Silicon and Non-Silicon Materials for BioMEMS Fabrication

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• Short presentation of the Tyndall National Institute, Cork, Ireland;

• Material properties of common polymer substrates;

• Polymer materials and fabrication;

• Evaluation of polymer materials vs. silicon for fabrication of BioMEMS microdevices;

• Properties of different types of polymers

• Examples of existing BioMEMS microdevices for DNA extraction manufactured in polymers;

• Concluding remarks.
• Established in 2004
• Brings together researchers in:
  - Photonics
  - Microelectronics
  - Materials
  - Microsystems
• Originally from the National Microelectronics Research Centre (NMRC), University College Cork (UCC) and Cork Institute of Technology (CIT)
• 300 research engineers, scientists and students
• Creates a critical mass of researchers in the field of ICT
John Tyndall, 1820 - 1893

- Born in Leighlinsbridge, Co. Carlow 1820
- Prof. of Natural Philosophy, Royal Institution 1853
- Succeeded Faraday as Director of the Royal Institution 1863
- Initiated the practical teaching of science in schools
- Developed spectroscopy
- Invented the light pipe
- Tyndall Scattering - explained why the sky is blue
- Tyndallisation - sterilisation process
- Studies of the atmosphere and the ozone layer
Mission Statement:

‘Tyndall will be a Centre of Excellence in Information and Communications Technology materials, devices and systems research, development and graduate education, recognised internationally for the quality of its outputs and its creation of new opportunities for Ireland’s economic growth.’
“from atoms to systems”
“From atoms to systems ……

…… creating value from research”

- Promoting excellence in Irish research and development and attracting the best in international researchers
- Promoting the pull-through to exploitation of the outputs from research
- Working with Irish industry to set the agenda for ICT R&D in Ireland
- Encouraging Irish manufacturing industry to invest in R&D in Ireland
- Producing well-trained postgraduate engineers and scientists to go into Irish industry
- Outreach in science and engineering
Tyndall

- Broad materials and device processing capabilities, coupled with very strong theoretical understanding of nanoscale electronic devices
- Strong activity in Photonic materials, systems and devices
- Strong activity in microsystems, especially for RF sensor modules and life-sciences interface
- ISO9000 fab with full CMOS process capability
- Good understanding of the issues involved in putting new materials and processes into practice in real devices
- Strong motivation to put the devices and systems work into products and industrial applications
<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical transparency</td>
<td>Can be transparent or opaque to different wavelengths</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>0.1-0.2 W/mK</td>
</tr>
<tr>
<td>Specific heat</td>
<td>~ 1200 - 1500 J/KgK</td>
</tr>
<tr>
<td>Electric conductivity</td>
<td>Can be an insulator or a (semi)conductor</td>
</tr>
<tr>
<td>Fabrication technology</td>
<td>A diversity of fabrication processes available depending on requirements relating to feature size, material properties, throughput, etc.</td>
</tr>
<tr>
<td>Density</td>
<td>~ 900 - 1300 Kg/m³</td>
</tr>
<tr>
<td>Mass production</td>
<td>Many polymer materials are very compatible with low cost, high throughput fabrication processes.</td>
</tr>
<tr>
<td>Cost of raw materials</td>
<td>~ 1 cent/cm²</td>
</tr>
<tr>
<td>High temperature sterilization</td>
<td>Tendency to deform</td>
</tr>
<tr>
<td>Biocompatibility</td>
<td>Dependent on the specific polymer</td>
</tr>
</tbody>
</table>
## Silicon vs. Polymer

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Polymer</th>
<th>Silicon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical transparency</td>
<td>Transparent or opaque, may absorb the UV light</td>
<td>Opaque</td>
</tr>
<tr>
<td>Thermal conductivity [W/mK]</td>
<td>0.1-0.2</td>
<td>148</td>
</tr>
<tr>
<td>Specific heat [J/KgK]</td>
<td>~ 1200 - 1500</td>
<td>700</td>
</tr>
<tr>
<td>Electric conductivity</td>
<td>Insulator or (semi)conductor</td>
<td>Semiconductor</td>
</tr>
<tr>
<td>Fabrication technology</td>
<td>Available, high processability</td>
<td>Available from IC industry</td>
</tr>
<tr>
<td>Density [Kg/m³]</td>
<td>~ 900 - 1300</td>
<td>2320</td>
</tr>
<tr>
<td>Mass production</td>
<td>Yes, slow processes, high cost</td>
<td>Yes, fast processes, low cost</td>
</tr>
<tr>
<td>Cost of row materials</td>
<td>~ 1 cent/cm²</td>
<td>~ 1 $/cm²</td>
</tr>
<tr>
<td>High temperature sterilization</td>
<td>Tend to deform</td>
<td>Yes</td>
</tr>
<tr>
<td>Biocompatibility</td>
<td>Depends on polymer</td>
<td>Yes (needs surface modification)</td>
</tr>
</tbody>
</table>
### Properties of different types of polymers

<table>
<thead>
<tr>
<th></th>
<th>PMMA</th>
<th>PC</th>
<th>COC</th>
<th>Polyimide</th>
<th>PS</th>
<th>PDMS</th>
<th>Polyaniline</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Polymer type</td>
<td>Thermo-plastic</td>
<td>Thermo-plastic</td>
<td>Thermo-plastic</td>
<td>Thermo-plastic</td>
<td>Elastomer</td>
<td>Thermo-plastic</td>
</tr>
<tr>
<td>2</td>
<td>Density $[g/cm^3]$</td>
<td>1.16</td>
<td>1.2</td>
<td>1.02</td>
<td>1.39</td>
<td>1.05</td>
<td>1.227</td>
</tr>
<tr>
<td>3</td>
<td>Glass temperature $[^\circ C]$</td>
<td>106</td>
<td>150</td>
<td>90-136</td>
<td>285</td>
<td>100</td>
<td>-127</td>
</tr>
<tr>
<td>4</td>
<td>Useful temp. range $[^\circ C]$</td>
<td>-70-100</td>
<td>-150-130</td>
<td>-73-80</td>
<td>-73-280</td>
<td>-40-70</td>
<td>-40-150</td>
</tr>
<tr>
<td>5</td>
<td>Mold (linear) shrinkage</td>
<td>0.001</td>
<td>0.005-0.007</td>
<td>0.001</td>
<td>0.0083</td>
<td>0.004-0.006</td>
<td>0.001-0.006</td>
</tr>
<tr>
<td>6</td>
<td>Linear expansion coefficient $[x10^{-6}\cdot ^\circ C]$</td>
<td>50-90</td>
<td>68</td>
<td>60</td>
<td>46-56</td>
<td>70</td>
<td>10-19</td>
</tr>
<tr>
<td>7</td>
<td>Thermal conductivity $[WmK]$</td>
<td>0.186</td>
<td>0.21</td>
<td>0.16</td>
<td>0.2</td>
<td>0.18</td>
<td>0.17-0.3</td>
</tr>
<tr>
<td>8</td>
<td>Dielectric Strength $[MV/m]$</td>
<td>16-20</td>
<td>15-16</td>
<td>-</td>
<td>16-22</td>
<td>19-135</td>
<td>16-22</td>
</tr>
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</thead>
<tbody>
<tr>
<td><strong>Optical properties</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9 Transmission of visible light [%]</td>
<td>92</td>
<td>89</td>
<td>92-94</td>
<td>87</td>
<td>90</td>
<td>91</td>
<td></td>
</tr>
<tr>
<td><strong>UV resistance</strong></td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Poor</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td><strong>Chemical resistance</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 Acid</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Fair-good</td>
<td>Good</td>
<td>Fair-good</td>
<td>Good</td>
</tr>
<tr>
<td>12 Alkalis</td>
<td>Excellent</td>
<td>Poor</td>
<td>Good</td>
<td>Fair-good</td>
<td>Good</td>
<td>Poor-Fair</td>
<td></td>
</tr>
<tr>
<td>13 Solvent</td>
<td>Poor</td>
<td>Poor</td>
<td>Fair-poor</td>
<td>Fair</td>
<td>Poor</td>
<td>Poor</td>
<td>Good</td>
</tr>
<tr>
<td>14 Surface charge (native surface)</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>15 Possible fabrication methods</td>
<td>Injection, molding, hot embossing, laser ablation</td>
<td>Injection, molding, hot embossing, laser ablation</td>
<td>Injection, molding, hot embossing</td>
<td>Injection, molding, hot embossing, laser ablation</td>
<td>Hot embossing</td>
<td>Soft lithography</td>
<td>Injection, molding, Electropolymerisation</td>
</tr>
</tbody>
</table>
Melt processing
- Hot embossing
- Injection moulding
- Extrusion
- Blow moulding
- Fibre spinning
- Soft lithography
- Optical lithography in deep resists
- Laser photoablation
- X-ray lithography
- Compression moulding

Solution processing
- Coating - films
- Spraying
- Solution spinning - fibres
- Electrospinning - fibres
- Spin coating - films
- Electropolymerization
DNA Extraction microdevices manufactured in polymer materials

Policarbonate, 8x40x70 mm

a) Anderson (Affymetrix Inc.)
Nucleic Acid Research, 28 (12), I-VII

b) Quake et al, Nature Biotech., 4, 438-439, 2004

PDMS
DNA Extraction and Amplification Module

- FP6, IST Program, MICRO2DNA project
Microchannel in PDMS with metallized SiC fiber microelectrodes

- Additive technique for metallization of microfluidic structures manufactured in PDMS

a) Contact resistance < 0.1 ohm; b) contact resistance > 20 Gohm

- FP6, IST Program, MICRO2DNA project
• Entraping DNA at specific sites
Hybridization chamber prototyped in PDMS

- Laminar flow inside of a hybridization chamber

Channels in PDMS

Outlet

Inlet
Flow profile
Flow profile
Flow profile
Flow profile
Flow profile
Flow profile
Flow profile
Flow profile
Flow profile
DNA Hybridisation: fluorescent detection

1-st hyb

2-nd hyb

3-rd hyb.

4-th hyb.

5-th hyb.
Conclusions

• Polymers are becoming very promising materials used for the fabrication of BioMEMS having advantageous properties of low cost, easy processability and wide range of material characteristics.

• BIOMEMS type devices will revolutionize the diagnostic tests through the development of compact, potentially disposable, automated systems that can be used in clinical laboratory or a POC setting.
Thank you for your attention