

Easy-to-sterilize surfaces with femtosecond lasers

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How nano-texturing limits bacterial adhesion without coatings

Bacteria become a serious issue when they attach and form biofilms. In healthcare, food processing, packaging and water systems, even small residues can trigger regrowth between cleaning cycles. Antibacterial surfaces therefore attract strong interest. Not as a replacement for hygiene, but as a smart complement that reduces adhesion and improves cleanability from the start.

Why bacterial adhesion is harder to control than you think

Bacterial adhesion is never driven by one single factor. It depends on the species (shape, cell wall stiffness, motility and extracellular polymers) and on the environment, including humidity, temperature, flow and organic residues.

The surface itself plays a decisive role. Surface energy, charge and wettability influence early contact. **Micro- and nanoscale roughness and topography** often determine whether bacteria



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Two strategies for antibacterial surfaces

There are **two main routes** to create antibacterial behaviour.

1. Biocidal surfaces

These surfaces actively kill bacteria. They may release antibacterial agents or rely on contact-killing chemistries.

They can be effective, but they raise **important questions**:

- Long-term durability
- Potential leaching of active compounds
- Regulatory approval
- Resistance to repeated exposure to detergents, sterilisation and mechanical wear

In many industrial contexts, robustness is critical. Any loss of activity over time reduces reliability.

2. Structure-driven surfaces

Structure-driven concepts aim to prevent stable attachment. Instead of killing bacteria, the surface makes adhesion **mechanically or energetically unfavourable**.

The objective is clear: to reduce early colonisation, delay biofilm formation and improve the efficiency of routine cleaning procedures. Because this approach does not rely on coatings or added chemicals, it is increasingly attractive for industrial applications where **robustness and process compatibility** are key.



Attachment point theory and the role of nanotopography

Why does structure matter so much?

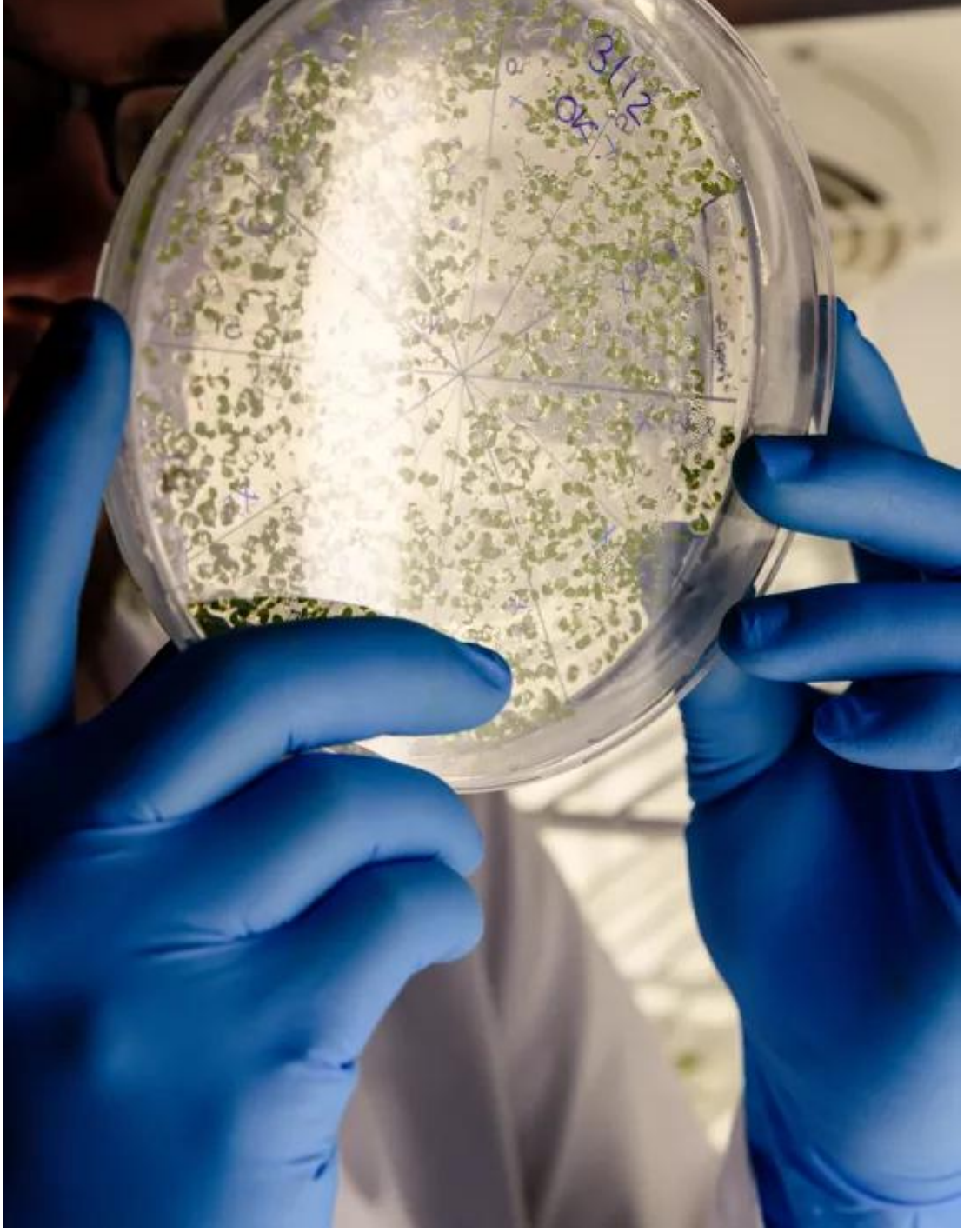
Attachment point theory offers a useful explanation. Most bacteria are about 1 to 2 micrometres in size. They are relatively rigid and do not spread like mammalian cells. Adhesion strength depends strongly on how many stable contact points they can create.

If a surface provides many accessible valleys or grooves at cell scale, bacteria can anchor firmly.

If the topography limits continuous contact, for example through peaks, steep slopes or gaps, adhesion weakens.

At the nanoscale, sharp or high-aspect features can introduce local mechanical stress on the cell envelope. This further discourages stable settlement and early colony growth.

By tailoring feature size, spacing and orientation, you can shift a surface from “easy to colonise” to “hard to colonise”, without changing its bulk chemistry.



Why femtosecond laser texturing makes the difference

Femtosecond lasers enable precise control over surface nanotopography. A well-known example is **Laser-Induced Periodic Surface Structures**, or **LIPSS**. These are nanoscale ripples generated in a controlled and repeatable way.

By adjusting fluence, pulse overlap, scanning strategy and polarisation, you can produce **defined nano-textures** instead of random roughness.

For antibacterial design, this control is crucial. **LIPSS can**:

- Reduce the effective bacterial contact area
- Limit the number and quality of stable attachment points
- Weaken early-stage colonies

The first hours after contamination are decisive. If adhesion is unstable during this phase, biofilm formation slows down. Depending on morphology, the ripples may also promote easier detachment during cleaning.

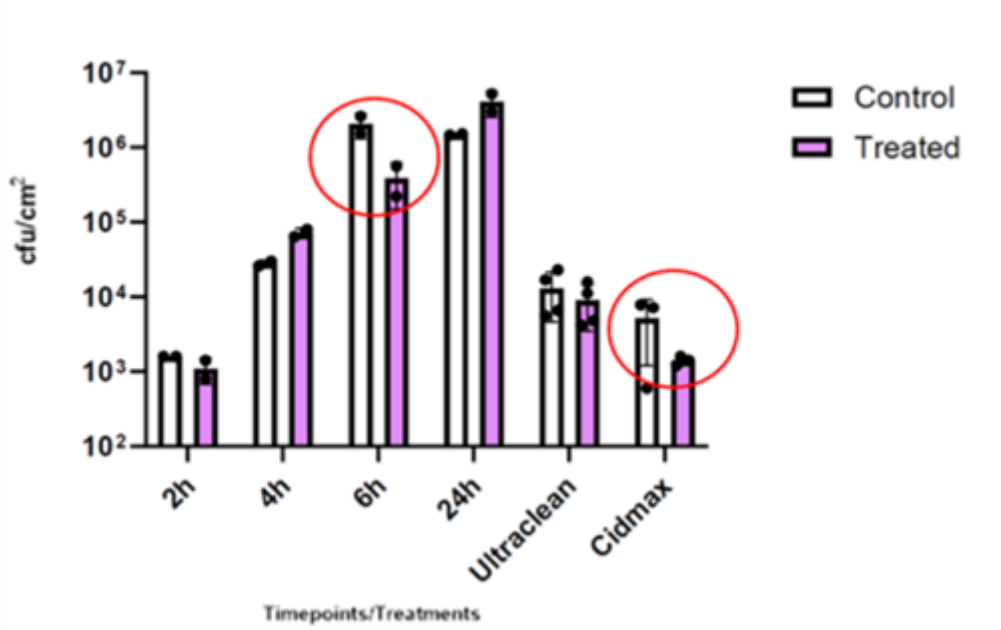
From concept to validation at Sirris

Sirris is currently developing **easy-to-sterilize surfaces** based on this structure-driven concept. Target applications range from door handles and handrails in medical facilities to machine components in food and pharmaceutical environments.

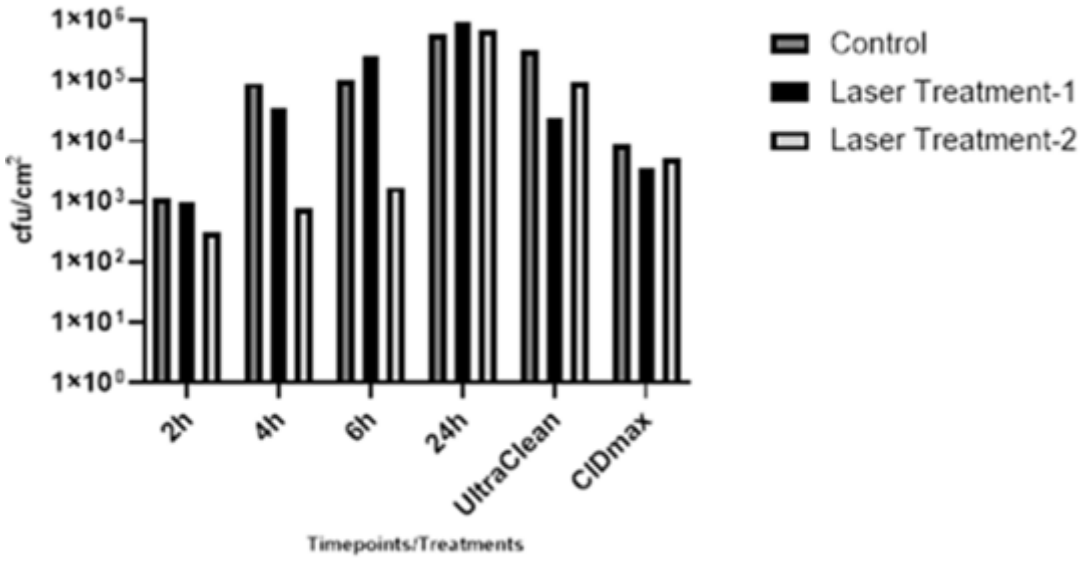
Tests were performed in a **CDC biofilm reactor**. Surfaces were inoculated with a bacterium, Staphylococcus aureus, at 2x105 CFU per millilitre for 24 hours at 37°C.

Stainless steel and **titanium coupons** were textured with LIPSS at different wavelengths, from UV around 350 nanometres to IR at 1035 nanometres. Viable cells were quantified after 2, 4, 6 and 24 hours. Additional measurements followed a cleaning and disinfection protocol using alkaline (UltraClean) and acidic cleaners (Cidmax).

In the figures below, Plot 1 shows UV-LIPSS on stainless steel, and Plot 2 shows IR-LIPSS on titanium.



Plot 1.?LIPSS textured with UV in stainless steel?



Plot 2. LIPSS textured with IR in titanium?

What we observe:

- On stainless steel, UV-LIPSS significantly reduced adhesion after 6 hours and after disinfection. This supports the easy-to-sterilize effect
- On titanium, IR-LIPSS strongly reduced biofilm formation during the first 6 hours. After sterilisation, the effect remained visible, although less pronounced

Towards robust, coating-free antibacterial design

In controlled tests, LIPSS reduced bacterial adhesion compared with untreated materials. The strongest effects appeared during early incubation and after cleaning, depending on substrate and laser settings.

These findings highlights the potential of femtosecond laser-induced surface structuring in anti-bacterial surface engineering. Structure-driven design may help to limit early biofilm establishment and support improved cleanability. By engineering nano-scale features with high precision and repeatability, femtosecond laser texturing could become a valuable complement to chemical strategies, pending further validation under application-relevant conditions.

Next steps towards industrial components

The next research phase moves beyond flat test coupons towards functional components. Real parts often include curved geometries and complex shapes, which require adapted processing strategies.

Current work therefore focuses on validating anti-adhesive performance on industrial components exposed to repeated cleaning cycles, mechanical wear and realistic contamination scenarios.

This validation step is essential to translate laboratory results into reliable industrial solutions. With further optimisation and application-specific tuning, nano-textured surfaces can contribute to safer

and more robust designs in healthcare, food and industrial environments.

Are you exploring antibacterial or easy-to-sterilize surface solutions for your products or facilities?

Sirris supports you in evaluating laser texturing strategies, testing under realistic conditions and translating lab results into industrial components. Let us assess together how nano-texturing can strengthen your hygiene strategy.

Contact us

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