Lecture 7, Part 1: Glass surfaces and coatings for biotechnology - Glass surfaces for biotechnology

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Glass Surfaces and Coatings for Biotechnology

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University Park, PA, USA
IMI – NFG Winter School, January 2008, Kyoto, Japan

Materials Research Institute
Center for Glass Surfaces, Interfaces and Coatings
Biomaterials and Bionanotechnology

lecture outline:

• relevant characteristics and properties of glass surfaces and coatings >>> introduction

• surface charge on flat glass substrates >>> substrates for cell transfer assays

• silane and hybrid sol/gel coatings >>> DNA and other microarrays

• carbon-doped “oxycarbide” glass >>> blood contact materials

• nanostructured coatings >>> engineered surfaces for biology, biomedicine and biotechnology

discussion and other applications:

• surfaces for pharmaceutical packaging
• superhydrophobic/superhydrophilic surfaces
• bio-active glasses and toxicity
Biomaterials and Bionanotechnology

Characteristics and Properties of Glass Surfaces and Coatings

- composition
- chemical functionality
- contact angle/wettability
- surface charge and other surface forces
- porosity/roughness/specific surface
- cleanliness and chemical durability
- uniformity of ALL the above
Methods of Characterization

- surface composition (XPS)
- depth profiling (SIMS)
- surface roughness (AFM)
- organic adsorbates (FTIR/Raman)
- chemical structure (NMR)
- ellipsometry
- surface charge (streaming potential)
- contact angle tensiometry
- adhesion (CFM)
Glass Surface Structure Models

- Clean silica surface
- Clean multi-component surface
- Hydroxylated silica surface
- Functionalized multi-component surface
Computer simulation of glass surfaces: their atomic/nanoscale heterogeneity, hydroxylation and organo-functionalization
Molecular Modeling of Water Interactions with Silica and Silicate Surfaces

Elam A. Leed and Carlo G. Pantano

Water Molecules Adsorbing on a Simulated Sodium Silicate Glass Surface
Leaching and surface layer formation:

- **a)**
  - Leached H-Glass Layer
  - Bulk Glass

- **b)**
  - Silica-Gel Layer
  - Leached H-Glass Layer
  - Bulk Glass

- **c)**
  - Silica-Gel Layer
  - Leached H-Glass Layer
  - Bulk Glass
Cubic Cell (22 Å)³
800 atoms

"relaxed" from 8000 K to 300 K (in 500 ps)
"relaxed" at 300 K (100 ps)

1 Bulk Glass Structure

Removal of above periodic boundary condition
"relaxed" at 300 K (200 ps)

Glass "Surface" Structure

Removal of: aluminum, calcium, and sodium

2 Simulated Surface Layer Structure Hydroxylation (charge neut.)

3 Hydroxylated Leached Glass Structure "condensed" at 300 K (200 ps) (2 OH's ~1.5 Å)

4 Leached Glass Structure
surface roughening by dissolution
Normalized dissolution rates vs. pH for sodium-aluminosilicate glasses in the NBO glass series.
Cell Transfer for Cervical Cancer Diagnosis
GYN cell transfer layer by SEM
Electrical double layer at the glass-water interface
Streaming potential determination of surface charge
Streaming Potential System for Flat Glass
Zeta potentials determined for the air and tin surfaces of soda-lime-silicate glass slides for $10^{-3}$ KCl solutions containing 100 ppm of AlCl$_3$ at different pH’s.
Surface compositions (by XPS) for the **aluminum-hydroxide sol/gel coated slides**, and the tin surface of an uncoated E slide for reference; Coating 5 was rinsed before the heat treatment.

<table>
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<th>Na (at%)</th>
<th>O (at%)</th>
<th>Sn (at%)</th>
<th>N (at%)</th>
<th>Ca (at%)</th>
<th>Mg (at%)</th>
<th>C (at%)</th>
<th>Cl (at%)</th>
<th>B (at%)</th>
<th>Si (at%)</th>
<th>Al (at%)</th>
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<td>0.2</td>
<td>0.0</td>
<td>0.1</td>
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<td>Coating 5</td>
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<td>54.2</td>
<td>2.2</td>
<td>0.2</td>
<td>1.4</td>
<td>1.5</td>
<td>10.9</td>
<td>1.3</td>
<td>0.3</td>
<td>16.1</td>
<td>5.5</td>
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<td>Tin Side</td>
<td>4.8</td>
<td>59.6</td>
<td>4.0</td>
<td>0.2</td>
<td>2.9</td>
<td>2.7</td>
<td>4.0</td>
<td>0.4</td>
<td>0.2</td>
<td>21.1</td>
<td>0.1</td>
</tr>
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</table>
Coated Glass Slides— inorganic and (commercial) organic coatings

![Graph showing zeta potential vs pH for different coatings and conditions.]

- Tin Side w/ 100 ppm AlCl3
- Air Side w/ 100 ppm AlCl3
- Soak 10,000 ppm AlCl3
- Coated

Materials Research Institute
IMI – NFG Winter School,
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Center for Glass Surfaces, Interfaces and Coatings
DNA Microarray: a glass-based biological sensor

Glass Substrate

OrganoFunctional Coating

Single strands of Oligonucleotides or DNA IMMOBILIZED at known locations

Glass substrates provide:
chemical inertness
optical platform
low fluorescence background
flatness and smoothness
low cost!
DNA Microarrays

A planar device comprised of an array of DNA single strands immobilized on the surface of an insoluble solid support.

**Solid support:**
- Glass slides
- Silicon
- Plastics, etc.

**Molecules:**
- Oligonucleotides, proteins, cells or tissues

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**SEGMENT OF THE MICROARRAY**
- 1x2 cm²
- # of spots = 100-500,000

**SPOT CONTAINING DNA Probes**
- (10-250μm)

**Immobile DNA Probe**
- For DNA arrays:
  - Each spot contains $10^6$ to $10^9$ of identical DNA fragments.
**DNA Structure: The Fundamentals**

- **Base-pair** appr. 3.5 Å
- **Sugar-Phosphate Backbone**
- **20 Å ≈**

**DNA is a linear polymer made up of a sugar and phosphate backbone with variable side groups of different nitrogen bases. (A, C, G, T)**

**DNA may be single or double stranded.**

**COMPLEMENTARY BASE PAIRING:**
Weak H-bonding between the base pairs

- G ↔ C
- T ↔ A

**(HYBRIDIZATION)**

<table>
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<th>T-C-A-G-G-T-T</th>
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<tbody>
<tr>
<td>A-G-T-C-C-A-A</td>
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</table>
DNA Microarrays (Gene Chips for sequencing)

Unknown DNA solution with fluorescent dyes.

Apply to pre-made DNA Microarray

Each spot contains identical DNA probes of different known sequence.

Laser Confocal Scan

Unknown DNA molecules attach to their complementary probes.

The sequence of the unknown strand is now determined.

i.e. Array probe

i.e. Unknown probe
Use of Microarrays: Gene Expression Experiment
Use of Microarrays: Drug Discovery

Untreated cells

Extract RNA

Reverse transcript to cDNA

Fluorescent labeling

Drug-applied cells

Apply to array

Scan

Image Analysis for Quantification
Protein Arrays: Diagnostic Analysis

- Squares of antibodies able to bind a specific protein representing a disease-causing agent.
- Apply blood to the array of antibodies → proteins from blood attach
- Apply fluor-labeled antibodies recognizable by the attached proteins, forming a antibody “sandwich”
- Dot indicating that the patient has anthrax.

Anderson and Valkirs, Scientific American, 2002
Multiple Surface Chemistries Provide Opportunities for Immobilization of Various Probes

**Surface Coatings**

- **Amino**
  - NH$_3$ + NH$_3$ + NH$_3$

- **Epoxy**
  - O(CH$_2$)$_2$O(CH$_2$)$_2$O(CH$_2$)$_2$

- **Aldehyde**
  - C-H + C-H + C-H

**Recommended Probes**

- PCR products
- Long oligos (size $\geq$ 50 mers)
- Short and long oligos
- PCR products
- Peptides
- Short and long NH$_2$-modified oligos
- NH$_2$-modified PCR products
- Antibodies

and in addition to DNA arrays/probes:
- ELISA's
- Protein arrays
- Carbohydrate arrays
- Chem-Bio Sensors
Unmodified DNA strands carry intrinsic (PO$_4$)$_3^-$ groups; glass surfaces functionalized with protonated amino groups (NH$_2$) can be used for their initial immobilization.
Because of the ease of use and affordability, microspotting has become the most common microarray technology for basic research.
Physical Chemistry/Engineering of the Microspotting Process

- Air-bubble entrapment
- Air/water interface
- Dissolved air
- Aggregation
- Outgassing
- Wetting
- Clogging
- Priming
- Cross-contamination
- Drop stability
- Volume reproducibility
- Directional stability
- Microfluidics
- Immobilization
- Contact angle
- Saturation

- Evaporation
- Adsorption
- Concentration
- Viscosity
- Microorganisms
- Oxidation (pH)
- Temperature
- Denaturation

Air/water interface:
- Surface/volume ratio
- Evaporation
- Adsorption
- Denaturation
- Surface tension
- Diffusion
- Drop-broadening
- Crystallization
- Aggregation
- Drying