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Reducing cost by choice

As global economic realities ensure solar manufacturers seek every possible advantage in improving product while reducing cost. **Mike Boger, Strategic Marketing Manager, Edwards and Yoshihisa Wakamatsu, Project Manager at Umoe Solar** discuss how vacuum design considerations can help reduce Cost of Ownership in crystalline silicon manufacturing.

Crystalline silicon technologies are likely to continue their domination of photovoltaic (PV) device production for the foreseeable future. The processes used to create crystalline silicon substrates (both mono crystalline and multi crystalline) require vacuum, and choices made in vacuum technology and system design can significantly impact the production cost of the silicon wafers.

Silicon wafer manufactures have many things to consider as they set up their manufacturing facilities. A key choice is the type of wafer they will produce and whether the ingots they produce will be single or multi crystalline. This fundamental decision drives their choice of ingot manufacturing tools. The two mainstream

types are a Czochralski (CZ) crystal puller, or a directional solidification of silicon (DSS) furnace.

The CZ puller produces boules of single-crystal silicon that, when sliced into wafers, provide for high efficiency (17 to 20 percent) solar cells. The process time for a boule used for the solar industry is typically two days. The mass of the boule starts out at around 120kg, and then is typically less than 100 kg after it has been shaped. In contrast, a DSS furnace can process a much larger amount of silicon in the same process time, typically 450kg with capabilities reaching up to 800 kg, but the resulting polycrystalline silicon ingot, when sliced into wafers, generally results in a lower efficiency (13 to 16 percent) solar cell.

Vacuum Pump Considerations

Vacuum considerations for both processes are similar, but CZ pullers generally require more argon gas at a lower pressure than required by a DSS furnace. Considerations include not only the actual process conditions required inside the chamber, and the resultant effects on the end product, but also issues related to base pressure, leak-tightness, pump location and associated piping, powder management and pump type. Argon, chosen for its inert nature, presents particular challenges to the vacuum pumps because of its poor thermal conductivity.

The level of vacuum required and the speed of evacuation are primary factors in determining the optimal pump size and type. Fast evacuation is generally desirable since it reduces overall processing time and cost, however, excessively fast evacuation of chambers containing poly-silicon fines can cause loss of the product into the vacuum line. In general, faster is better since the quicker a chamber is brought to base pressure, the sooner the crystallization process can start. A low base pressure is generally required for no other reason than to conduct a rate-of-rise leak test. Oxygen or nitrogen leaking into the chamber can contaminate the silicon.

Pump location and the design of the piping system significantly impact evacuation speed. Larger diameter pipe increases the conductance of the system, but also increases the volume of gas to be evacuated. Shorter pipe runs, i.e. pump locations closer to the chamber, are desirable, however short pipe runs are only applicable when pumps with low vibration are used, or where additional vibration damping is provided to noisy pumps. Figure 1 shows the effects of various piping arrangements on pumping speed for Edwards' GXS160/1750 pump. Piping size most significantly impacts the pumping speed at lower pressures. Poor design results in much longer evacuation time.

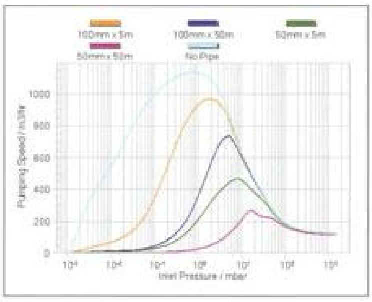

Figure 1: Effects of piping system design on pumping speed

Powder Management

The molten silicon generates silicon vapor that is pumped away by the vacuum system. The vapor forms a powder when it condenses in the piping and pump. The powder is abrasive and causes

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Figure 2: Vacuum side of seal (left) shows significant powder accumulation. Clean surface downstream of the seal (right) demonstrates seal efficiency

increased loads and wear in the pump. It also has the potential to generate hazardous levels of heat by reacting with oxygen or nitrogen when the system is vented. In particular, where a quartz crucible is used, silicon monoxide may also be generated. Depending on process conditions, there may be as much as a kilogram of powder produced over a two day process cycle. Powder may be managed by trapping before the pump or oxidizing it and collecting it after the pump. Either option requires periodic maintenance. In the case of pre-pump trapping, the efficiency of the trap must be balanced against its effects on pumping efficiency.

Powder handling is a fundamental consideration in the choice between conventional oil-sealed rotary or piston pumps and high performance dry pumps. Oil-sealed pumps use oil to seal the reciprocal or rotary pumping mechanism. The initial cost of an oil-sealed pump is low; however, maintenance costs can mount quickly to generate a high total cost of ownership. Because the powder becomes trapped in the oil, the oil must be changed frequently, as often as every two process cycles, and the pumps must be completely overhauled as frequently as every month. Maintenance downtime reduces productivity, and disposal of the contaminated oil contributes additional cost. An oil cleaner unit is an option; however, it too adds additional cost as a result of the added electrical consumption and maintenance requirements. The relatively low frequency mechanical vibrations generated by these pumps are readily transmitted to the process chamber where they can impact crystal formation. Rotary pumps also generate considerable noise.

Dry Pumps

For these reasons, the industry is moving toward the adoption of dry pumping technologies. The move follows a similar transition made by the semiconductor industry a decade ago. Although their initial cost is higher, dry pumps often demonstrate a lower total cost of ownership, due largely to lower maintenance costs. There is no oil to change or dispose of and periodic maintenance is required infrequently or not at all depending on the pump design. Powder handling remains important. If there is a powder trap mounted before the pump, then powder handling requirements depend on the trap's efficiency.

Dry pump compressor design is very important. Dry pumps require tight mechanical clearances, making thermal management a primary design consideration. Unless managed effectively, thermal expansion can reduce the clearance between the

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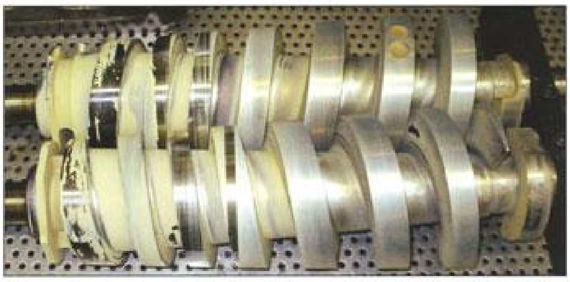

Figure 3: GXS160/1750 rotors with the exhaust end on the left hand side demonstrates successful result of running the pump on a CZ puller application with no inlet filter

stator and the rotor causing seizure. This consideration becomes even more significant with high powder loads or when pumping argon because of its poor heat transfer characteristics.

Environmental Concerns

Modern dry pumps are designed for optimal energy efficiency, reducing operational costs and environmental impact (carbon footprint). They typically use high speed screws or other types of pumping mechanisms that are quieter acoustically and have less vibration. Advanced thermal design reduces the volume of water used, when and if water cooling is required. Dry pumps have smaller footprints, optimizing the utilization of expensive fab floor space.

Rotating seals are used within the dry pump to prevent contamination of the vacuum space with lubricating oil from the gearbox and drive components. If oil enters the vacuum space, it can mix with powder in the pump and make a paste that can cause subsequent pump failure. Likewise, the seals prevent powder from entering the gearbox. Powder that enters the gearbox can then contaminate the bearings and cause premature failure, especially since the powder in this application is silicon, a very hard material.

In the semiconductor and flat panel manufacturing industry, where dry pumps are used almost exclusively, it is very common to remotely monitor pump operating parameters, such as temperature, input power, input current, and rotational frequency, in order to watch for trends that may suggest pump maintenance may be required. Automated monitoring and data logging has been used to help plan pump maintenance. Although not yet common in the silicon crystal manufacturing industry, performance monitoring has the potential to provide similar benefits.

Although many pumps may address the concerns raised in this paper, an example dry pump from Edwards is used for illustrative purposes. The pump incorporates the features required for low cost of wafer manufacturing, high reliability, and has excellent environmental features: noise less than 64 dB (A) without a silencer and only a 0.43 m2 footprint. Elimination of the silencer improves reliability since the silencer can act as an unwanted trap of power. Shaft seal efficacy was confirmed on this pump that was used on a CZ puller without an inlet dust filter. Figure 2 shows how the shaft seals have prevented dust entering the gearbox, and also prevented oil from entering the vacuum space. Such high quality seals lead to long service life and, consequently, lower running costs. The rotors of the pump shown in Figure 3 demonstrate how powder was transported from the inlet to the outlet effectively. The GXS screw dry pump has an integral booster pump that can handle 120 slm of argon at 10 Torr, uses only 4 slm of seal purge, and has an ultimate power of 4.3 kW. With a repeatable powder handling capability of 750 g, many of the vacuum considerations discussed in this article are favorably addressed. In addition, an on-board web server and supported serial communication protocol provides the facility with pump operating parameter measurement in real time.

Conclusion

Photovoltaic device manufacturers continue their quest to achieve cost parity with other energy production technologies. With the likely prospect that crystalline silicon technologies will continue to dominate for some time, the industry must look closely at the cost of the wafer manufacturing processes.

Choices made in the design of the vacuum system and choice of pumps used in these processes can have a significant effect on profit. It is important that the industry consider the total cost of ownership as the primary criterion for these choices, including environmental costs. On this basis, dry pump technologies are likely to replace oil-sealed pumps in most applications.