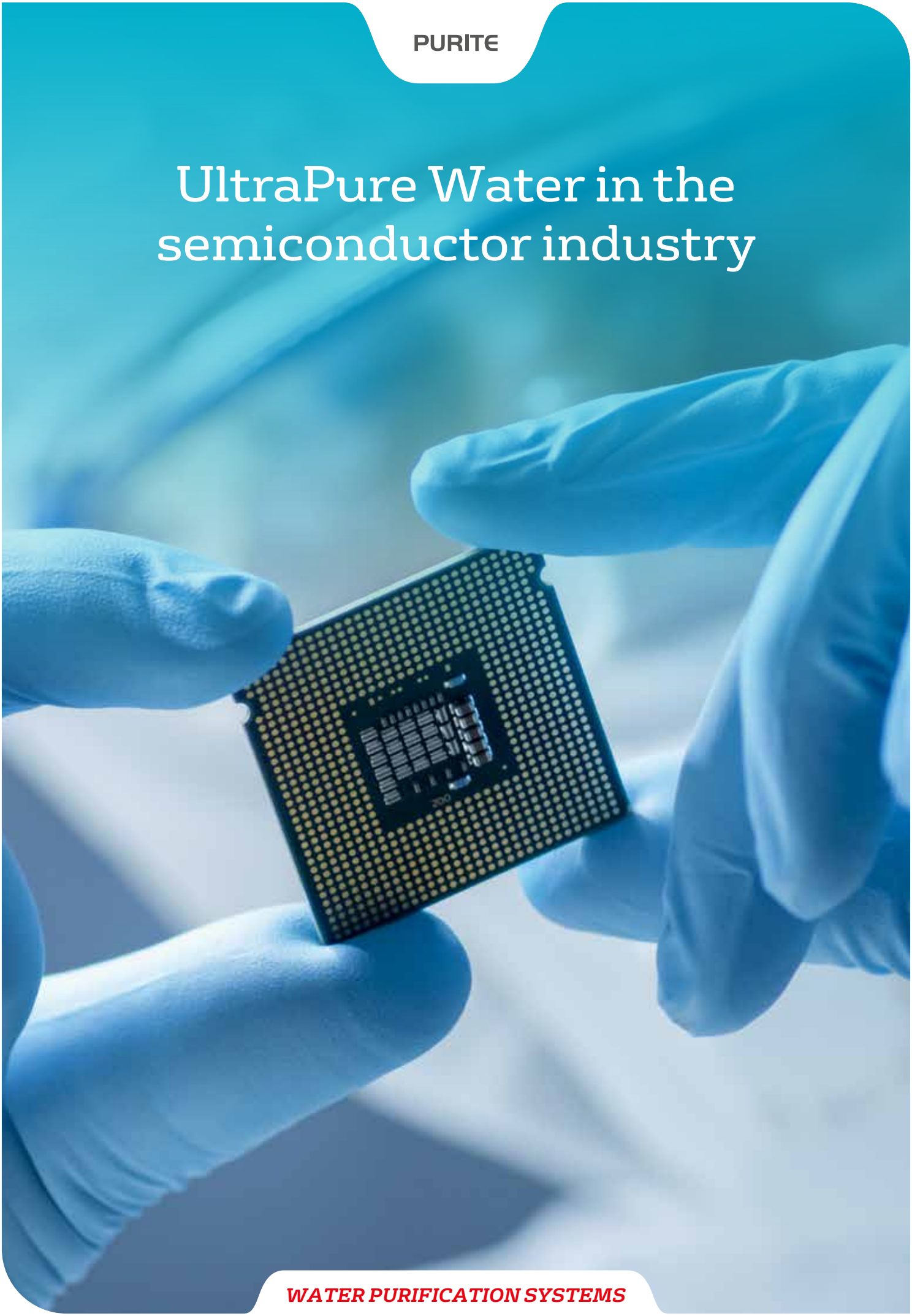
PURITE

UltraPure Water in the semiconductor industry



WATER PURIFICATION SYSTEMS

Semiconductor manufacturers need a consistent supply of high-quality water to ensure component fabrication success.

In 2021, semiconductor unit sales reached a record 1.15 trillion shipments, which equates to approximately 145 chips for every person on earth[1]. This figure looks only set to increase as demand for consumer electronics and vehicle electrification amongst other things continues to rise. The European semiconductor materials market size alone was estimated at USD 5.45 billion in 2023, and is expected to reach USD 6.94 billion by 2028, growing at a CAGR of 4.94% during the forecast period (2023-2028)[2].

Both Europe and the UK are focusing on increasing their semiconductor industries, with the European Chips Act aiming to strengthen Europe as a key location for production capabilities and expertise. And, following the unveiling of the UK government's semiconductor industry 20-year plan in May 2023, the future looks bright for UK manufacturers as well.

With the UK already in the top 10 when it comes to the number of semiconductor fabrication plants in the country[3], the government's planned support looks set to help the sector access improvements to infrastructure, drive more R&D and promote international cooperation[4].

Semiconductors underpin todays and future technologies, such as AI, 6G, Cybersecurity, Electrified Mobility and Quantum. Further investment will help build on the UK and Europe's particular strengths in semiconductor design, compound semiconductors, advanced packaging, and world-leading R&D ecosystems.

Supercharging production with UltraPure Water
One of the foundational components that cannot be underestimated in the strength and growth of the European and UK semiconductor industries is an essential but humble element – water.

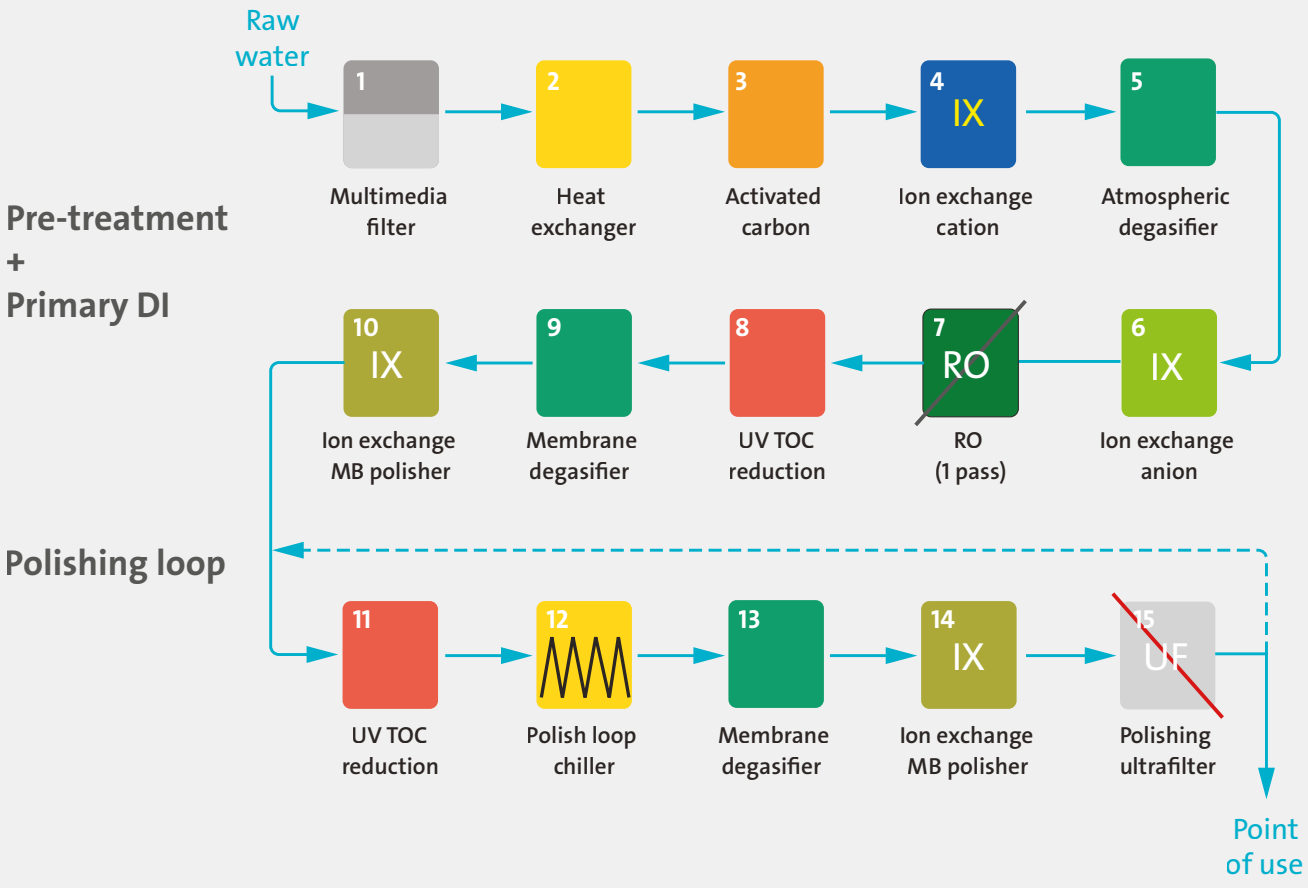
And not just any water but UltraPure Water (UPW). From the initial cleaning of wafers to the final fabrication of semiconductor and microelectronics components, UltraPure Water is key to the success of the process and the functioning of the end product. It helps secure the purity of the component and enhances productivity throughout the semiconductor production process.

As even the smallest impurity in the water can affect the performance and reliability of an electronic component, it is no wonder that UPW – that is free from impurities, contaminants and minerals - is seen as an essential part of semiconductor manufacturing.

UltraPure Water is used for cleaning, etching and rinsing processes and it is usually produced onsite. To create UPW involves distillation, deionisation and reverse osmosis and a typical UPW system is made up of three stages:

- **Pre-treatment** - to remove suspended solids and to produce purified water. This stage may involve two pass Reverse Osmosis, Demineralisation and Reverse Osmosis or High Efficiency Reverse Osmosis, as well as a Sodium Bisulfite or Activated Carbon step for water dechlorination.
- **Primary deionisation** - to further purify the water. This involves passing the water through a membrane degasifier to remove CO_2 and extend the life of the cylinders further. Then the water is passed under UV light and through a mixed bed ion process for biological inactivation or Total Organic Carbon (TOC) reduction. The UV @ 185 nm for TOC breaks down organic molecules into smaller more chargeable ions that are easier to remove with the mixed bed ion exchange media. The UB=V @ 254 nm prevents biological proliferation in the mixed bed media thus mitigating fouling risk in the cylinders/process.
- **Polishing deionisation** - to raise water quality high enough to meet production line purposes and create ultrapure water. This involves using UV light and passing the water through an ion exchange and membrane or vacuum degasifier process.

An example of a UPW circuit in a semiconductor plant



Source: Francois de Dardel, 2018.

When is water ultrapure?
The unit of measure most often used to assess water at such high purity is resistivity, expressed in Megohms centimetre (MΩ.cm). The higher the resistivity, the purer the water, owing to the lack of ionic contaminants present to conduct electrical charge. As a basic requirement, water is classed as ultrapure when it has a resistivity of 18.2 MΩ.cm (conductivity 0.055 µS/cm) and its organic and inorganic matter must be very low. The water's TOC (total organic carbon) should only be 1 to 3 µg/L (ppb).

Water quality standards for UPW used in the semiconductor industry

Test Parameter	Advanced Semiconductor UPW[7,8]	Monitoring Method
Resistivity (25°C)	>18.18 MΩ.cm	Online resistivity meter
Total organic carbon (on-line for <10 ppb)	<1 µg/L	Online TOC meter
On-line dissolved oxygen	10 µg/L	Online dissolved oxygen meter
On-line particles (>0.05 µm)	<200 particles/L	Online light scatter
Non-volatile residue	100 ng/L	Particle counter and non-volatile residue monitor
Silica (total and dissolved)	50 ng/L	GFAAS or inductively coupled plasma
22 most common elements (see F63-0213[8] for details)	<1–10 ng/L	(ICP/MS)
7 major Anions and Ammonium (see F63-0213[8] for details)	50 ng/L	Ion chromatography or inductively coupled plasma
Bacteria	<1 CFU/100 mL	Microbial culture techniques or ATP testing

High Purity water system design
For promoting sustainable practices - For environmental and cost reasons, the semiconductor industry wants to reduce the amount of UPW used in its processes. According to the International Technology Roadmap for Semiconductors (ITRS), device fabs utilized 7 liters/cm^2 of UPW per wafer out. This means that a typical 200 mm wafer fab that processes 20,000 wafers per month can use up to 3,000 m^3 of UPW per day. As a result, more and more semiconductor companies are realising the benefits of using well-designed UPW recycling systems to promote more sustainable production[5].

For maintaining water purity - It is difficult to maintain the purity of UPW whilst in use and storage, as it has a high solvency potential. That is why it is important to monitor parameters closely. Also, despite processes being in place to create UltraPure Water, device linewidths are getting smaller, and this means that standards are rising. As a case in point, the linewidth of the earliest integrated circuits (ICs) was 10 µm (1/100 mm), whereas the latest technology has reached the level of 14 nm processing[6]. That is why system design is so integral to maintaining water purity.

Designing a UPW system
As UPW is so difficult to store, any UPW system should be designed to minimise the length of time/pipework between the point of UPW generation and the points of use. In the part of the system where the UPW is generated, careful consideration must be given to the material of all wetted parts, as contaminants will leach out of most materials.

The norm is to use polyvinylidene difluoride (PVDF) pipe work and fittings for the polishing system and either polypropylene or ABS for the primary loop and pre-treatment stage. The final pure water storage tank should be fabricated of PVDF or polypropylene depending on the final treatment methodology. It should also include nitrogen blanketing to prevent the ingress of CO_2 that would result in a marked reduction in water resistivity, and a shortening of the life of the deionising resins. This is because the removal of CO_2 exhausts the resins prematurely.

Building resilience into the UPW system

To ensure uninterrupted operation, it is advisable to include redundant systems within the UPW's design, as even a few seconds of disruption can cause systems to shut down, or reset, in the meantime allowing contaminants to enter the clean water. The benefit of incorporating a redundant system into the automation or electrical distribution system or communications network is that it can take over if the primary controls stop working and enhances the overall UPW system's reliability and uptime.

Tackling biofilm growth

The system design is also fundamental in maintaining microbiological purity. For example, good hydraulic design will not include for dead-legs or static water and recirculating water should be maintained at sufficient pipe work velocity to inhibit the formation of biofilm on pipe work surfaces.

Even within UPW systems, where theoretically there is little to support micro-organisms, biofilm growth on pipework remains an issue. There are a number of important design considerations that must be considered to minimise microbial contamination. The first line of defence is to take regular steps throughout the system to reduce the number of micro-organisms. The first of these is the RO membrane that will remove <99% of micro-organisms. UV at 254 nm is commonly used at various stages of the process to disinfect the water, with a properly sized system capable of reducing the number of viable micro-organisms by more than 99.9%. Filtration in the range 0.2 microns is commonly used to remove inactivated bacteria, post UV. This is also known as 3 log reduction and UV can be sized to offer higher log reductions as required.

Ultimately, regardless of the technologies employed, contamination with micro-organisms can occur, and because of this all systems will require periodic sanitisation using, for example, hot water, ozone or hydrogen peroxide.

UltraPure Water and Purite

Generating and maintaining UPW is a careful process, but with the right system design, it is achievable and sustainable. With four decades of experience in water purification for the most demanding industrial and scientific applications, Purite can help you navigate the challenges involved in delivering sustainable, reliable, and cost-effective UltraPure Water for semiconductor and electronic applications. Our engineering teams can design and develop site-specific solutions for facilities of any scale, and we offer complete build, installation, and commissioning services. Purite is continually developing its products to meet the evolving needs of today's semiconductor manufacturers.

Sources:

1 https://www.asml.com/en/news/stories/2021/semiconductor-manufacturing-process-steps
2 https://www.mordorintelligence.com/industry-reports/europe-semiconductor-materials-market/market-size
3 https://worldpopulationreview.com/country-rankings/semiconductor-manufacturing-by-country
4 https://www.gov.uk/government/news/new-1-billion-strategy-for-uks-semiconductor-sector
5 Qi Wang et al. Environmental data and facts in the semiconductor manufacturing industry: An unexpected high water and energy consumption situation, Water Cycle, Volume 4, 2023,Pages 47-54, ISSN 2666-4453, https://doi.org/10.1016/j.watcyc.2023.01.004.
6 https://tel.com/museum/magazine/material/150227_report04_01/
7 https://en.wikipedia.org/wiki/Ultrapure_water#cite_note-ASTM_D5127-2
8 https://en.wikipedia.org/wiki/Ultrapure_water#cite_note-SEMI_F63-3

PURITE

Get in touch

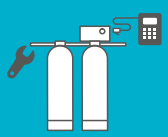
Veolia Water Purification Systems Ltd trading as Purite
Bandet Way, Thame, Oxon, OX9 3SJ, United Kingdom

T +44 (0)1844 217141
E vtc.vwts.puritemail.all@veolia.com
W purite.com

Design

Build

Install



Maintain

Founded over 40 years ago, the Purite brand has a long and proud heritage leading the way in water pre- treatment and process. We are now part of Veolia, one of the world's largest manufacturers and suppliers of specialist water treatment technologies, products and services.