Transdermal Skin Patch
Drug Delivery Devices

Emily McBride
August, 2007

Transdermal Patches: Applications

<table>
<thead>
<tr>
<th>Type</th>
<th>Reservoir</th>
<th>Monolithic</th>
<th>Drug-In-Adhesive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure</td>
<td>Backing layer + Drug reservoir layer + Rate-controlling layer + Adhesive polymer matrix</td>
<td>Backing layer + Drug reservoir layer + Adhesive polymer matrix</td>
<td>Backing layer + Adhesive polymer matrix (containing drug)</td>
</tr>
</tbody>
</table>

Transdermal Skin patches are drug delivery devices that are applied to the skin to deliver medication directly into the bloodstream. They are typically used for chronic conditions where continuous medication is necessary, such as insulin for diabetes. Transdermal patches are more convenient than traditional oral medication, as they do not require daily administration and can be left on for an extended period. They are also useful for patients who have difficulty swallowing pills or tablets. Examples of transdermal patches include nicotine patches for smoking cessation and contraceptive patches.
### Transdermal Patches: Treatments

- Parkinson’s Disease
- Sleep Aid
- Quitting Smoking
- Depression
- Local Anesthetics
- Testosterone Deficiency
- Immunization
- Pain Management
- Hypertension
- Weight Loss
- Male “Enhancement”

### Transdermal Patches: Materials and Properties

- **Porous Membrane:** microporous polypropylene/nylon/polycarbonate
- **Drug:**
  - Found in adhesive or reservoir
  - May be combined with skin penetration enhancers (alcohols, glycols, urea) and anti-irritants
  - Small size required for standard transdermal patches; larger size molecules can be diffused using microneedles and iontophoresis or phonophoresis
- **Adhesive:** natural or synthetic rubbers, polyacrylates, silicone
  - Pressure sensitive
  - Chemically stable
  - Biologically inert
  - Retains adhesion in presence of moisture
- **Microneedles:** Metal, glass, degradable plastic, or silicon
- **Release Liner:** Paper, polystyrene, polyethylene, or polyester
- **Backing:** Foil, polyethylene coated foil, polyethylene, Mylar polyester, polypropylene
  - must be breathable, allow evaporation of moisture, and not cause skin irritation
Transdermal Patches: Materials and Properties, Cont.

- Thin, layered film
- Thinnest, most flexible option has drug incorporated in adhesive
- Slightly larger when drug is across a membrane (adhesive layer is along the outer edges)
- Variety of shapes (square, rectangle, oval, circle, etc.)
Transdermal Patches: Typical Product Geometries Cont.

Transdermal Patches: Key Processing Methods

- SU-8 Photoresist Mold Processing
- Film Extrusion
- Slot Bead Coating
- Solvent Casting
**Transdermal Patches:**
**Key Processing Methods, Cont.**

**SU-8 Photoresist Mold Processing**
- SU-8 molds fabricated on top of glass handle wafers
- SU-8 heights range from 50 µm-200 µm
- Allows for rapid prototyping

**Transdermal Patches:**
**Key Processing Methods, Cont.**

**Slot-Bead Coating**
- Tight die lip-to-web clearance (50 µm-1000 µm)
- Small 2-D transfer flow
- Wide range of coating thicknesses (10 µm-500 µm)
- Used extensively in coating suspensions
Transdermal Patches:
Key Process Design Equation

\[- \frac{dp}{dx} = q^n \left( \frac{w_1}{w_i} \right)^{2n+1} \beta \left( \frac{T_w - T_0}{T_i} \right)\]

Pressure drop/flow rate equation in the slot section.

- \(w_i\): slot gaps
- \(q\): dimensionless flow rate per unit die width
- \(n\): power-law index
- \(\beta\): material constant
- \(T_w\): wall temperature
- \(T_0\): reference temperature
- \(T_i\): dimensionless temperature

Transdermal Patches:
Key Processing Issues

- Shrinking of processed polymers
- Consistency in film thickness
- Drug molecule size
- Cohesion of multiple layers
- Compatibility and mixing of drug with adhesive (solubility)
References

- http://images.google.com/imgres?imgurl=http://www.weightlosscenter.co.uk/slim_steady/dermopatch.jpg&imgrefurl=http://www.weightlosscenter.co.uk/slimsteady.asp&w=150&h=318&tbnid=kZFq7WLSEJSKBM:&tbnh=108&tbnw=78&prev=/images%3Fq%3Dtransdermal%2Bpatch%26start%3D80%26gbv%3D2%26ndsp%3D20%26svnum%3D10%26hl%3Den%26sa%3DN
- http://img.shopping.com/cctool/PrdImg/images/pr/177X150/00/01/ec71/b1/32272817.JPG
- http://membership.acs.org/C/coll/DCabstracts.html
- http://www.mylantech.com/images/transdermal/estradiol_patch_0.025.jpg

Artificial Pancreas

Shannon Williamson
Polymer Processing Summer 2007
Application Needs

- Currently patients with Diabetes have no transplant options that don’t include immunosuppression drugs
- A polymer system is under investigation to provide a suitable matrix for transplant of islet cells
- This system would eliminate the need for suppression drugs
Application Needs

A system must be:
- Geometrically optimized for cell transplant
- Mechanically robust
- Chemically compatible with human tissue
- Allow for diffusion of insulin
- Resistant to immune system attack

Materials & Properties

Linear Model
- Macro-encapsulation of cell clusters
- Acrylic based hollow fibers or flat sheet membrane
- Fabricated from thermoplastics
- Controlled MW cut-off to exclude inward diffusion
Materials & Properties

Spherical Model

- Micro-encapsulation of cell clusters
- Polyelectrolyte interaction to create “gel capsule”
- Polyethylene glycol is also being used for this type of coating
- Semi-permeable membrane created at surface to prevent inward diffusion

Product Geometry

Source: http://www.biomed.metu.edu.tr/courses/term_papers/AycaMuvaffak_files/image002.jpg
Product Geometry

Source: http://www.isletmedical.com/pages/science_bioartificial.htm

Key Methods

- Linear Model
  - Polymetric membrane co-extruded with an inner biological stream
  - Both are extruded through a common port having at least two concentric bores
  - Creating an outer polymetric surface filled with biological material at the same time
Key Methods

Spherical Model
- Cells are suspended in a dye and placed in polymeric solution
- The solution is excited with a laser creating uniform polymerization; creating a conformal coat
- Novocell is testing PEG coatings but no process information was available

Process Design Equations

The linear model could have an equation similar to that of an extruder model equation:

\[ Q = \frac{VW(h-\sigma)}{2}(F_d) + (Wh^3/12\eta_p)(-\frac{\delta p}{\delta z})F_p(1+f_l) \]

-I am unsure as to how I would model the spherical system due to its difference from standard manufacturing practices
Processing Issues

**Macro-Encapsulation**
- Mechanically stable but requires a low packing density
- Low packing density means to scale up to human trials ~50m of material would have to be used
- Wall thickness is still an issue; causing unwanted release of insulin in a short amount of time

**Processing Issues**

**Micro-encapsulation**
- Ideal shape for diffusion
- Polyelectrolytes are mechanically fragile and chemically unstable
- PEG coatings sound more successful, but I wonder about type of processing
- Rupture Issues
- Difficult to remove after implantation
References

1. US Patent number: 6080412 Date: 06/27/00 Inventor: Patrick Aebischer, Oliver Jorday, Jean-Francois Clemence Title: Pharmaceutical Microencapsulation

2. US Patent number: 5418154 Date: 05/23/95 Inventor: Patrick Aebischer, John F. Mills, Lars Wahlberg, Edward J. Doherty, Patrick A. Tresco Title: Method of Preparing Elongated Seamless Capsules Containing Biological Material


Polymers in Remediation

Christen Glarborg

8/16/2007
Applications

- Soil
  - Ex situ and In situ applications
  - Gels, membranes

- Water Remediation
  - Gels, membranes

Materials

- Types of polymers used:
  - Polyacrylic acid/Polyvinylidene Fluoride
    - PVDF – resistant to solvents, acids and bases
  - Polycrylate – High molecular weight
    - Super absorbent
Product Geometries

- PVDF
  - Tubular
  - Spiral Wound
  - Flat Sheet
- Acrylics
  - Hollow fiber

Processing

- PAA/PVDF
  - PVDF membrane
  - PAA coating
  - Ethylene glycol crosslinker
  - Bi-metallic nanoparticles
Processing

- Polyacrylates (High molecular weight)

  - Purchased polymer
    - Molecular weight 40 million
    - No crosslinking
    - Potassium counter ion

Process Design Equations

- Membrane equations

\[ J = \frac{\text{TMP}}{R_m + R_g + R_f} \]

- TMP = Transmembrane Pressure
- \( R_m \) = Resistance of flow through the membrane
- \( R_g \) = Resistance of flow through the gel polarization layer
- \( R_f \) = Resistance of flow due to membrane fouling
Processing Issues

- Environmentally stable polymers
- Removal of polymer after use
- Economic feasibility

References

POLYMER/CLAY NANOCOMPOSITES

Nuh M. Simitcioglu

Outline

- History
- Components
- Process
- Applications
- Research
HISTORY

- Conventionally polymer matrix filled w/ 20-40 wt.% glass fiber, talc, CaCO$_3$, C, etc.
- Not homogenously mixed, small interface, interaction is limited
- Typically problems fiber pull-out, delamination, wetability of matrix, distribution

History

- Hybrid composite concept w/ molecular size filler (Takayanagi et al.)
- Nylon matrix w/ 5 wt. aramide fiber
- Toyota proposed nano dimension clay mineral
Components

- Montmorillonite (MMT), a smectite clay mineral platelet type molecular filler
  - composed of several layers of silicates
  - 1 nm thick, 100 nm² surface area
  - Extremely smaller than the regular fillers
  - well-known intercalation properties w/ H₂O and organic cations
Components

- **Nylon-6**
  - a caprolactam
  - tough, possessing high tensile strength
  - high elasticity and lustre,
  - highly resistant to abrasion, chemicals like acids, alkalis, etc.,
  - wrinkle proof,
  - typical engineering polymer of auto industry
Caprolactam

- **Caprolactam** is an [organic compound](https://en.wikipedia.org/wiki/Organic_compound) which is a cyclic [amide](https://en.wikipedia.org/wiki/Amine) (or [lactam](https://en.wikipedia.org/wiki/Lactam)).


Components

- **Polymerization**

  - when heated at about 533 K in an inert atm of N₂ for about 4-5 hours, the ring breaks

![Polymerization Reaction](image1.png)

```
\[
\text{Caprolactam} \xrightarrow{533\text{K}} \text{Polymer}
\]

\[
\text{O} \quad \text{N} \\
\text{CH}_2 \quad \text{CH}_2 \quad \text{CH}_2 \quad \text{CH}_2 \quad \text{H} \\
\text{C} \quad \text{C} \\
\text{CH}_2 \quad \text{CH}_2 \quad \text{CH}_2 \quad \text{CH}_2 \quad \text{H} \\
\text{C} \quad \text{C} \\
\text{CH}_2 \quad \text{CH}_2 \quad \text{CH}_2 \quad \text{CH}_2 \\
\text{N} \\
\text{O}
\]
Intercalation

*intercalation reaction*

A reaction, generally reversible, that involves the introduction of a guest species into a host structure without a major structural modification of the host. In the strictest sense, intercalation refers to the insertion of a guest into a two-dimensional host; however, the term also now commonly refers to one-dimensional and three-dimensional host structures.

Example:

The insertion of lithium into layered TiS$_2$:

\[ x \text{Li} + \text{TiS}_2 \rightarrow \text{Li}_x\text{TiS}_2 \quad (0 \leq x \leq 1) \]

Synonymous with *insertion* reaction.

1994, 66, 583; R.B. 79


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Processing

**Conventional Micro-Composite Approach**

- Clay Aggregates
- Polymer

Breaking Aggregation

Conventional Composites

**Nanocomposite Approach**

- Clay Aggregates
- Polymer

Breaking Aggregation

Nanocomposites
Processing

Methods
- In situ polymerization
- Solution induced intercalation
- Melting process

In Situ Polymerization
- inserting a polymer precursor between clay layers
- expanding and dispersing the layer into the matrix
- well-exfoliated PNCs
- can be applied a wide range of polymer systems
- good for raw polymer producers
Processing

- Solution induced intercalation
  - uses a solvent to swell and disperse clays into a polymer solution
  - high cost solvents required
  - separation of the synthesized product from solvent costly
  - health and safety issues

Processing

- Melt processing
  - traditional methods can be used
  - induces the intercalation of clays and polymers during melt
  - clay distribution not homogeneous
  - not as efficient as in-situ polymerization
  - good for industry to speed up
### Applications

- Timing belt cover (Toyota, 1991),
- Engine cover (Mitsubishi GDI)
- Chevrolet Impala doors (GMC, 2001)
- Drink packaging (Aegis)
- Multilayered PET bottles (Nanocor)

### Current Research

- Liquid Crystal-Clay composites, ability to control the structure and properties by controlling the layers of block co-polymer,
- Fire retardant properties without deterioration of polymer properties,
- Nanocomposite hydrogels, using clay as crosslinker.
Metamaterials

By Morgan Pilkenton

Application Needs

Current Applications and Uses
- significantly improved radar resolution
- substantial decrease in microchip size
  - “left hand” materials
  - Lenses
  - Antennas
Future and Theoretical uses

- Cell sized biomedical imaging
- Invisibility Clocking
- Wide range of lens applications
- Electronic applications

Materials and Properties

- Molds are made out of Silicon dioxide and Silicon
- Polymethyl methacrylate (PMMA)
  - Small thermal expansion
  - Small shrink Coefficient
Probable Composition

- cadmium–telluride
- Au-Ag
- Other metals
- Polymers?
- Still Secret!

Geometry

- Metamaterials are planer structures
- Designed to have a negative refractive index

\[ \eta = -\sqrt{\mu \varepsilon} ; \mu < 0, \varepsilon < 0 \]

For a complete list goto: http://www.metamorphose-eu.org/Metamaterial_Applications.40.0.html
Geometry Continued

Metamaterials obtain functionality from structure not chemical makeup.

Size of pattern is what determines which wavelengths the property will be sensitive to.

Red light is currently the smallest functional wavelength.

Most applications are currently in the microwave region.

Processing Methods

Synthesized using Nanoimprint Lithography

1. Press Mold
2. Remove Mold
3. RIE
Nanoimprint Lithography

Important Equations

Navier-Stokes equations, important for polymer flow properties inside the mold:

\[ \rho \left( \frac{\partial \mathbf{v}}{\partial t} + \mathbf{v} \cdot \nabla \mathbf{v} \right) = -\nabla p + \mu \nabla^2 \mathbf{v} + \mathbf{f} \]

Inertia

Unsteady acceleration

Convective acceleration

Pressure gradient

Viscosity

Other forces

Velocity of polymer flowing between walls of the mold pattern:

\[ u_x = \frac{1}{2 \mu_T} \left( \frac{dp}{dx} \right) (y^2 - 2y) \]
Important Physical Properties

Relationship between \( d \) (depth of mold) and embossing time \( T \)

\[
d(t) = \frac{L}{2} \sqrt[5]{\frac{P}{\mu(t)}} \times T
\]

Take home from these equations
- Time (\( T \))
- Pressure (\( P \))
- Viscosity (\( \mu \))

Key Issues in Processing

- High temperature required
- High pressure required
- Needs to be done in a vacuum
- Speed of production
- Size of production
- Cost
Summary of Metamaterials

- Metamaterials have a wide variety of uses
- Are created through Nanoimprint Lithography
- Pressure, Temperature, and Viscosity dependent
- Contain a planar structure
- Are becoming easier to produce but still expensive

References

- [Link to Research Overview](http://xlab.me.berkeley.edu/MURI/Research_Overview.htm)
- [Link to Metamaterial Applications](http://www.metamorphose-eu.org/Metamaterial_Applications.40.0.html)
- [Link to Science Direct](http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V0W-4FMVSH-1&_user=2148430&_coverDate=04%2F30%2F2005&_rdoc=1&_fmt=&_orig=search&_sort=d&_acct=C000056308&_version=1&_userid=2148430&md5=56bcaaa17d7f79e8500f93aaf8821755a)
- [Link to Nature](http://www.nature.com/nature/journal/v446/n7134/full/446364a.html)
- [Link to Images](http://images.google.com/images?imgurl=http://sagar.physics.neu.edu/lhm-2.jpg&imgrefurl=http://sagar.physics.neu.edu/metamaterials.htm&h=113&w=181&sz=43&hl=en&start=134&tbnid=wAGLC66tLn3I2M:&tbnh=63&tbnw=101&prev=/images%3Fq%3Dmetamaterial%26st art%3D120%26ndsp%3D20%26svnum%3D0%26saN%26hl%26safe%3Doff%26client%3Dfirefox-a%26rls%3Dorg.mozilla:en-US:official%26hs%3DNNC&sa=N)
- [Link to Hampton Roads](http://content.hamptonroads.com/story.cfm?story=105487&ran=132986)
- [Link to Science Daily](http://www.sciencedaily.com/releases/2007/01/070104144655.htm)
Artificial Knee Joints

Jan Trenkel
Mid-Term Presentation

What a Knee Needs to Do

• The knee is made up of three bones: Femur, Tibia and Patella. These bones provide the rigid structure of the joint
• Cartilage covers the ends of the bones. It cushions and protects them while allowing near frictionless movement.
• While commonly referred to as a hinge joint the knee does more than flex and extend. There is also a slight rotational component in this motion.
To Make a Knee…Historically

- The earliest arthroplasty procedures were attempted in the 1860’s.
- The first materials used in making artificial knees included skin, muscle, fascia, fat, rubber, ivory and glass.
- Early procedures had a very high failure rate due to material incompatibility, wear, infection and loosening of the components.
- The first metal-on-plastic knee replacement was put into use in 1968.

To Make a Knee… Today

- Today most artificial knees are made of cobalt-chromium alloy and UHMWPE.
- Functionally the alloy replaces the bone while the UHMWPE replaces the cartilage.
- Common failure mechanisms
  - Structural failure or fatigue of PE in non-conforming knee joints
  - UHMWPE wear particles released into the tissues cause adverse cellular reaction resulting in bone resorption and loosening.
Typical Geometries of Fake Knees

Processing of a Knee

- UHMWPE can be formed using:
  - Direct compression molding
  - Machining
- The different manufacturing processes typically utilize different UHMWPE resins
- Differences in fabrication lead to difference in clinical wear behavior

<table>
<thead>
<tr>
<th></th>
<th>Density</th>
<th>Tensile Yield</th>
<th>Ultimate Tensile Strength</th>
<th>Elongation to Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extruded GUR 1020</td>
<td>935</td>
<td>22.3</td>
<td>53.7</td>
<td>452</td>
</tr>
<tr>
<td>Molded GUR 1020</td>
<td>935</td>
<td>21.9</td>
<td>51.1</td>
<td>440</td>
</tr>
</tbody>
</table>
Before Machining

- UHMWPE isn’t the easiest polymer to process.
- Semi-finished UHMWPE is produced by
  - Compression molding
  - Ram Extrusion

Machining

- Idealized model for the surface morphology of as-machined UHMWPE as a triangular wave:

  \[ d = \frac{f}{2s} \]

  - \(d\) – peak to peak distance
  - \(f\) – tool feed rate
  - \(s\) – cutting speed

Machining marks in as-machined GUR 1050 UHMWPE
Direct Compression Molding

• Typical Processing conditions:
  – Power fill height is 2.0-2.2 times the intended sheet thickness
  – Centerline temp of sheet: 190-200°C at 70 to 100 bar
  – Sintering time: 1 hr per 10 mm of sheet thickness
  – Cooling time: 50% of sintering time

Processing Issues

• There are multiple methods of processing currently in use – Which one is best?
  – Machining:
    • Ram Extrusion or or slab compression molding may not produce uniform conditions in the compacted mass.
    • Machining marks add to surface roughness which affects lubrication, friction and surface deformation
  – Direct compression molding
    • if the surface is overheated it may exhibit more rapid wear.
    • Expensive/not suitable for prototype
Polymer Applications in Medical Sutures

Anthony Galvan
MSI 2007
Professor: Sundar Atre

Suture History

• In ancient India, physicians used the heads of beetles or ants to effectively staple wounds shut. The live creatures were affixed to the edges of the wound, which they clamped shut with their pincers. Then the physician cut the insects’ bodies off, leaving the jaws in place.¹

• Other natural materials doctors used in ancient times were grass, cotton, silk, pig bristles, and animal gut (ie: catgut).¹
Basic Suture Requirements

- No inflammatory or toxic response.
- Sterile.
- Knot easily and securely.
- Lowest tissue drag.
- Design aspects include: configuration, diameter, capillarity, fluid absorption, tensile strength, elasticity, plasticity, and memory.\(^8\)

Suture Options

- Absorbable or Non-absorbable.
- Monofilament or Braided.
- Natural and/or Synthetic.
- Expected Suture Lifetime.
Characteristics of Absorbable Sutures

<table>
<thead>
<tr>
<th>Property</th>
<th>Gut</th>
<th>Polyglycolide Acid</th>
<th>Polyglactin</th>
<th>Polydioxanone</th>
<th>Polytrimethylene Carbonate</th>
<th>Polyglycaprone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Handling</td>
<td>Fair</td>
<td>Fair-good</td>
<td>Good</td>
<td>Poor</td>
<td>Good</td>
<td>Excellent</td>
</tr>
<tr>
<td>Knot security</td>
<td>Poor</td>
<td>Fair-good</td>
<td>Fair</td>
<td>Poor</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Moderate</td>
<td>High</td>
<td>High</td>
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<tr>
<td>Protolysis at 60-90 days, unpredictable</td>
<td>High</td>
<td>Hydrolysis at 90-120 days</td>
<td>Hydrolysis at 60-90 days</td>
<td>Hydrolysis at 180-210 days</td>
<td>Hydrolysis at 180-210 days</td>
<td></td>
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<tr>
<td>Coefficient of friction</td>
<td>--------</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Memory</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Tissue reactivity</td>
<td>High</td>
<td>Low-moderate</td>
<td>Low-moderate</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Uses</td>
<td>Sutures in mucosal tissues, vessels</td>
<td>Buried sutures</td>
<td>Buried sutures</td>
<td>Buried sutures in wounds requiring longer dermal support</td>
<td>Buried sutures in wounds requiring longer dermal support</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>--------</td>
<td>Low elasticity</td>
<td>Low elasticity</td>
<td>--------</td>
<td>High elasticity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>--------</td>
<td>Clear or green</td>
<td>Clear or violet</td>
<td>Clear or green</td>
<td>Clear</td>
<td></td>
</tr>
</tbody>
</table>

Synthesis of polylactic acid (PLA) (D&L)

**Synthesis of polyglycolide (PGA)**

**Synthesis of polydioxanone**

**Synthesis of polyglyconate**

Absorbable Sutures Chemistry

**Synthesis of poly(-caprolactone)**

**Synthesis of poly(lactide-co-glycolide)**
Medical Polymer Processing

- Only FDA approved materials should be used for construction.
- 316 or 316L stainless steel are typically used on product contact surfaces and 304 or 304L are commonly used on frames or non-contact areas.
- Gaskets and seals are typically white and FDA approved polymers.
- Surface finish requirements vary, but typically a #8 finish with electro-polish is used for contact and a 2B or #4 finish is used for exterior surfaces.
- Welds are always sanitary continuous, ground smooth and free of pits, cracks, burrs or inclusions.
- Welds must be passivated to avoid the possibility of rust or contamination.

Fiber Processing

- Wet Spinning (submerged spinnerets, precipitate fibers)
- Dry Spinning (fibers dried in gas flow)
- Melt Spinning (fiber in full-melt)
- Gel Spinning (fiber only in partial melt)
Current Absorbable Sutures

- Coatings, drag reduction
- Anti-biotic Coatings
- Copolymers

<table>
<thead>
<tr>
<th>Current Absorbable Sutures</th>
<th>Polyglycolic Acid</th>
<th>Dexon S</th>
<th>Davis &amp; Geck</th>
<th>Homopolymer of glycolic acid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyglycolic Acid</td>
<td>Dexon S</td>
<td>Davis &amp; Geck</td>
<td>Homopolymer of glycolic acid coated with poloxamer 188</td>
<td></td>
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<tr>
<td>Polyglycolic Acid</td>
<td>Dexon H</td>
<td>Davis &amp; Geck</td>
<td>Ethicon</td>
<td>Homopolymer of glycolic acid coated with polycaprolactone</td>
</tr>
<tr>
<td>Polyglycolic Acid</td>
<td>Vicryl (coated Vicryl)</td>
<td>Polyglycolic acid coated with calcium stearate and polyglycolic acid 570</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polydioxanone</td>
<td>PDS</td>
<td>Ethicon</td>
<td>Polyglycolic acid coated with calcium stearate and polyglycolic acid 570</td>
<td></td>
</tr>
<tr>
<td>Polydioxanone</td>
<td>PDS-2</td>
<td>Ethicon</td>
<td>Modified PDS</td>
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<tr>
<td>Polyglyconate</td>
<td>Maxon</td>
<td>Davis &amp; Geck</td>
<td>Copolymer of trimethylene carbonate and polyglycolic acid</td>
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<tr>
<td>Polyglyconate</td>
<td>Monosor</td>
<td>Ethicon</td>
<td>Copolymer s-caprolactone and glycolide</td>
<td></td>
</tr>
</tbody>
</table>

New Directions

- Synthesis by manipulation of the genetics and enzymology of synthesis of polyhydroxybutyrate (PHB) and polyhydroxyalkanoate (PHA) polyesters at the molecular level in prokaryotic and eukaryotic cells, especially plants.\(^\text{13}\)

- Knotless Sutures
- Nano-fibers
- Hollow Fibers
References

3. Footberg Ltd. 14 Dolgobrodskaya St., Minsk Republic of Belarus. [http://www.footberg.com](http://www.footberg.com)
7. ShoulderDoc.co.uk. [http://www.shoulderdoc.co.uk/education](http://www.shoulderdoc.co.uk/education)

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**Carbon Nanotubes (CNTs)**

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Polymer Processing 2007

Mid-Term
Background Info.

- Discovered in 1991 by Dr. Sumio Iijima
- Sheet of Graphite
- Categorization
  - Diameter, Length, twist, wall width
- Classification by Structure
  - Single Walled (SWNTs)
  - Multiple Walled (MWNTs)

Application Needs

1. Increase strength
2. Increase conductivity
3. Increase toughness

For Many different Applications
Basic Properties of CNTs

✓ Very Large Young’s Modulus\(^2\)
  Ex. CF Reinforced Plastic: 125-150 GPa
  Steel: 190-220 GPa
  one CNT: 1,000 GPa
  Diamond: 1000-1200 Gpa

✓ Highest Conductive Carbon Fibers
  Resistance of 0.34 \( \times 10^{-4} \) \( \Omega \)-cm\(^3\)

Processing CNTs\(^4\)

✓ Arc Method
  ✓ 2 highly pure graphite rods
  ✓ Helium atmosphere
  ✓ Voltage is added and rods are positioned for arc to be achieved
  ✓ CNTs produced on Cathode along with other carbon molecules
  ✓ SWNTs need the rods to be doped w/ small amounts of metal catalyst
Laser Ablation (SWNTs)
- First used to synthesize Fullerenes
- Use laser to vaporize graphite
- Atmosphere of 1200°C
- Graphite is coated w/ cobalt and nickel catalyst
- Material is condensed & collected on water cooled target
Laser Ablation Schematic\textsuperscript{4}

Fig. 6. Schematic of the laser ablation process (after Ref. [4]).


Processing Problems\textsuperscript{4}

- Limited to carbon source size
  - Arc Method: Anode Size
  - Laser Ablation: Graphite Sample
- Many purification steps are needed
  - Remove bi-products
Processing CNTs\textsuperscript{4} (cont.)

- Chemical Vapor Deposition
  - Decompose Carbon from the Gas Phase
  - Use CO or CH\textsubscript{4}
  - Uses continued source of Carbon (gas fed)
  - High Purity in Product, minimal purification

Processing Problems

- SWNTs formation\textsuperscript{5}
  - Form bundles or pairs
  - Lowers Surface Area

- Formation via Melt Spinning and Drawing with PMMA\textsuperscript{5}
  - Slow draw rates lead to bad alignment
  - Highest modulus obtained \(\sim\) 50 GPa
Product Geometry

- Sheets
  - “Nanotube Paper” or “Bucky Paper”
- Fibers
  - Melt Spinning and Drawing
- Composites

Applications

- Hydrogen Storage in Fuel Cells
  - Highly Controversial Issue in US
- Flat Panel Displays
  - Reduce cost of Thin-film transistor LCDs
- Strengthen Carbon Fiber Materials
  - Carbon fibers woven together weak point is inter-fiber space filled with epoxy
  - CNTs added to epoxy
  - i.e. Easton manufactured Carbon Fiber reinforced with CNTs
- Increased armor strength for military uses
References

1. “Physical properties of Carbon Nanotubes”
2. Sharpe, W.N., Jr et al; Measurements of Young’s modulus, Poisson’s ratio, and tensile strength of polysilicon; MEMS, 1997
6. Carbon Nanotube (CNT) Technology,