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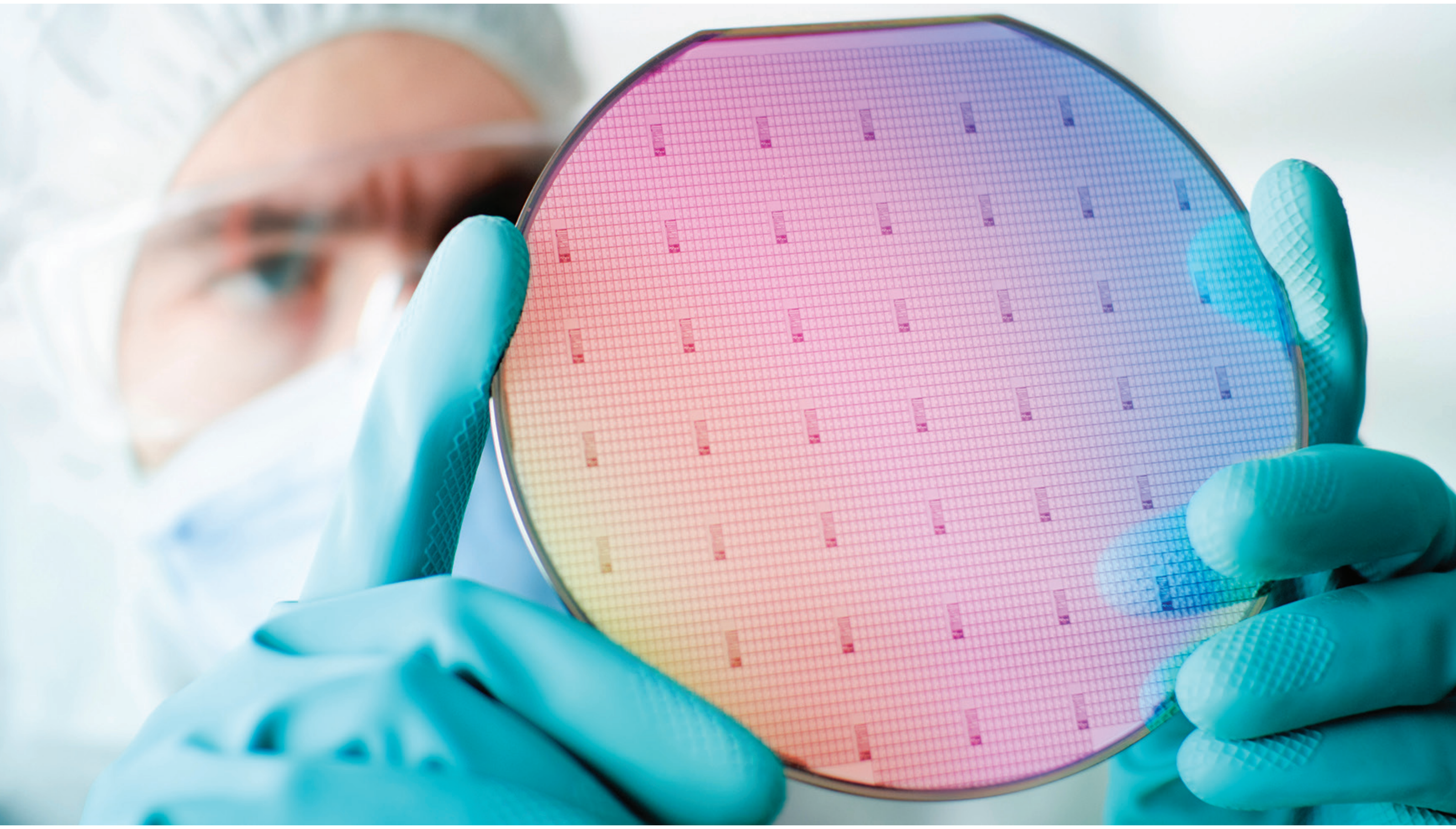


Securing high-purity hydrogen

For low risk, low-cost production of high-purity hydrogen, makers of compound semiconductor epiwafers should install electrolysers based on proton exchange membrane technology

BY TOM SKOCZYLAS FROM NEL HYDROGEN

AN ESSENTIAL PROCESS in the manufacture of compound semiconductor chips is the growth of a stack of epitaxial layers, which are subsequently processed into devices. Most often the growth of this heterostructure is carried out by MOCVD, a process that involves the decomposition of two or more types of organic molecule on a heated substrate to yield a thin film.

In this growth process, two key ingredients are metal-organics and the gases containing group V elements, such as arsine and phosphine – it is the decomposition of these sources and their subsequent reactions that produce the compound semiconductor epilayers. However, these are not the only materials with a critical role to play. There is also hydrogen, which is widely used in the production of devices based on arsenides and phosphides. This gas transports the metal organics, along with phosphine and arsine, from their containers to the growth chamber. Due to the rise in production of all forms of compound semiconductor chips, the demand for scalable, reliable, affordable, high-purity hydrogen is at an all-time high.

How pure is pure?

To ensure high-quality LEDs, VCSELs, transistors and the like, rigorous standards have been set for hydrogen purity. However, it is critical that this is assessed in a quantitative manner, rather than vague marketing terms. Different purity grades and terms are used by different suppliers, such as ultra-high purity and semiconductor grade – but they are just marketing nomenclature, and they fail to provide a quantitative description of the purity of the gas.

Makers of compound semiconductor devices will want to know the purity of hydrogen. It is often given in terms of the number of 'nines'. For example, 'fivenines' would be used to describe hydrogen that is at least 99.999 percent pure. But that is not all that these chipmakers want to know. The nature of the impurity is also critical. It may be that the impurity is 'destructive' to the process, degrading process yield or impairing process control and leading to a cost increase in manufacturing. Or, worse still, impurities could result in device malfunction. That's the threat with methane and CO, which may have to be completely avoided, or kept below well-determined limits.

Since the purity of hydrogen is so critical, it must be maintained up to the point of use. It is fruitless ensuring that the purchased hydrogen meets the level of purity for the process, and then compromising its integrity by transporting it to the facility through long-distance piping.

Delivery options

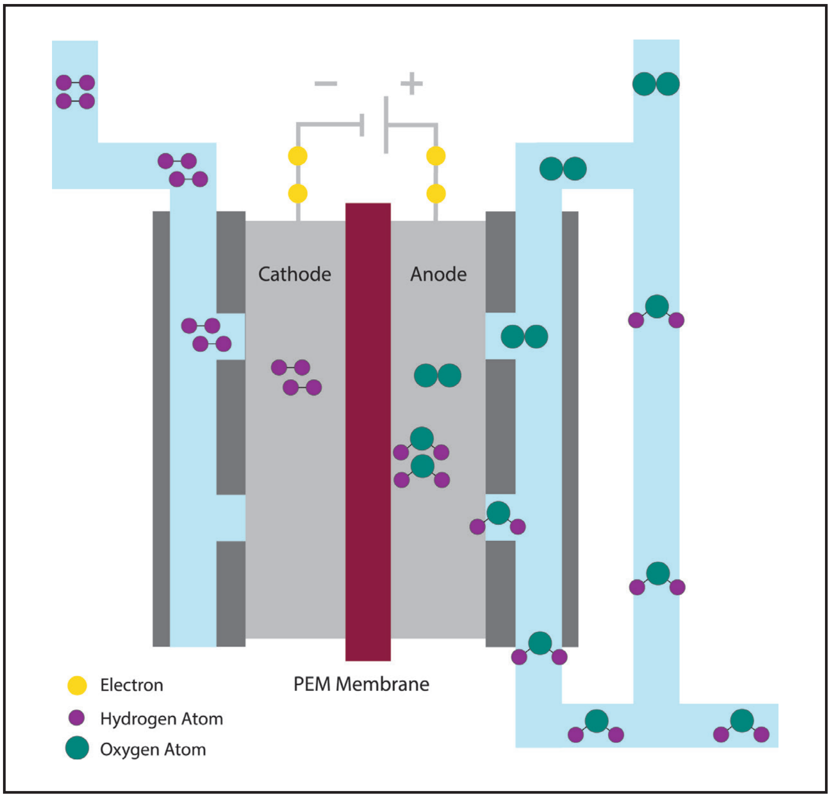
A pipeline is by no means the only option for delivering hydrogen. In fact, using a pipeline is rare, as it is only available when sites are near a large hydrogen production facility. More typical is delivery by truck. In that case, hydrogen either arrives in a compressed form in cylinders or high-pressure tubes; or for larger users, it is supplied as a liquid in a tank trailer, and offloaded into a site storage tank. There is also a third option, gaining in popularity: on-site generation using proton exchange membrane water electrolysers.

There are many challenges involved with delivered hydrogen, including specifying and maintaining purity. For instance, purity can be dependent on the method of production. Options for manufacturing hydrogen include methane or other hydrocarbon processing, salt brine electrolysis, and water electrolysis – and they can all introduce different impurities. Once generated, all hydrogen is purified. How this is done is critical, depending on both what is removed and how this is accomplished. What are the risks to purity with this process?

Purity may be inconsistent, varying between batch deliveries. The cleanliness of the delivery vessels is beyond the customer's control, as is the possibility of introducing contaminants every time a connection is made or broken on the supply side. Compromises to hydrogen purity can occur when filling up at the supplier's facility, offloading at a previous stop or at the customer's facility, or when changing out cylinders and tubes.

When deciding how to receive hydrogen, there are factors to consider that go beyond the integrity of purity. Delivery and offloading compressed gas or liquid hydrogen introduces site and personnel risk. There is also a safety risk associated with the moving, connecting and disconnecting of cylinders and tubes, and the transfer of liquid hydrogen from a tank trailer to a storage tank at the customer's facility. All these tasks must be managed with strict discipline.

Many manufacturers of silicon wafer chip, semiconductor and MEMs use proton exchange membrane water electrolysers.



A proton exchange membrane water electrolyser cell stack produces hydrogen by splitting deionized water into hydrogen and oxygen. Unlike hydrogen produced from fossil fuels and other methods, there are no other contaminants present that can enter the hydrogen stream.

One drawback of having hydrogen delivered to a site is that its supply cannot be guaranteed. Deliveries can be delayed by a natural disaster, such as a storm or flood; by demand exceeding supply capabilities; and by labor strikes affecting the supplier's plant or delivery methods. Whatever the reason, interruptions can wreak havoc. In the worst case scenario, chip making may have to stop, leading to the loss of key customers due to delays in shipments.

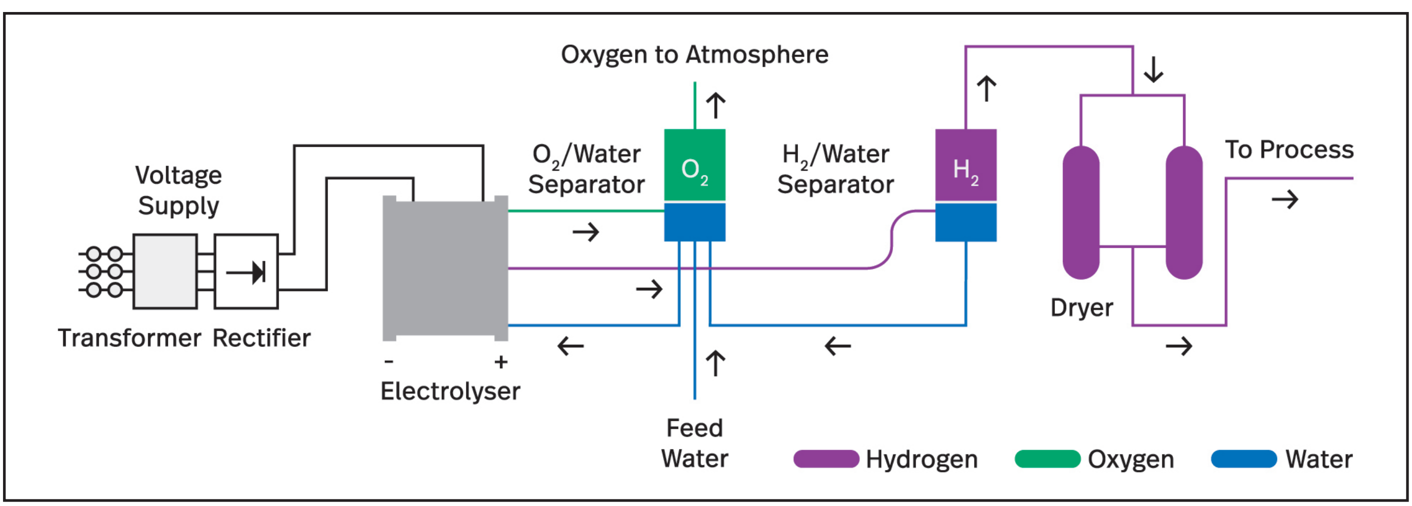
When hydrogen arrives on site, it needs to be stored with great care. It is a highly hazardous and flammable material, and it must be accommodated in tanks or cylinders that are compliant to codes and standards enforced locally and nationally.

In the US, storing of hydrogen must be undertaken in a way that meets precautions based on quantity and pressure, according to the NFPA2 Hydrogen Technologies Code, as well as codes prevalent in various states and municipalities. These codes may include EPA, NFPA, OSHA and frequently even more stringent local regulations.

To meet these requirements, hydrogen storage may have to be sited well away from other buildings, in order to separate tanks from sources of ignition, air intakes, wiring, pathways and building walls. This situation brings its own issues, such as the need for expensive piping, which could become prone to leaks. There may also be the need for special permits, depending on local safety standards, that insist that engineering details are provided to appropriate authorities.

It is also important to be aware of the magnitude of the hazard. Just 1 m^3 of hydrogen gas has a chemical energy equivalent to 2.9 kg of TNT. So a typical portable cylinder tank, which holds about 6.9 m^3 of hydrogen, has as much energy as 20 kg of TNT – a sobering thought when maneuvering hydrogen tanks and cylinders on or off manifolds feeding a facility. Note that typical facilities may store between 100 m^3 and 3,000 m^3 of hydrogen, equating to 290 kg to 8,700 kg of TNT. And if hydrogen is stored in liquid form, the magnitude of its energy is far, far higher. The remote possibility of a hydrogen explosion may not just be a major concern for those that work at the facility – it can be a worry for those that live nearby, who may over-estimate the risks and react in ways that do not support local chip making.

When siting a hydrogen storage area, several criteria must be considered. As hydrogen is not odorized, unlike natural gas, sensors and alarms may be required to alert safety personnel in the case of a leak. Storage may also need to comply with maximum inventory limitations according to regulatory codes, and there may be requirements for fencing and signage of the storage area. Generally, the sterile area near hydrogen storage is unavailable for parking or other uses.



The flow of hydrogen, oxygen and water in a proton exchange membrane water electrolyser.

On-site generation

An increasing number of compound semiconductor chipmakers are avoiding issues associated with the over-the-road delivery and storage of hydrogen by switching to on-site generation of hydrogen, in the form of proton exchange membrane (PEM) water electrolysers.

A key benefit of this technology is that it eliminates risks associated with deliveries and the maintaining of a hydrogen supply – because there is zero inventory required. Eliminating a hydrogen inventory means that the regulations associated with bulk hydrogen storage no longer apply. With a hydrogen generator, the magnitude of any leak cannot exceed the hydrogen production rate. Thanks to this, there is no danger of a leak filling the surrounding area with hazardous levels of hydrogen. What's more, all piping remains tight, as there is no need to remove, replace or refill tanks.

When considering purchasing a PEM water electrolyser for on-site hydrogen generation, one should make sure the system is designed in accordance with NFPA and OSHA regulations for indoor installation. This means that the hydrogen supply can be closer to the point of use, trimming the length of piping, and in turn minimizing the risk of leaks and contamination.

With appropriate drying, PEM water electrolysers can produce pressurized hydrogen with a purity of at least 99.9995 percent on a constant basis, due to the stoichiometry of the generation process. Using this approach, production avoids the introduction of contaminants associated with the manufacture and transport of hydrogen from other sources, such as petroleum-based raw materials. The technology also eliminates variations in impurities from batch to batch, because electrolysers continually produce hydrogen from water. In addition, contamination issues arising from cylinder change-out and refilling are eliminated.

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Reliability also benefits from the use of electrolysers. As hydrogen is made on-site and on-demand, the supply of this source is not disrupted by uncontrollable situations such as severe weather, traffic tie-ups, accidents, labor strikes at the supplier or trucking facility, and shortages in the supply chain. The generators are fully automatic, so no personnel are required for 24/7 operation (dependability is proven in submarines, where PEM electrolyser cell stacks provide oxygen for life support). Since there are limited moving parts – primarily a circulation pump, a circulation fan and a few solenoid valves – these units require minimal maintenance.

PEM water electrolysers also have the upper hand in terms of cost control. The price for hydrogen delivered from an off-site source may fluctuate significantly, while the costs for hydrogen generated on-site with an electrolyser are relatively fixed, and limited to capital, electricity and preventive maintenance.

Another benefit of PEM water electrolysers is that they allow users to produce very pure hydrogen at a lower cost than alternatives, even at low usage rates. And if the user's demand increases, there are options for increasing capacity. Depending on the model, units can be expanded by adding components to increase output capacity, or more machines can be installed to match the customer's process needs.

PEM water electrolysers will transform the industry. Up until recently, larger fabs have had to store large quantities of hydrogen to meet their production requirements. Now, with the introduction of electrolysers that have a capacity of up 1 Nm^3/hr to 4,000 Nm^3/hr, a greater range of operations, from small start-ups and educational facilities to high-volume plants, are able to benefit from on-site hydrogen generation systems that are armed with the attributes of high purity, low risk, and low-cost.

For more information on generating high-purity hydrogen on-site, contact Nel Hydrogen:
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