

The Unseen World of Semiconductor Insulation

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Artificial intelligence (AI) is pushing semiconductor demand to new heights. With this, demand also is escalating for new technologies that address industry pain points such as the need for advanced cleanliness, reduced space requirements and applications that increase energy efficiency.

Tackling any one of these demands would be challenging by itself. When combined with the reality that fabrication plant and data center development also are booming, the semiconductor industry is at an inflection point.

In this environment, any innovation is welcomed. A small but incredible development is occurring within the little considered world of semiconductor insulation.



It is poised to bring about significant positive effects.

Specifically, energy-efficient thermal insulation solutions are emerging as critical process enhancements. These advanced insulation and thermal management technologies help reduce heat-transfer loss, improve process stability, and support higher-performance manufacturing. Such solutions also allow existing fabrication facilities to modernize operations and transition to more sustainable technologies, without requiring complete facility overhauls.

Companies can transition to new heating jacket designs without changing their equipment or facilities. Fabs can also add an additional heating jacket cover to existing heating jackets to improve performance.

Global electrification challenges

To better understand the importance of thermal insulation for semiconductors, a big picture view is required. Much has been written about how data centers are fast becoming one of the largest consumers of electricity. In some regions, the strain these centers impose on the electricity infrastructure is approaching critical levels. This challenge is worsened in regions where energy costs are high or supply is constrained, making facility location a key factor in how acutely capacity limits are felt.

At the same time, surging demand for semiconductor chips, driven by growth in AI and digitalization, is adding further pressure on chip manufacturers because the production process itself gulps huge amounts of power.

Together, the expansion of data centers and semiconductor fabs is placing enormous stress on fragile, aging electric grids, raising concerns about long-term power availability and intensifying the need for more energy efficient technologies.

According to a 2025 McKinsey report [1], companies across the compute power value chain, a complex ecosystem transforming to meet AI demand, will need to invest $5.2 trillion into data centers by 2030 to meet global AI demand. Technology developers and chip designers are expected to benefit the most from the race for greater computing power, as they supply the processors and hardware underpinning it all. Yet while demand for these products is surging, chip innovators also face a similarly high investment burden, expected to exceed $3 trillion over the next five years [2].

Such massive capital investments are emerging across the semiconductor manufacturing industry, particularly to support growing compute and data center demands. This surge is increasingly at odds with an aging electric grid, especially in the U.S., where infrastructure has seen limited modernization over several decades. As a result, the pace of technological expansion is beginning to outstrip the capacity and reliability of existing energy systems,

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creating a critical bottleneck for future growth. These constraints are prompting greater interest in thermal insulation technologies that improve energy efficiency in semiconductor manufacturing.

For data centers facing global requirements to upgrade electricity grids while manufacturing chips, energy demand has become a major concern.

Chipmakers face the need to address the high energy intensity of production, driving the need for advanced insulation and thermal management solutions that can perform reliably, especially in extreme cleanroom environments.

Thermal insulation methods

In semiconductor manufacturing, gases must be delivered through lines at tightly controlled temperatures to ensure proper processing. Manufacturers use heating jackets with thermal insulation around gas delivery lines to maintain stable gas temperatures and prevent condensation or performance issues. Semiconductor manufacturers have traditionally relied on fiberglass insulation due to its inexpensive, widely available and easy-to-work-with characteristics. It is not, however, a perfect fix. Fiberglass may be able to handle the temperature, but it is bulky and takes up valuable cleanroom space. Meanwhile, another common solution, silicone, has temperature limits that prevent its use at higher heat levels.



Manufacturers like W. L. Gore & Associates, are now bringing forward aerogel-based insulation due to its better overall thermal performance. This innovation has a thermal conductivity (K-value) that can be roughly 30–40% lower than traditional solutions [3]. As a result, heating systems have the potential to become smaller and more efficient, enabling more equipment to fit into complex cleanroom environments while also reducing the amount of energy required to maintain the necessary process temperatures.

The aerogel insulation technology creates an opportunity for manufacturers to either use a thinner insulation layer while maintaining the same thermal performance or keep the same thickness and reduce overall energy consumption. The challenge with aerogel, however, is that it consists of extremely fine particles that are highly dusty. As a result, competing solutions simply coat a substrate with aerogel, which requires jacket heater manufacturers to use additional personal protective equipment (PPE) during handling and to take extra steps to fully seal the insulation inside the device. This is necessary because airborne aerogel dust can pose health risks and, over time, may migrate out of the heater's enclosure, creating contamination concerns within semiconductor fabs.

To address these issues, polytetrafluoroethylene (PTFE) can be used as a scaffold to encapsulate the aerogel particles within the tape structure. Enclosing the aerogel particles directly within the tape product enables safe and easy handling without the need for additional PPE. The result is a cleanroom-compliant material that can be seamlessly integrated into devices without requiring any extra processing steps.

Energy efficiency and thermal insulation

From a regulatory perspective, semiconductor equipment must meet strict safety requirements, particularly with respect to touch-safe surface temperatures and material flammability. Heating jacket manufacturers, therefore, must design systems with sufficient thermal insulation to ensure surfaces remain within regulated touch-safe limits, while also using materials that meet a UL94 V0 flammability rating that ensures they are self-extinguishing.

High-performance insulation materials such as aerogels are especially beneficial in this context because their superior thermal performance can provide significantly better temperature stability to avoid significant heat loss. Fabs using these technologies have demonstrated energy savings of up to 35% (Data available upon request) in process gas delivery systems, which are among the most energy-intensive parts of semiconductor manufacturing.

Just as an emerging standard for environmental responsibility is coming to the fore, this approach may also significantly improve energy efficiency. This approach reduces heat loss and lowers overall energy consumption in high-temperature processes. The past several years have seen the industry relying more and more on aerogel-insulated jacket heaters. Companies that can deliver innovations in thermal insulation, in collaboration with equipment providers consistently showcasing comparative data, will be able to demonstrate clear energy savings compared

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to traditional heater designs. This shift reflects broader industry pressure to balance increasing chip complexity and production scale with sustainability and cost efficiency. Aerogel-based solutions address challenges related to cleanroom cleanliness and process consistency, particularly through advanced thermal insulation for semiconductor heating jackets that enhances performance stability and operational efficiency.

Stronger collaboration for the future

Advanced thermal insulation technologies are seeing clear market acceptance by semiconductor manufacturers. One of the industry's key challenges is that manufacturers supply the insulation, while customers control the design. Heating jacket manufacturers determine how much insulation is used and can adjust controls to influence energy consumption.

Maximizing the impact of insulation requires collaboration and clear understanding of these choices. This multi-step chain can create a disconnect between insulation suppliers and end users. Success will rely on close collaboration with customers to ensure their needs are properly met and the technology achieves its full potential.

Only in this way will the unseen world of semiconductor insulation achieve the visibility it deserves.

About the author

Jes Barrett is a Global Product Owner at W. L. Gore & Associates. With a background in chemical engineering and an MBA in business development, she brings a unique blend of technical expertise and business acumen to the world of semiconductor manufacturing. Jes manages multiple products for the Semiconductor market, ensuring innovation and performance in high-precision manufacturing environments. Recently, Jes lead an intrapreneurial initiative focused on integrating thermal insulation into semiconductor equipment to drive energy efficiency.

References

1. https://www.mckinsey.com/industries/technology-media-and-telecommunications/our-insights/the-cost-of-compute-a-7-trillion-dollar-race-to-scale-data-centers
2. https://www.mckinsey.com/industries/technology-media-and-telecommunications/our-insights/the-cost-of-compute-a-7-trillion-dollar-race-to-scale-data-centers
3 https://www.gore.com/resources/data-sheet-gore-thermal-insulation-semiconductor-heating-jackets

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For teams used to traditional chiller and tower management, the shift to continuous coolant monitoring represents a step change: it replaces reactive troubleshooting with proactive control. That in turn reduces the risk of corrosion, biofouling and particulate fouling, failure modes that can cause expensive rework, void warranties, and trigger the dreaded unplanned downtime.

Practical steps operators should take now

Operators don't need to choose between water and no-water; they need a framework to use water wisely. Practical first steps include:

1. **Site-level assessment:** Evaluate watershed risk, source options (potable, reclaimed, non-potable), and power-water tradeoffs to determine the right mix of cooling strategies.
2. **Commissioning discipline:** Adopt staged filtration, hydrotesting, and flushing procedures that protect cold-plate passages, passivate surfaces, and remove construction debris before systems go live.
3. **Telemetry baseline:** Instrument critical points during commissioning to create an auditable record that connects acceptance testing to operational KPIs.
4. **Continuous monitoring:** Move from monthly lab samples to real-time telemetry for key fluid parameters; use analytics to predict when corrective action will be needed.
5. **Cross-industry collaboration:** Engage utilities, regulators and neighboring industrial users early to align reuse, discharge and permitting pathways.

Conclusion

As AI compute density climbs, water has moved from a back-office utility to a strategic asset that determines performance and regulatory standing. Semiconductor fabs and high-performance data centers share more than a supply chain link; they share acute, albeit distinct, water challenges. While fabs rely on ultrapure water (UPW) for nanometer-scale creation, data centers demand massive thermal capacity for operation. Yet, the solution for both lies in the same engineering rigor: site-aware design, rigorous pre-commissioning, and continuous telemetry. By applying the semiconductor industry's legacy of precise fluid management to the data center's cooling needs, the sector can ensure that the infrastructure running next-gen chips is as sophisticated as the facilities that built them.