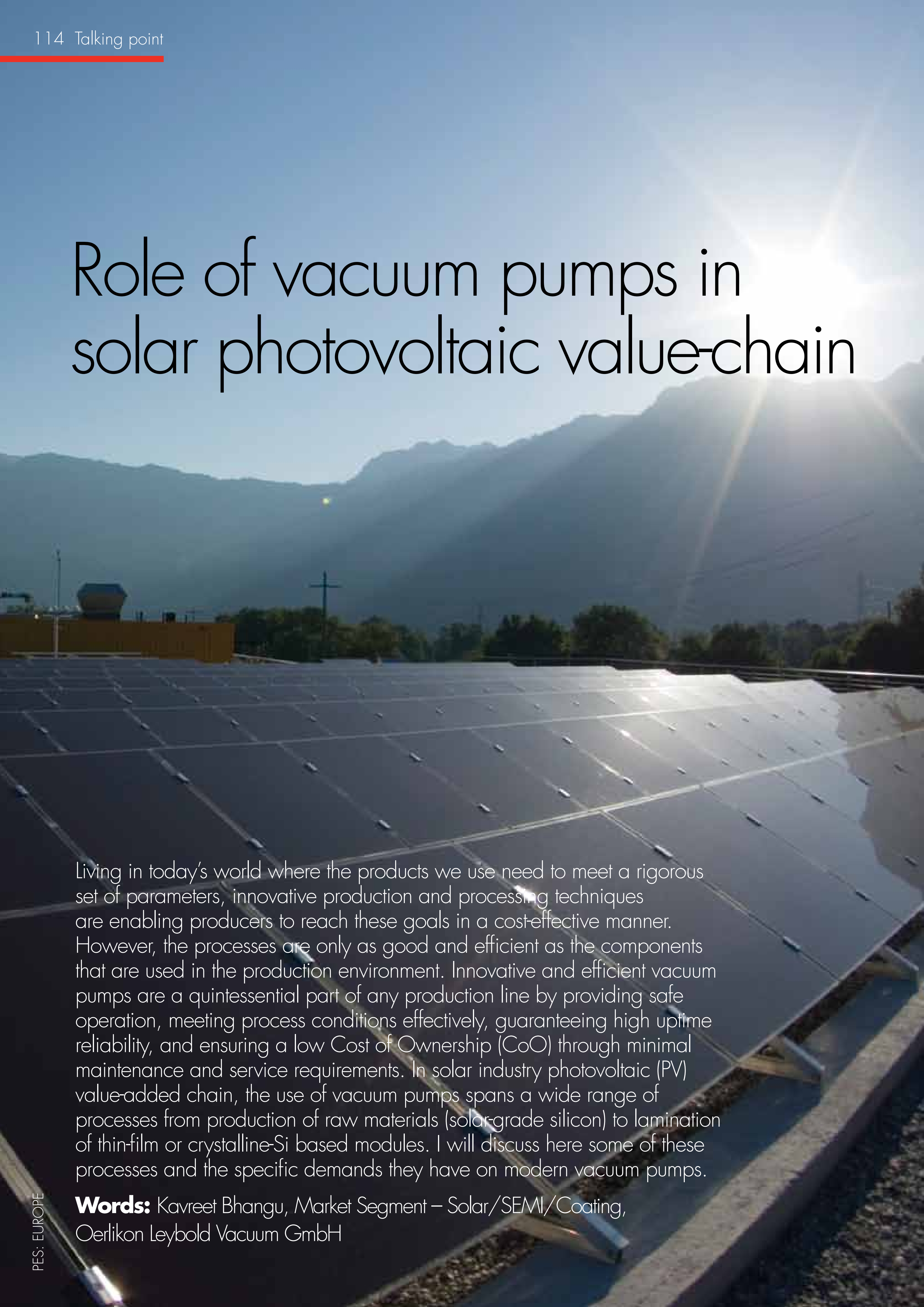
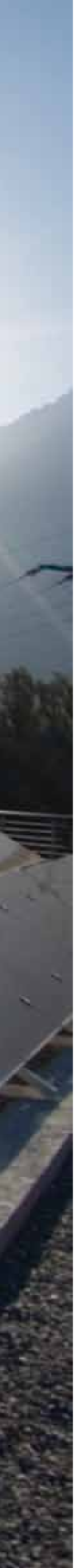


Role of vacuum pumps in solar photovoltaic value-chain

Living in today's world where the products we use need to meet a rigorous set of parameters, innovative production and processing techniques are enabling producers to reach these goals in a cost-effective manner. However, the processes are only as good and efficient as the components that are used in the production environment. Innovative and efficient vacuum pumps are a quintessential part of any production line by providing safe operation, meeting process conditions effectively, guaranteeing high uptime reliability, and ensuring a low Cost of Ownership (CoO) through minimal maintenance and service requirements. In solar industry photovoltaic (PV) value-added chain, the use of vacuum pumps spans a wide range of processes from production of raw materials (solar-grade silicon) to lamination of thin-film or crystalline-Si based modules. I will discuss here some of these processes and the specific demands they have on modern vacuum pumps.

Words: Kavreet Bhangu, Market Segment – Solar/SEMI/Coating, Oerlikon Leybold Vacuum GmbH



Introduction

The use of vacuum pumps is not entirely novel in the solar industry. Most of the CVD and PVD processes used for producing PV modules are well known from the semiconductor and glass coating industry. Deposition method of TCO layers on glass for thin-film solar modules either through sputtering or LPCVD has remained largely unchanged from the flat panel display time. Amorphous or micro-crystalline silicon (a/µc-Si) deposition and anti-reflective silicon-nitride (Si3N4) layer on wafers using PECVD technique is extensively used in the semiconductor sector. Although the basic need to have an oxidant-free environment has remained the same for the solar PV industry, much larger particle loads and larger gas flows encountered here require vacuum pumps to demonstrate high robustness and uptime reliability.

Even on the well-known processes adapted from other industries, what is different for the solar industry are special needs such as special handling equipment for large solar modules, more rigorous safety concepts for large hydrogen and fluorine amounts in PECVD systems, special traps and abatements systems for large amounts of reactive LPCVD gases, or specific filters used in CdTe module production. These are just a handful of examples depicting the special nature of solar PV processes. Vacuum pump suppliers are also moving into a consultant role by providing complementary products and services to guarantee the necessary level of monitoring, performance, and efficiency.

Typical requirements in the solar industry from modern vacuum systems are:

1) Robustness and reliability
Ability to handle toxic and corrosive gases while guaranteeing highest uptime to maximise productivity

2) Compactness
Small footprint and volume to make more room for production machinery

3) Low Cost of Ownership
Savings in utilities like energy, water, purging and isolating gases, and in efforts for maintenance and service contributing to lowering operating costs and maximising return on investment

4) Intelligent monitoring
Active interfacing of vacuum pumps and accessories with system control for minimising risk, maximising equipment uptime, and planning maintenance in advance

5) Flexible systemisation
Allowing for future product upgrades and capacity expansion for larger pumping needs in addition to ease of installation making factory planning easier

Vacuum systems

Vacuum pumps have been constantly evolving through continuous research and development efforts of companies around the world. Earlier pump offerings that served most pumping needs and are popular even today in many applications include oil-sealed rotary vane (Fig. 1) and rotary piston pumps. However, safety and environmental issues are raised due to the specific nature of many solar PV processes where corrosive and/or toxic gases in the exhaust stream, like cadmium (Cd) or fluorine (F), coming into close contact with the oil. Although these pumps are inexpensive and a reliable source of vacuum, the nature of their mechanism cannot entirely prevent condensation of gases and particles in the pump. Such condensates and reactive gases not only contaminate oil, but also degrade it, disrupting lubrication and requiring frequent oil exchanges and additional disposal facilities. Even inert and costly PFPE oil needs regular exchanging, albeit not as often as the more commonly used ester-based oils. To avoid such particles and gases entering the pump, costly vacuum-side inlet traps and filters are needed that add to capital investment.

In recent times, the dry vacuum pumps, especially the compressing screw-type pumps (Fig. 2) have successfully replaced oil-sealed pumps in many of the solar applications. This technology is mature enough now to deliver excellent pumping performance, especially when pumping down from atmospheric level, while keeping the operating parameters of energy, water, purging gases, and oil exchanges to a minimum. A combination of the above factors offsets the higher capital costs for these pumps lowering the CoO and maximising Return On Investment.

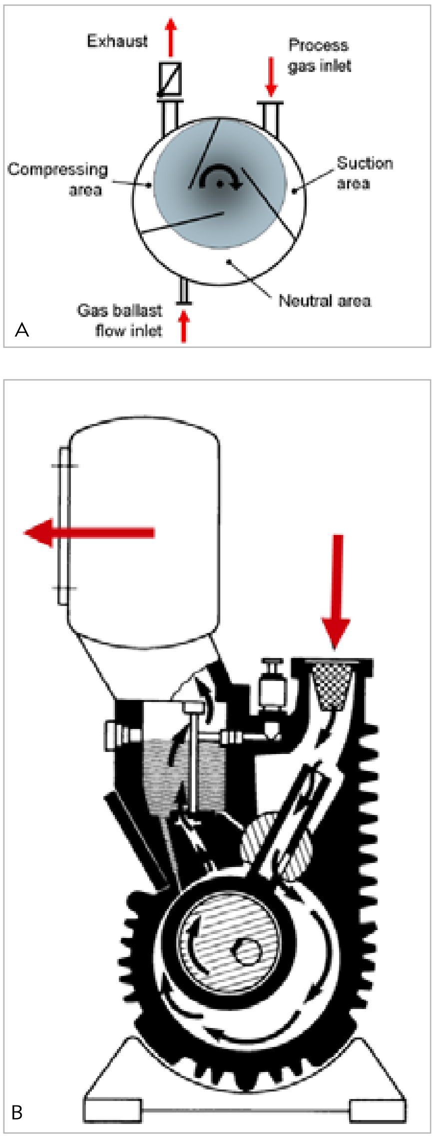


Fig 1: (A) rotary vane pump (B) rotary piston pump]

Some of the features of dry screw-type vacuum pumps that help in trouble-free working are:

1) Gas-ballast
A small amount of gas is injected into the pump to increase the vapour pressure, allowing for process gases to be pumped without condensation.

2) Purge-gas
To protect the sealing separating the vacuum and the gear/motor side of the pump, an inert gas is introduced in a small volume. This not only protects the seals against corrosive media in the gas stream

Fig 2: Dry screw compressing vacuum pumps from Oerlikon Leybold Vacuum (A) SCREWLINE 630 (B) DRYVAC 650S-i]

but also prevents any particles diffusing to the gear or motor oil and any oil entering the vacuum pump chamber.

3) Monitoring
A set of sensors fitted on to the pump make sure that any potential failures are detected early and fixed. Rotor temperature, exhaust pressure, oil temperature and level indicator, and vibration sensors provide a direct control of the pump performance. Other indicators as current drawn and frequency indirectly provide a wealth of additional information.

Solar PV industry value-chain

The legacy of the solar PV industry as we know lies in the developments that took place in the semiconductor industry. Since then, the solar PV has branched into the traditional crystalline-Si based and thin-film technologies (a/μ-Si, CdTe, and CIGS) that promise a bright future. These technologies comprise a vast array of differing processes for producing solar modules using complex machinery of which vacuum pumps are an integral part. A simple overview of some vacuum processes in the solar PV industry is shown below.

Silicon Based wafers	
Si production	Mono-Si ingots by pulling Poly-Si ingots by casting
Anti-reflective coating	Si3N4 by PECVD
Lamination	using commonly EVA film
Thin-films	
TCO glass coating	Metallization by LPCVD/ Sputtering
a/μc-Si	PECVD
CdTe	Condensation/Sublimation
CIGS	Co-evaporation and/or Selenization
Lamination	using commonly PVB film

Table 1: Different processes used for producing PV modules]

There has been a recognisable trend in the use of vacuum pumps in different solar PV processes. Although there are many factors that influence the choice of vacuum pumps for a certain process, some have been outlined below.

Si production

Irrespective of monocrystal pulling or polycrystal casting process, the vacuum pump in silicon production is subjected to a large amount reactive SiO dust. In the past it was necessary to use costly vacuum side filters for preventing dust from entering the oil-sealed vane or piston pumps. In contrast, dry pumps, as the ones shown in figure 1, mostly can operate without any filters as they run free of oil in pump vacuum chamber. A patented technique of introducing air into the pump oxidises the reactive SiO and converts them into passive SiO2 which can be easily separated from gas stream by installing cheap, yet effective exhaust-side filters (figure 3).

Due to innovative design of the pumps, the consumption of utilities like water, power, and nitrogen are kept to a minimum. This coupled with annual exchange of oil delivers an excellent cost-performance solution for the customer. There are also specialised solutions available for processes that generate phosphorus laden gases from the crystal doping step.

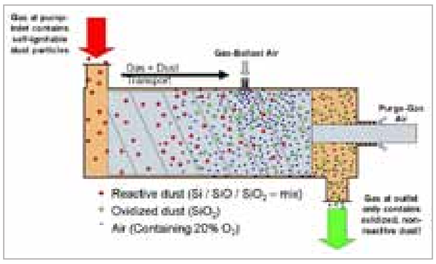


Fig 3: Oxidation of reactive SiO particles using air gas-ballast to produce passive SiO2 particles (Patent OLV)]

PECVD Process

One of the biggest challenges for vacuum pumps in this process is the handling of large flows of H2 and fluorine, and some other gases in smaller volumes. Excellent pumping performance for light gases, such as hydrogen, is critical to reaching the desired quality of the product. Although very small amounts of H2 act favourably by hydrogenating defects in μ-Si thereby enhancing product efficiency, lack of effective H2 removal from the chamber may lead to reduced deposition rates on substrate surface. Another gas, fluorine (F) for cleaning chambers is normally obtained from NF3, CF4/O2, C2F6/O2, C3F8/O2, etc. is decomposed using plasma. Elemental fluorine in the exhaust gas going through the vacuum pump is extremely corrosive and requires the use of special constructional and sealing materials. Fluorine also tends to react vigorously with Si releasing heat that needs to be removed effectively out of the pump.

Modern dry vacuum pumps use chemically inert materials for housing and rotors and fluorinated polymer seals for protection against F-attack. Also useful is the hermetically tight design that prevents any leakage into the pumping chamber, eliminating any chance of reactions with chemical species, and to the atmosphere removing safety issues that might be associated in working surroundings. Effective removal of heat generated within the pump is also of prime importance. In the DRYVAC pump shown in figure 1, a patented direct cooling circuit around the pump continuously takes heat out of the pump. Additionally, a set of sensors helps in monitoring pump parameters and minimising downtime. Traps and gas abatement systems are used to prevent these corrosive and toxic from escaping to the atmosphere.

TCO process for glass coating

Most of the commercial production of TCO glass for thin-film solar PV modules is undertaken either by MOCVD (metal organic CVD), LPCVD (low pressure CVD), and sputtering. Among the most common TCO materials is ITO (tin-doped indium oxide), AZO (aluminum-doped zinc oxide), ZnO (zinc oxide), and ICO (indium-doped cadmium oxide). Due to availability of indium and resulting price situation in recent years, AZO and ZnO are gaining in popularity.

In the LPCVD process, presence of unreacted process gases entering the vacuum pump and reacting therein is a major problem. In the presence of elevated temperatures inside a vacuum pump, this typically surface-controlled reaction is accelerated and layer formation is encountered. Suitable hot-traps working at high temperatures and using specific materials with large surface areas are normally installed between the LPCVD chamber and vacuum pumps. In addition to large surface area, hot-traps may also use

Vacuum Solutions
for the Solar PV Chain

UNIVEX | **RUVAC** | **DRYVAC**

Oerlikon Leybold Vacuum, a worldwide leading company for vacuum technology, has a comprehensive process and application know-how offering a broad range of innovative vacuum components and solutions for manufacturing and analytical processes as well as for high-tech research projects.
In coating systems for the solar, PV or process industry you may expect high vacuum performance regarding operating pressure, cycle time and system uptime. We recommend vacuum pumps and systems from the RUVAC WH line in combination with our new DRYVAC. UNIVEX experimental coating systems are proven in industrial research and suited for pilot production for demanding tasks. Full-scale application support, customer consulting and training, and a vast global sales and service network ensure that our customers are able to concentrate on their main objectives. Vacuum technology from Leybold Vacuum is shaping the future - with experience, performance, quality and passion for vacuum.

Welcome to our unlimited world of Vacuum!

Oerlikon Leybold Vacuum GmbH
Bonner Strasse 498
D-50968 Köln
T +49 (0)221 347-0
F +49 (0)221 347-1250
info.vacuum@oerlikon.com
www.oerlikon.com/leyboldvacuum

oerlikon
leybold vacuum