm) is treated in encapsulated cells where hazardous fluoride ions are continuously removed by separating ionic fluoride within a polymer resin bed and membrane. Treated liquid with reduced fluoride content (acid concentration ~ 20 ppm) is returned as recycled water to the abatement tool. Apart from water recycling the ERIX systems also acts as a heat exchanger.

The waste water stream leaving the ERIX now has a much higher acid concentration (> 20,000 ppm) but its volume is significantly reduced. This remaining volume can be treated in a batch operated liquid abatement system consisting of crystallizers and neutralizers (example tank size 8 m^3). During this process calcium chloride ($CaCl_2$) is added to the concentration, calcium fluoride (CaF_2) is formed turning the mixture into a sludge. The solid CaF_2 can be pressed out and actually sold on as a commodity chemical. A clear solution remains which, after a neutralising step, can be discharged to the municipal drain. The investment cost of such a system is only a fraction that of a full scale precipitation plant – making the whole solution very attractive for thin film solar cell manufacturing.

Edwards is following other options for further reducing waste streams. For example, recycle of process gases, instead of abatement, can be a viable option both commercially and environmentally. An SF6 recycle unit is able to recover more than 90% of the unused SF6 and return it to the process while built-in gas reactor columns remove process by-products eliminating the thermal abatement and wet scrubbing steps.

6 CONCLUSION

Thin film solar cell manufacturing is a complex process. Dealing with its exhaust gases seems very much as complicated as the actual production step. By taking a differentiated approach towards treating these gases, both the environment and the operator benefit. Each application needs analysing and naturally, the concept presented today will not fit all thin film solar manufacturing processes the same way. I hope though what I was able to show is that tailored treatment solutions offer financial and environmental benefits. Introducing 'dry' abatement concepts eliminate waste water streams and its subsequent treatment costs. What is left when treating fluorinated etch gases can be on a much smaller scale thereby offering huge cost benefits.