Developments in the market for UHP hydrogen purifiers

Long treated as the Cinderella material of semiconductor processing, with limited usage in silicon semiconductor, LCD and GaAs manufacture, hydrogen and in particular ultra-high-purity hydrogen is becoming an increasingly important ingredient in new and high-growth areas of semiconductor processing technologies, says Noel Leeson of Power & Energy Inc.

The dramatic growth in LED production since 2008 has attracted much scrutiny and many articles have been written about the growth in metal-organic chemical vapor deposition (MOCVD) tool demand, the challenges faced by the substrate makers, and the rush to expand the production capacity of inorganometalic chemicals and of high-purity NH_3, a critical gallium nitride (GaN) precursor.

Less well publicized has been the need to improve the supply of UHP hydrogen (the gas that transports all the organometalic chemicals into the MOCVD reaction chambers). For the highest-performance GaN devices, for example, the need to eliminate oxygen from GaN epitaxial layers means that typically the hydrogen must reliably and consistently contain <<1ppb (parts per billion) of both oxygen and H_2O impurities. As supplied, hydrogen typically contains far higher levels of impurities when it is delivered to the fab, so GaN epitaxy processors must purify the hydrogen on-site.

Since the early days of the MOCVD industry, most processors have used H_2 purifiers that work by diffusion through a hot palladium membrane (Figure 1). Each MOCVD tool would typically have been equipped with its own palladium (Pd) purifier.

Modern GaN epi plants typically operate many MOCVD tools, and facilities engineers are increasingly adopting a centralized purification model, where several purifiers are installed in parallel to supply a group of

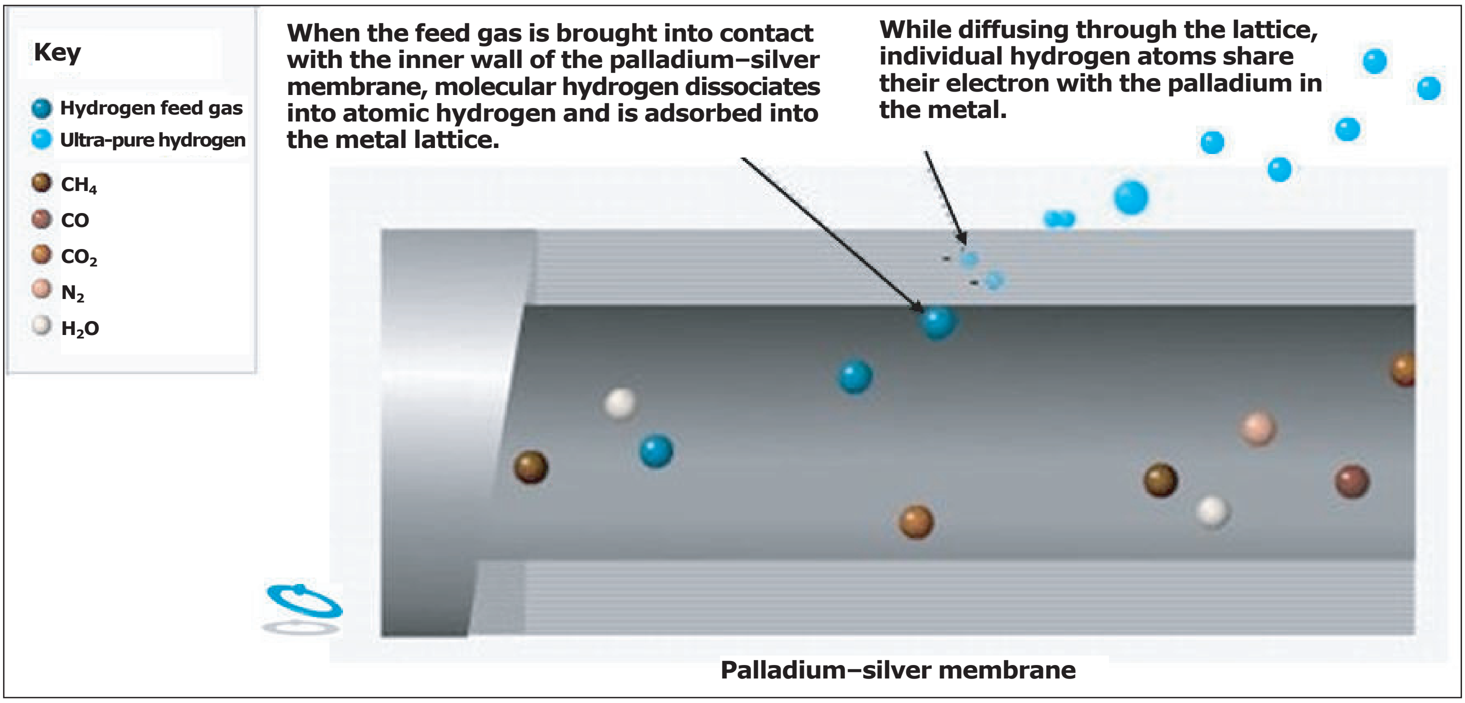

Fig 1. Principle of palladium purification of hydrogen.

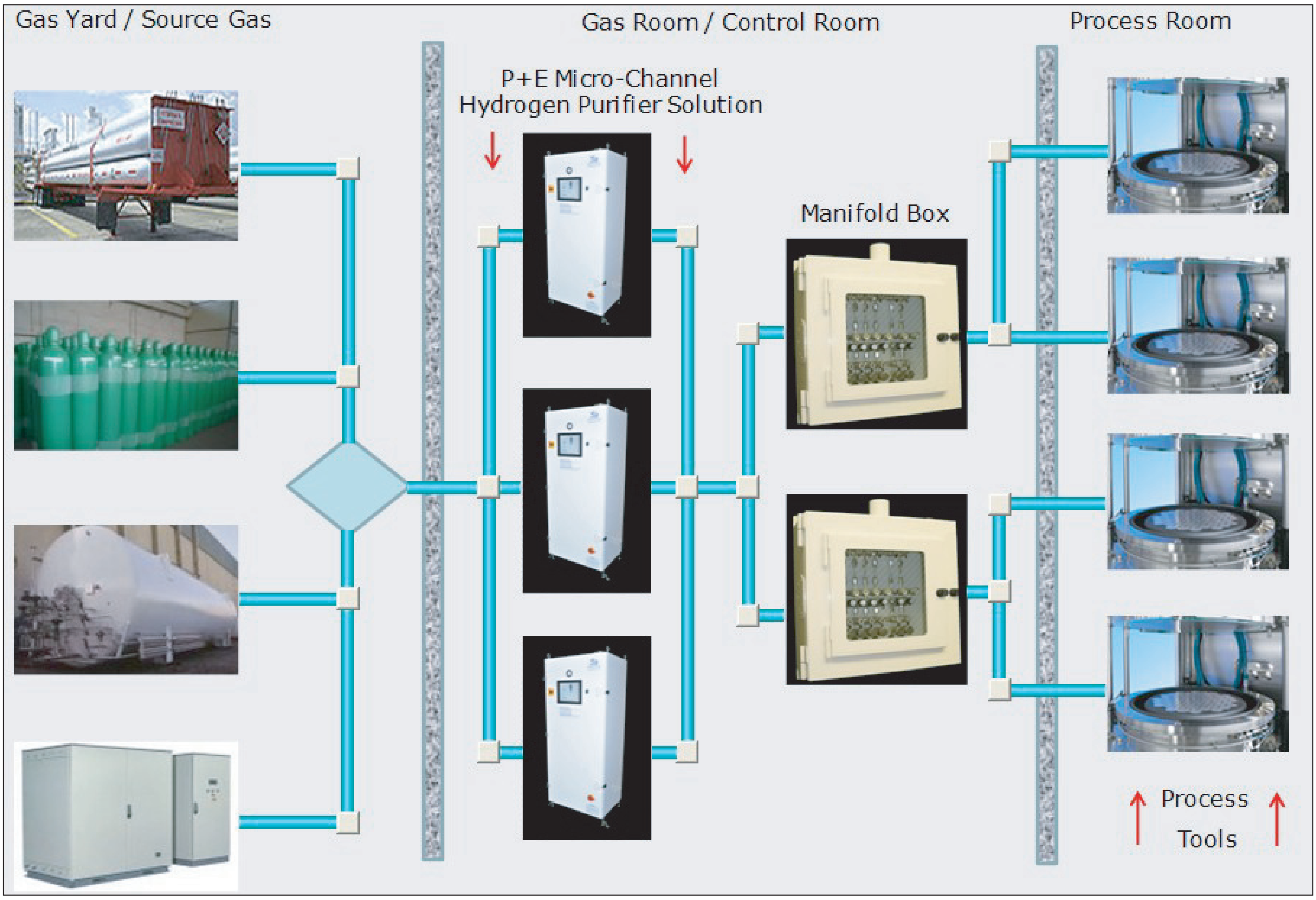

Fig 2. Centralized purification layout.

tools or even an entire fab. This approach allows a facilities manager to build redundancy into the purifier system design by installing an additional stand-by purifier (Figure 2), increasing reliability and uptime while reducing capital and operating costs by making use of larger capacity purifiers. With this philosophy, facilities managers are also able to pace purification capacity additions to match the tool installation and production ramp of the fab, thereby optimizing cash flow. Pd purifiers capable of purifying hydrogen from 97% to 99.9999999% are now available with nominal flow capacities of up to 160NM^3/Hr, a capacity unthinkable a couple of years ago.

While there are alternatives to Pd for the purification of hydrogen, Pd remains the technology of choice, as it is the only technology that provides absolute purification, i.e. only H_2 can diffuse across the Pd membrane. All other technologies work by adsorbing some proportion of the impurities from the H_2 stream and struggle to contain the impurity spikes to which all hydrogen systems are prone, particularly those fed by H_2 of variable consistency such as the H_2 supplied in much of China, India and other parts of Asia. Given the high cost of an impurity excursion in terms of lost epi-wafers, down-time for tool clean-up, and the cost for replacement of contaminated MOCVD chemistry, few facilities managers are willing to give up the security provided by palladium. Also, with the lower unit costs achieved through the adoption of the centralized purification model, there is little economic incentive for a facilities manager to take a risk on an alternative technology.

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Pd purifiers use either the traditional 'outside-in' approach to purification or the more modern 'inside-out' micro-channel technology (Figure 3). Each approach has its advocates, but currently only inside-out micro-channel technology purifiers are available in nominal capacities of greater than 60NM^3/hr.

In addition to the demand from LED production, thin-film silicon photovoltaic (PV) cell production processes require large volumes of UHP hydrogen. China-based producers are increasingly turning to Pd technology to

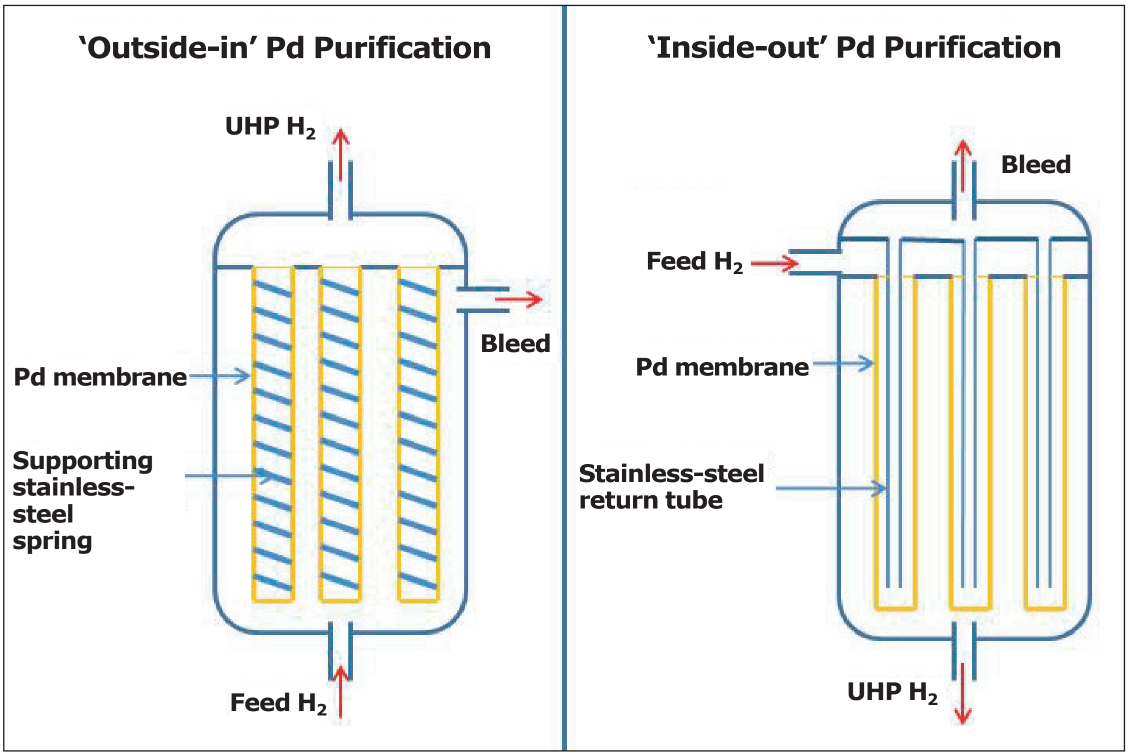

Fig 3. 'Outside-in' and 'inside-out' purification schematic designs.

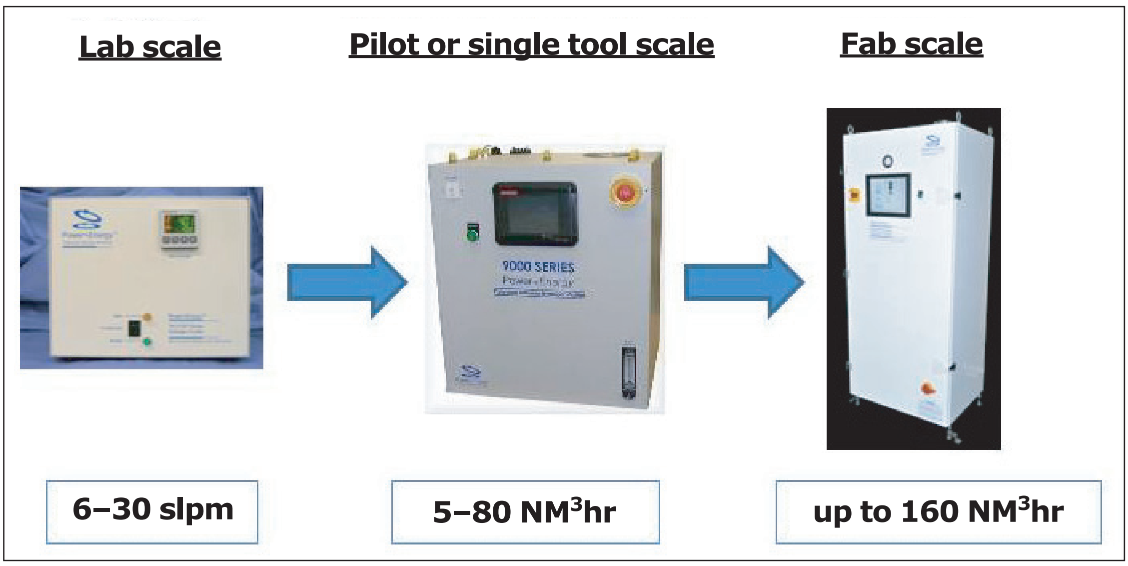

Fig 4. 'Lab to fab' using identical purification elements.

protect their processes from variability in quality of the the local hydrogen supply. For these thin-film processes, N_2 and O_2 are particularly unwelcome impurities. Unlike other purification technologies, Pd purifiers can reliably maintain sub-ppb impurity levels even in the face of large spikes of contamination possible from routine operations such as tube trailer change-over or from leaking fittings.

The expectations for growth of power semiconductor devices are also high, driven by the exploding growth in wired and wireless data transmission capacity, increasing adoption of non-traditional grid-linked electricity generation, and the general growth in electric vehicles. Power devices can be based on silicon technology but increasingly devices are being designed on gallium nitride (GaN) or silicon carbide (SiC) epiwafers. Like GaN, SiC epi is grown using an MOCVD process but, in addition to removing oxygen, nitrogen must be controlled to < 1ppb. Pd once again is the ideal technology to consistently achieve the demanding hydrogen purity needed by SiC producers. Inside-out micro-channel purifiers employ identical membrane elements in all sizes of purifier. Researchers and producers can eliminate one source of variation by using consistent hydrogen purification at all stages of technology deployment, from R&D through pilot operations into mass production (Figure 4).

As we approach the sub-20nm generation of silicon semiconductor processing, tolerance for impurities in silicon epi layers and in the super-thin gate structures is also decreasing, continuing the requirement for employing UHP hydrogen in these critical process steps.

The surging demand in traditional and new applications for UHP hydrogen, coupled with the move to centralized purification systems, is driving growth and change in the market for hydrogen purifiers. Manufacturers are responding by increasing the capacity of Pd purifiers from $60NM^3$/hr up to $160NM^3$/hr and higher, thereby allowing a semiconductor manufacturer to reduce unit costs and ensure process uptime while guaranteeing that only the highest-purity hydrogen consistently reaches the process chamber. ■

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