

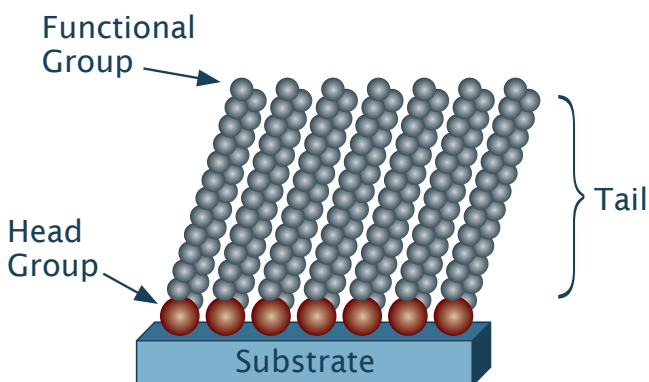
Vapor-phase deposition of self-assembled monolayers represents a versatile and low cost solution to rapidly functionalize a variety of surfaces including metals, oxides and polymers. Through a low thermal budget process ( $<120^{\circ}\text{C}$ ), surface properties can be tailored at the atomic scale to achieve optimal performances including control of wettability (hydrophobicity, hydrophilicity), adhesion and stiction, electrical, chemical properties to name a few. SAMs also provide an ideal vehicle to anchor nanoparticles, bio-molecules or be used as a seed layer.



### What are SAMs?

SAMs are organic monolayer films whose self-assembly is driven by the amphiphilic chemical structure of the molecule. By selecting head groups with high affinity to the substrate, chemisorbed surface reactions inducing high energy bonds result in a highly stable structure. The alkyl chains (tails) are functionalized through organic synthesis to generate well-defined surfaces with a broad range of characteristics.

Two main families of SAMs include thiols (or organosulfurs) for deposition on metal substrates, and silanes (alkylchlorosilane, alkylalkoxychlorosilane) for oxides and *polymer-based films*.

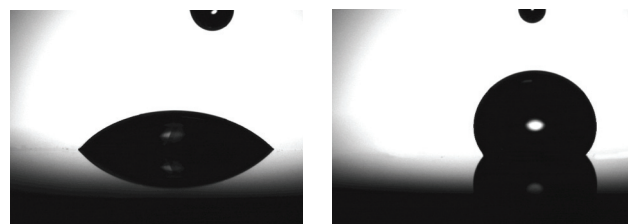


• Figure 1: SAMs molecule is composed of 3 parts: head group that chemisorbs on surface, tail (alkyl chain) and functional group R. R is tailored to provide desired surface functionality (hydrophobic, hydrophilic...). Examples of functional groups:  $-\text{NH}_2$ ,  $-\text{COOH}$ ,  $-\text{CH}_3$ .

### Applications

The self-ordered and self-assembled nature of SAMs in combination with the highly stable structure of the organic chains and wide variety of chain functionalization lead to a broad portfolio of applications, including (but not limited to):

- Organic thin film transistor (gate dielectrics, contacts)
- Permeation coating for flexible electronics
- Nanostructure functionalization
- Anti-stiction for MEMS and NEMS
- Cell adhesion / protein adsorption
- Large surface area surface coating for permeation / wettability control



• Figure 2: Water droplet on a) ALD-coated  $\text{Al}_2\text{O}_3$  b) ALD-coated  $\text{Al}_2\text{O}_3$  with DTS SAM ( $105^{\circ}\text{C}$ , 1 s pulse, 600s exposure) with  $111^{\circ}$  contact angle

## Benefits of SAMs deposition in vapor phase

With vapor phase deposition, stable monolayers can be deposited in 5-10 min, including over the most complex 3D micro and nanostructures encountered in MEMS and NEMS. This dry vacuum-based process ensures sample cleanliness and integration with other thin film processes. Using our demonstrated ALD-based technology, the process is readily scalable to large surface area coatings required in manufacturing.

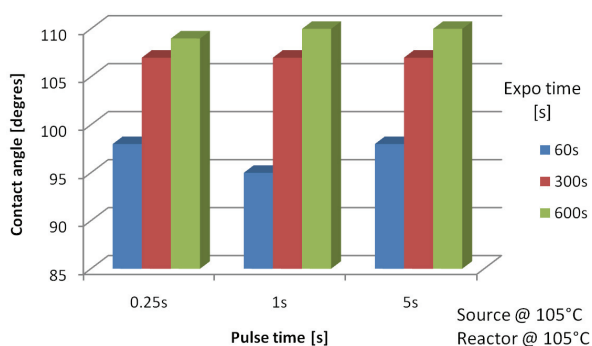
From a process perspective, vacuum-based deposition limits particle formation induced by parasitic interchain polymerization from residual water, a problem particularly acute with organosilanes. It also facilitates the evaporation /deposition of heavy molecules with lower vapor pressures.

## Contact angles for DTS on Al<sub>2</sub>O<sub>3</sub>

As illustrated in Fig. 2, the wetting properties of Al<sub>2</sub>O<sub>3</sub>-coated surfaces\* were successfully modified from hydrophilic to hydrophobic with a single 1s gas pulse of dodecyltrichlorosilane (DTS) followed by a 10 min. exposure\*\*. The deposition was performed in a Savannah S200 reactor at 105°C. Static contact angle reached the maximal reported limit of 110°.(Fig. 3)<sup>1</sup>

\* The Al<sub>2</sub>O<sub>3</sub> samples were coated as-is without preliminary cleaning.

\*\* Saturation time for organosilane in solution range from 12 to 48 h.<sup>2</sup>



• Figure 3: Contact angle for DTS SAMs deposited on Al<sub>2</sub>O<sub>3</sub> substrates at 105°C for varying pulse time and exposure times.

## Organic electronics

Organic electronics provide a low cost, technologically simpler alternative to high performance Si-based VLSI technologies. Expandable to large surface areas, organic Field Effect Transistors (OFETs) and Light Emitting Diodes (OLEDs) are being routinely integrated in flexible electronics, solar panels, displays and sensors.

Control of the interface properties using SAMs can lead to significant improvement of OFETs performances<sup>3</sup>. Janssen and al. have shown that molecule/substrate interaction energy can be controlled using interfacial SAMs to improve Pentacene crystal growth, resulting in improved device performances, e.g., higher mobility, smaller hysteresis and reduced V<sub>T</sub>.<sup>3</sup> Today the use of SAMs as gate dielectric is gaining attention as a result of its insulating properties, tunable thickness and process integration capabilities.<sup>4</sup> Using aromatic-terminated alkylsilane SAMs as gate dielectrics, OFETs devices exhibited a 1 cm<sup>2</sup>.V<sup>-1</sup>s<sup>-1</sup> mobility with 106 on/off ratio and sub-threshold slope of 100 mV/decade.<sup>5</sup>

## Anti-stiction coating for MEMS

As a consequence of their high surface-to-volume ratio, microelectromechanical systems are prone to in-use failure caused by stiction, the unintentional adhesion of surfaces to one another. Anti-stiction monolayers have been increasingly implemented in MEMS fabrication to minimize the surface energy. For bare SiO<sub>2</sub> and DTS-coated surfaces, work of adhesion on cantilever beam has been reportedly reduced from 20000 to 3 μJ/m<sup>2</sup>.<sup>6</sup> Silane-based SAMs were also shown to be effective for bio-MEMS devices by modifying the adsorption of protein under physiological conditions.<sup>7</sup>

## SAMs for biological applications

For over 20 years, Whitesides and others have demonstrated that inert and bio-specifically adsorbing surfaces with well-defined molecular characteristics can be patterned to selectively bind proteins and cells.<sup>1-8</sup> Today SAMS functionalized surfaces play a critical role for developing biochips and quantitative biochemical assays of protein binding and enzyme activity.<sup>9</sup> For example, Mrksich and al. have shown that arrays of immobilized carbohydrate chains on monolayers with benzoquinone group could be used to identify binding specificity of proteins.<sup>10</sup>

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Cambridge  
**NanoTech**  
Simply ALD

68 Rogers Street  
Cambridge, MA 02142

T: 617-674-8800

www.cambridgenanotech.com