WHITE PAPER

SPECTROSCOPY IN GLASS & COATINGS - ENABLING NEXT GENERATION APPLICATIONS

INTRODUCTION

Glass is everywhere in our daily lives, but in modern industry it's rarely just plain glass. What makes it perform is the coating on top. A thin layer can turn a window into an energy-saving barrier, a screen into a glare-free surface, or a facade into something that stays clean after every rain shower.

The challenge lies in ensuring these coatings perform consistently and precisely every time. A slight variation in thickness or optical response can mean higher energy loss, shorter lifetime, or a product that doesn't meet customer specifications. For manufacturers and researchers, keeping that consistency is critical.

This is where spectroscopy proves its value. By measuring how glass and coatings interact with light in real time, it gives direct feedback that helps improve processes, validate performance, and bring new coating technologies to market with confidence.

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1. ESTABLISHED GLASS COATING USES TO EMERGING INNOVATIONS

Coatings have long been essential in industries like architecture, automotive, and consumer electronics. In buildings, low-E layers help cut energy bills by reducing heat transfer through windows. In cars, heat-blocking coatings keep interiors cooler and improve driver comfort. On displays, anti-glare and scratch-resistant coatings protect image quality and durability. These are proven applications where coatings have become standard.

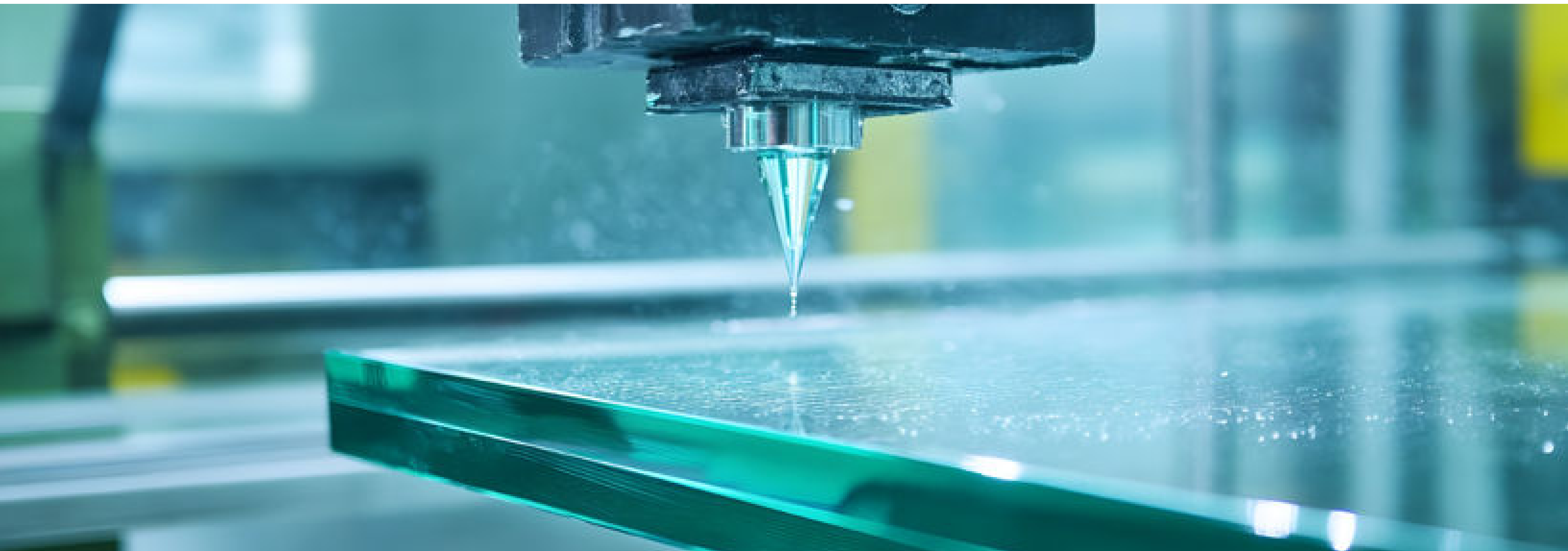
But the real momentum today is in new types of coatings that push glass beyond its traditional roles.

Self-cleaning glass is one example. Using photocatalytic layers, often based on TiO_2, the coating reacts with sunlight to break down organic dirt and allows rainwater to wash it away. That means glass facades, skyscraper windows, or solar modules can stay clear without frequent manual cleaning, saving time and cost (Scientific Reports, 2017).

Another fast-moving area is **anti-reflective nanostructures**. By carefully designing multilayer or nanoscale coatings can minimize reflection while transmission is maximized. This is critical for solar panels, where every percent of extra light absorption counts, and for high-performance optics and displays where clarity is key (J. Optics, 2025).

Finally, there's growing interest in **smart functional coating**s. These go beyond optics and start to add completely new functions. Think of antibacterial coatings for hospital glass, UV-blocking layers to protect sensitive interiors, or adaptive coatings that change their properties depending on light or temperature. These concepts are moving quickly from the lab to real-world applications.

These innovations bring exciting new capabilities, but they also raise the bar for quality control. Keeping coatings uniform, reliable, and stable under different conditions is far from straightforward, and that's where advanced measurement tools like spectroscopy become indispensable.



2. THE CHALLENGES BEHIND INNOVATION

As coatings become more advanced, the demands on production and validation also grow. Moving from lab-scale experiments to large-area manufacturing is where many promising ideas get stuck. The innovations in self-cleaning, anti-reflective, and smart coatings are no exception.

One of the biggest challenges is **uniformity**. A self-cleaning facade or a solar panel needs to perform consistently across square meters of glass. Even slight variations in coating thickness or structure can lead to patchy performance or unwanted optical effects.

Durability is another hurdle. Coatings that look great in the lab often struggle under real-world stress. UV exposure, changing humidity, temperature swings, and mechanical wear can all degrade performance over time. For technologies like anti-reflective or adaptive coatings, stability is just as important as initial efficiency.

Finally, there's the issue of **scaling up**. A concept proven on a small sample still has to be manufactured at an industrial scale, with reproducible results, if it's ever going to market. That means reliable, fast, and repeatable quality checks are essential.

Traditional inspection methods aren't always sensitive enough to detect these subtle but important differences. Small defects or variations may not be visible, yet they can compromise performance or shorten product lifetime.

This is where spectroscopy bridges the gap between lab and production. By measuring optical behavior directly and non-destructively, it gives manufacturers and researchers immediate feedback on uniformity, durability, and functionality. In the next chapter, we'll look at the different spectroscopic techniques that make this possible and how they apply across glass and coating innovations.

3. HOW SPECTROSCOPY SUPPORTS GLASS & COATINGS

The challenges we just looked at - keeping coatings uniform, proving durability, scaling up production, and validating new materials - all come down to one thing: the need for precise, reliable feedback. This is exactly what spectroscopy provides. Different techniques highlight different aspects of performance, and together they give manufacturers and researchers a complete picture.

Transmission and reflection
For coatings like low-E glass or solar control layers, the key question is how much light and heat they let pass. A coating where the cut-off wavelength shifts too far in one direction can either block too much light or fail to insulate properly. UV-Vis-NIR spectroscopy is the standard way to measure these properties. By mapping the full transmission and reflection spectrum, it gives direct feedback that allows manufacturers to fine-tune coatings for both clarity and energy performance.

Thin-film metrology
The thickness of a coating layer makes all the difference in how it behaves optically. Too thick or too thin, and the coating loses its intended function. By analyzing interference patterns in reflected or transmitted light, spectroscopy can measure thickness with nanometer precision. This level of control is vital for multilayer coatings such as anti-reflective stacks, where each layer must be exactly right to achieve the desired result.

Material validation
New functional coatings are entering the market quickly, from self-cleaning films to adaptive smart coatings. The challenge is proving that these materials remain stable once they leave the lab and face sunlight, humidity, or temperature swings. Raman spectroscopy helps by revealing structural changes, stress, or impurities that might compromise performance. It gives researchers confidence that the coating's properties are not just effective but also reliable.

Color and appearance
Performance alone is not always enough. In architecture and consumer products, coatings also need to look right. A layer that shifts the color of a building facade or changes the brightness of a display is unlikely to be accepted, even if it performs technically okay. Radiometry and colorimetry provide accurate measurements of brightness, glare, and color neutrality, helping to align functionality with visual expectations.

Scaling up to production
Many coatings that work well in the lab fail when they are scaled to industrial production. Maintaining uniformity over large areas and across thousands of units is a different challenge altogether. In-line spectroscopy addresses this by integrating directly into coating systems, where it can monitor deposition processes in real time. This allows manufacturers to catch variations immediately, cut down on waste, and ensure consistent quality.

Spectroscopy does not solve the challenges of glass and coatings by itself, but it provides the insight needed to do so. It connects R&D to production, offering a clear view of what is happening at every stage and giving both researchers and manufacturers the confidence to move forward.

4. SPECTROSCOPY IN ACTION: USE CASES

The role of spectroscopy in glass and coatings is not just theoretical. Researchers around the world are already applying these methods to validate new coatings and push innovations toward real-world use. A few examples show how spectroscopy provides the kind of feedback that other techniques simply cannot.

Self-cleaning films
A study published in Scientific Reports (2017) looked at TiO_2-based self-cleaning coatings for glass. The researchers used UV-Vis spectroscopy to measure how much light passed through the coated surfaces and to confirm the photocatalytic activity of the films. The results showed that the coatings not only maintained optical clarity but also actively broke down dirt when exposed to sunlight. This combination of transparency and function is exactly what is needed for applications such as building facades and solar panels. (Scientific Reports, 2017)

Anti-reflective coatings
In Journal of Optics (2025), a team investigated nanostructured anti-reflective coatings designed to reduce reflection and increase transmission across the visible spectrum. Spectroscopic measurements confirmed that the coatings significantly improved light transmission, making them attractive for use in displays and photovoltaic modules. Without these optical tests, the performance improvements would have been impossible to quantify or optimize. (J. Optics, 2025)

The Future of functional coatings
Beyond these published studies, new research is looking at coatings that go even further, from antibacterial layers for hospitals to adaptive coatings that respond to light or temperature changes. Early work has shown how spectroscopy can track these properties under stress conditions, ensuring that the coatings remain stable and effective outside the lab. Papers from groups such as those on arXiv (2023) and ScienceDirect (2025) highlight spectroscopy's role in validating these emerging technologies before they can be scaled up.

Together, these examples make one thing clear: spectroscopy is not an optional extra, but a necessary tool in coating development. It enables researchers to prove functionality, optimize performance, and build the foundation for commercial adoption.

5. AVANTES SOLUTIONS IN GLASS AND COATINGS

The examples from research highlight how spectroscopy makes the difference between a promising idea and a proven technology. At Avantes, we see this every day in the way our instruments are used across both R&D and industrial production.

In research labs, Avantes spectrometers help characterize coatings with high sensitivity and flexibility. They are used for transmission and reflection measurements, thin-film thickness control, and Raman analysis of material composition. Our modular setup allows researchers to adapt systems to their specific experiments, whether they are studying self-cleaning surfaces, testing anti-reflective films, or developing entirely new functional coatings.

In production environments, the needs are different: speed, reliability, and the ability to integrate into existing lines. Here, our spectrometers support in-line monitoring of coating processes, giving manufacturers real-time feedback on uniformity, color, and optical performance. This immediate insight helps reduce waste and ensures that coatings meet strict specifications.

AvaSpec-VARIUS™

AvaSpec-VARIUS™ OEM

AvaSpec-HERO

Our instruments, including models such as the AvaSpec-VARIUS™ and the AvaSpec-HERO, are trusted by researchers and manufacturers who need accurate, reproducible data. Whether it's validating a new material or maintaining consistent output on the production floor, our solutions provide the precision that coatings demand.

In need of a spectroscopy setup, but not sure which products suit your application best? Contact us about our demo program, where you can try our products for free to see which is best for you.

6. LOOKING AHEAD

The role of coatings in glass will only grow in the coming years. Buildings are expected to be more energy efficient, vehicles safer and more comfortable, and consumer products more durable and functional. Meanwhile, there is a growing demand for coatings that clean themselves, block harmful radiation, or adapt to changing conditions.

Meeting these expectations requires absolute control over how coatings are developed and produced. This is where spectroscopy will continue to play a central role. By providing real-time, non-destructive insight into optical and material properties, it helps researchers move faster from concept to prototype and gives manufacturers the tools to scale innovations into reliable, market-ready products.

As industries push toward higher performance and sustainability, the connection between spectroscopy and coatings will only become stronger. The future of glass will not just be about transparency; it will be about functionality, efficiency, and adaptability. And spectroscopy will be the tool that helps ensure those promises are met.

Curious to learn more or to try out some of our solutions? Click here to contact us.

CONTACT

WE'RE HAPPY TO HELP

Curious how spectroscopy will help you reveal answers by measuring all kinds of material in-line, at your production facility, in a lab, or in the field? Visit our website or contact one of our technical experts.
We are happy to help you!

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