Surface Functionalization

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In the development of microfluidic products, the choice of the substrate material is of critical importance and must be thoroughly analyzed depending on the application. However, bare material properties do not always offer the right surface characteristics to reach, for instance, optimal flow control and biocompatibility. It is then needed to modify or functionalize such surfaces with the right treatments. At Micronit, we master various techniques for surface functionalization, with which we can apply (localized) coatings or deposit biomaterials on different surfaces. This allows us to create higher quality platforms with multiple functionalities.

Surface functionalization processes

What can be achieved through surface functionalization? To answer this question, we must distinguish between processes that take place between the surface and the liquid of the test sample (surface-liquid processes), and processes that take place between two surfaces (surface-surface processes).

Surface-liquid processes include, for example, the application of hydrophilic or hydrophobic coatings and the application of a passivating layer. A specific area of interest within the surface-liquid interaction is the application of bioreactive layers. These layers contain biomaterials that react with the sample material.

As for surface-surface processes, one can think of the utilization of complementary chemistry. Like the treatment of both surfaces with reactive groups (for instance, amine or epoxy groups) that react with each other and can achieve a bond at lower temperatures when compared to the standard thermal bonding processes. The application of anti-stiction coatings is another functionalization tool to aid surface-surface processes.

In the following sections, we describe both of these processes into more detail.

Surface-liquid processes

Hydrophilic/hydrophobic coatings

These coatings are critical to achieve the desired wettability of the surface, a very important factor to allow the required liquid flow within the device. By changing the characteristics of the surface, one can regulate the behavior of the liquid sample. Making a surface hydrophilic ensures proper wettability, while a (local) hydrophobic coating could stop the flow at a designated location, or favor the interaction with one liquid over another. Oil favors hydrophobic surfaces while water does not, for instance.

- Polymers are often hydrophobic or only slightly hydrophilic. This affects the passive flow behavior of the sample and/or needlessly lengthens the duration of the assay. In some cases, an external pump is needed to overcome this.

- A hydrophobic surface is poorly wettable, which might lead to fabrication problems when a liquid layer has to be applied.

- On the other hand, a hydrophilic surface (like glass, contact angle ~40°) could lead to uncontrollable flow. In this situation, the liquid might not react to fluidic features like capillary stop valves, or spread to unwanted areas of the substrate.

Non-reactive/passivating coatings

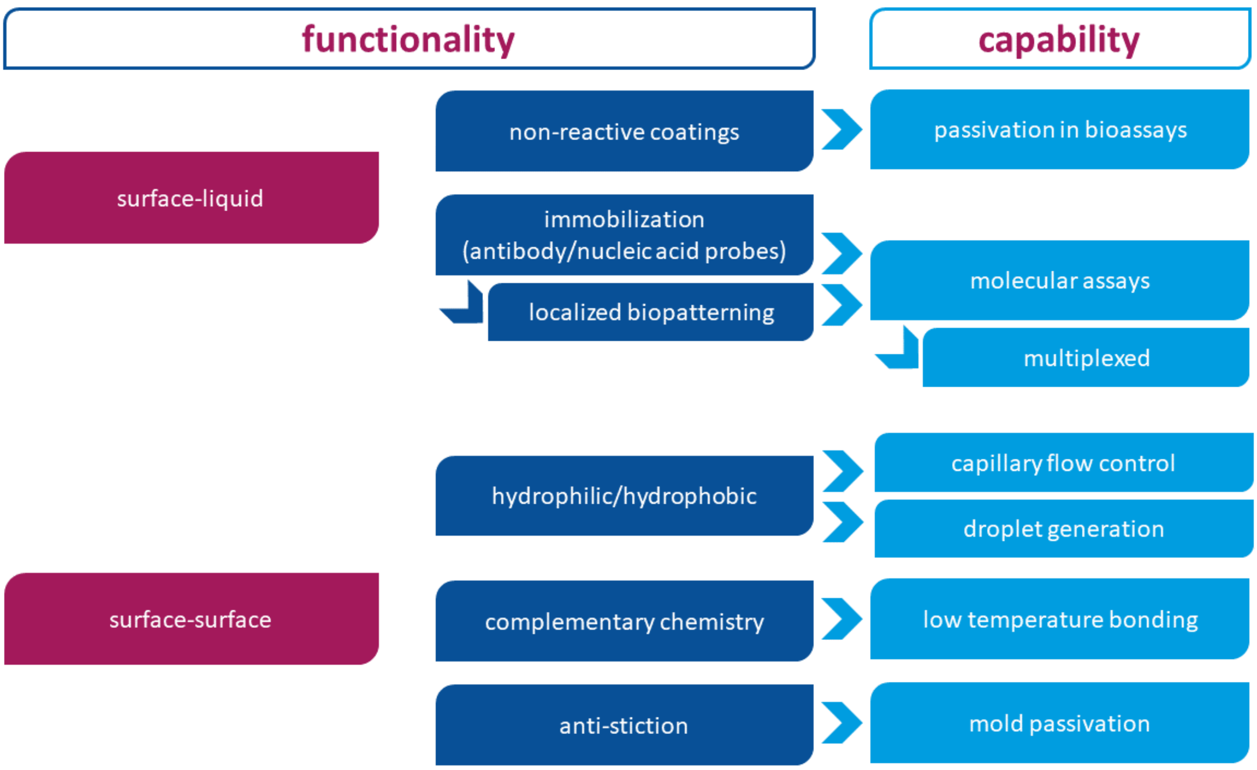
Passivation of the substrate material is a vital step especially in molecular diagnostic assays, because it prevents unwanted interaction between the molecules in the sample and those on the surface.

- The surface is made inert or repellent to prevent binding of molecules in unwanted parts of the device.

- Unwanted molecule binding can lead to false read-outs by interfering with the signal or hindering the capture of the target molecule.

Immobilization of (bio)molecules

By functionalizing the substrate surface with a layer of capture molecules (for instance antibodies or nucleic acid probes), it is possible to specifically target the molecules of interest within the sample.



Surface functionalization processes.

- Often the deposition consists of an intermediate layer between the surface and the (bio)molecules to ensure a secure bond between the two.
- Localized biopatterning: the sensor (bio) molecules can be accurately patterned on defined areas by the use of spotting technology.

Surface-surface processes

Complementary chemistry

By functionalizing surfaces with complementary chemistry (for instance, amine (NH2) and epoxy groups), the surfaces can be bonded with one another on a chemical level. The type of chemistry used often involves silanization of the surface with the appropriate complementary reactive groups.

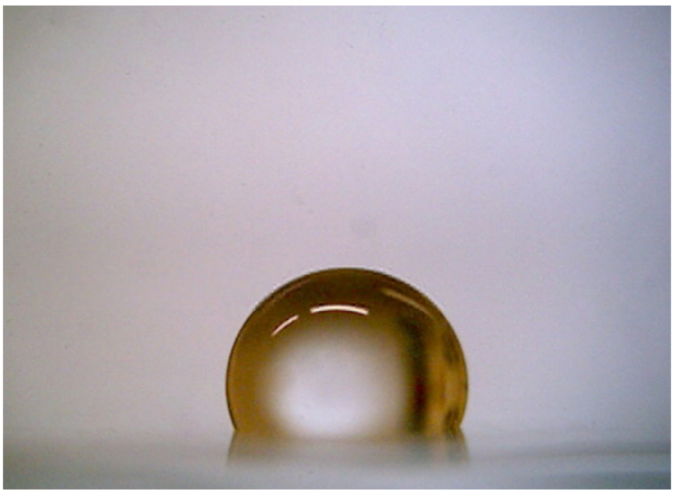
- This is especially of interest when traditional bonding methods involving high temperatures are not an option, for instance because the device contains biological material or the integrity of the fluidic structures is of particular concern.
- When two surfaces are incompatible to bond via traditional bonding methods (for instance two polymers with different glass-transition temperatures), complementary chemistry can overcome this.

Anti-stiction

Anti-stiction coatings are deposited to prevent the bonding and/or to help with the delamination of interacting components.

- These types of coatings are usually applied during the fabrication process to allow two substrates to interact with one another without bonding.
- Anti-stiction coatings are especially important during the hot-embossing process: the structures need to be transferred from the master to the substrate, but the subsequent separation process of the two parts can create strong shear forces. The coating prevents this from causing any defects and ensures the integrity of the structures to remain intact during delamination.

Wettability: low contact angle.



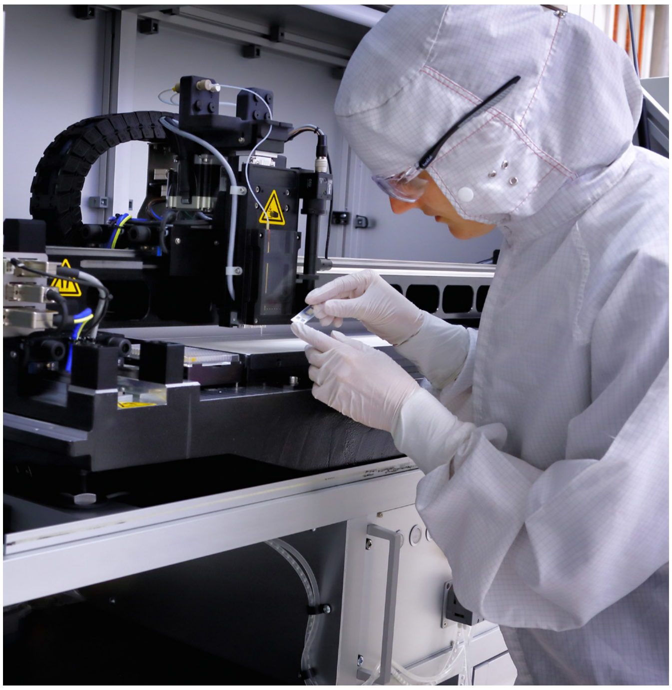
Wettability: high contact angle.

Use of biomolecules

Biomolecules are often used in surface functionalization. Typical examples of these molecules are: antibodies, proteins, and nucleic acids. When the surface is functionalized with these biomolecules, the capture of the target(s) can be detected through various methods (colorimetric, fluorescence, etc.). Biomolecules are often highly specific for a single target and thus can be used to capture these targets from the sample environment. This ability makes them particularly interesting in the diagnostics market, to confirm the presence of antigens involved in infections and diseases, for example, or detect certain markers of heart failure.

In the abovementioned case, the biomolecules remain in the same place – they are bonded to the surface. Another possibility is to have reagents integrated on-chip to be resuspended into the sample. This can be done either by dispensing the reagents and having them stored in dry form on the chip, to be resuspended into the sample when the chip is used, or to include the reagents in liquid form (e.g., in a blister), to be activated at the time of usage.

Plasma tool.



Non contact precision spotter.

Deposition techniques

How are these coatings applied? One of the major processes used is chemical vapor deposition (CVD). In this technique, a thin molecular layer is deposited in its vapor form onto the surface of a substrate. Sufficient reactive groups (e.g., silanol groups) need to be present on the surface of the substrate, which should be easily achieved using an adequate O2 plasma treatment. This gives the user greater control of the desired surface composition. Hydrophobic coatings can in this way be applied to glass, silicon and polymers.

Hydrophilic coatings are typically applied via plasma enhanced chemical vapor deposition (PECVD). In this case, plasma is being used to bring the monomer into a plasma state to increase its reactivity with the substrate. This technique can be applied to all materials. The PECVD system can also apply a glass-like layer on polymers, thus achieving hydrophilic qualities.

A non contact precision dispenser (spotter) is used to apply localized and/or patterned coatings. It can also deposit biomolecules on a local surface, for example only on a specified part or area of a microfluidic chip.

Conclusion

By choosing the right surface functionalization treatments, one can make sure that a diagnostic test is performed accurately. Trends are towards applying coatings to more and more specific areas of the surface. For instance, exclusively on an integrated sensor. Being able to functionalize selected parts of the substrate allows maximum flow control and regulation, which is essential given the progressive complexity of microfluidic platforms and the assays performed on them.

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Surface functionalization expert

Maciej Skolimowski is Research Manager at Micronit. He joined this company in 2013 as an R&D Scientist. Maciej studied biotechnology at Warsaw University of Technology, received his PhD in Micro- and Nanotechnology at the Technical University of Denmark (DTU), and worked as a postdoctoral researcher at DTU and at Groningen University (RUG). Maciej has extensive knowledge of microfabrication techniques, in particular of the fabrication of polymer microfluidics.

About Micronit

Micronit bv, founded in 1999, with development and manufacturing facilities in the Netherlands and Germany, provides innovative lab-on-a-chip and MEMS solutions using micro- and nanotechnologies. Solutions that help customers improve their products and research, contributing to the quality of life.

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