Use of Photoresists in the Electronics Industry

Christoph Schauwecker

What are photoresists?

- Light activated polymers
- Used extensively in electronics industry since 1960s
- Backbone of chip and circuit board production
General process

- Substrate is produced
- Conductive coating applied
- Photoresist is applied
- Polymer is baked
- Part is masked
- Part is exposed
- Un-reacted polymer is removed
- Exposed conductive material etched away

How is the photoresist applied?

- Spin coater
- Role coater
- Thin sheet
- Spray application
Baking and exposing

- “Soft” Baking
- Apply pattern (mask)
- Expose to light

Creating the wires

- Development
- Etching
- Hard baking
Positive and negative photoresists

Properties of positive photoresists

- No swelling
- Fine resolution
- Water activated
- Formaldehyde

Polymer is more soluble after exposure.
Positive photoresist chemistry

- Phenolic resins
- Impregnated with Diazonaphthaquinone (DQ) to make them hydrophobic

\[
\text{Diazonaphthaquinone (DQ)} + \text{Resin} \rightarrow \text{Carbene} + \text{Nitrogen (N}_2\text{)}
\]

\[
\text{Carbene} \rightarrow \text{Hydration} \rightarrow \text{Indene Carboxylic Acid (ICA)}
\]
Negative photoresists

- Well understood
- Long history
- Inexpensive
- Solvents more difficult to handle
- Lower resolution

Polymer is less soluble after exposure.

Negative photoresists chemistry

poly(vinyl cinnamate)
Current processing limitations

- Environmental regulations
- Processing speed
- Continued miniaturization
- Tighter tolerances
- Cost

Continued miniaturization

Width of “wires” controlled by wavelength of light and polymer size

\[ W_{\text{min}} = k_1 (\lambda / \text{NA}) \]

Where:

- \( W_{\text{min}} \) = minimum line width of the printed feature
- \( k_1 \) = dimensionless scaling factor
- \( \lambda \) = exposure wavelength
- NA = numerical aperture
Tighter tolerances

- Currently can produce 130nm features
- Need to produce sub 100nm features
- Means your tolerances are below 5nm

Summary

- Process of creating circuit boards
- Polymers used to create “wires”
- Positive and negative photoresists
- Currently limited due to wavelength and tolerances
Sources

- Introduction to Polymer Chemistry: Chemistry of Photoresists
  Http: chem.chem.rochester.edu/~chem421/polymod2.html
- Limitations of Lithographic Techniques and the Drive for advances in nanotechnology
  http://plasticdog.cheme.columbia.edu/undergraduate_research/projects/patricia_wang_project.htm
- EE 527 Microfabrication R.B. Darling
  http://www.ee.washington.edu/research/microtech/cam/PROCESSES/PDF%20FILES/PhotoresistPos.pdf

Hip Replacement

Chris Gabrielli
Polymer Processing 2007
Mid-Term
Typical Prosthetic Hip

Background Information

- Procedure was first performed in 1962
- 1.4 million annually (large market)
- Procedure has been plagued from the start
- Issue:
  - Inferior materials
  - Loosening of the stem
  - Wear and subsequent material deposition into the body
  - Short lifespan of prosthetic
Where Things Went Wrong

- Original replacement hips:
  - Stainless Steel
  - Cobalt Chrome Alloy
  - Titanium Alloy
- Bone/Metal modulus mismatch
  - Stress-shielding → Bone resorption → Micromotions
- Metal on metal/ceramic joint degradation
  - Particles cause accelerated wear
- Need a new material!

Application Needs

- Low Coefficient of friction
- Biocompatibility
- Easily processed
- High toughness, Impact Strength, and Abrasion Resistance
  - While jumping a hip joint can experience forces equivalent to 10x the person's weight.

The Answer?
The Polymer of Choice: UHMWPE

- Highest impact strength of any thermoplastic
- MW of 2 to 6 million (400,000 for HDPE)
- Low wear rate
- Self lubricating, COF equal to that of Teflon
- Excellent chemical resistance

Processing

- Three Step Process
  1. Polymerization from ethylene gas
  2. Consolidation of resin powder
     - Sheets, rods, or near-net shape
  3. Final machining

In some instances resin powder is processed directly into the implant shape through compression molding
Polymerization

- Three Main Ingredients
  - Ethylene (gaseous form, and very reactive)
  - Hydrogen
  - Titanium Tetra Chloride (catalyst)

- The reaction occurs in a solvent used for mass and heat transfer

Consolidation

High melt viscosity prevents the use of conventional molding and extrusion processes

**Compression Molding**
- Up to 24hr processing time
- Sheets up to 2m x 4m and 30 to 80mm thick

**Ram Extrusion**
- Continuous feed
- Rods up to 12” diameter
- Production rate of 2-3”/hr
Direct Compression Molding (DCM)

- Mold of final product
- Control over surface roughness
- Control over resin selection
- Optimization of applied heat and pressure for each component configuration
- Elimination of machine lines on articular surfaces.

Process Equation – Ram Extrusion

No particular equation was found, However, Some parameters are considered:

- Time
- Temperature
- Ram pressure
- Frictional drag (causes back pressure)
- Melt Viscosity
- Material consolidation
Rheological Features of Powders

Carr Index (%)

\[ IC = \frac{d_{\text{tapped}} - d_{\text{aerated}}}{d_{\text{tapped}}} \times 100 \]

Hausner Ratio

\[ RH = \frac{d_{\text{tapped}}}{d_{\text{aerated}}} \]

Equations related to the flowability and compressability of powders

- \( d_{\text{tapped}} \): Tapped density (g/cm³)
- \( d_{\text{aerated}} \): Aerated density (g/cm³)

Processing Issues

- Non-consolidated or unmelted cores
- On/Off nature of ram may produce a non-uniform product
- Lubricating and release agents may increase the rate of material oxidation accelerating wear
Fabrication of Microfluidic Structures using SU-8 Polymers

Microfluidics

- Science of designing, manufacturing, and formulating devices and processes that deal with volumes of fluids on nanoscale and picoscale
Applications and Needs

- Cheap, disposable cell sorting device
- Inkjet printing devices
- Biochemical assays
  - Lab-on-a-chip biochemical analyzers
  - Smaller sample sizes
  - Shorter analysis times
- Template for assembly of nanoscale particles

Price Comparisons
SU-8

• Negative, Epoxy based photoresist (UV cured at 365-435nm)
  ▪ Based on EPON SU-8 epoxy resin from Shell Chemical and patented by IBM
  ▪ Ether derivative of bisphenol-A novolac
• 3 basic components
  ▪ Epoxy resin
  ▪ Solvent (γ-Butyrolactone, GBL)
  ▪ Photoinitiator (triarylum-sulfonium salts)
• Photolithography on thick films with high aspect ratios (height:width)
• Applied by spin-coating

SU-8 Properties

• Low $M_w$ allows for ease of dissolution -- high solids
• High Functionality leads to highly crosslinked structure
• High chemical and thermal resistance and good mechanical properties
• Low optical absorption -- allows the patterning of thick films
• Comparatively cheap (other Microfluidic materials)
• $T_d \sim 380^\circ C$
• $T_g > 200^\circ C$ after exposure
Product Geometry

SU-8 Processing

- Spin Coating
- Soft Bake
- Exposure
- Post Exposure Bake
- Developing
- Hard Bake
Spin Coating

- Procedure which applies a thin film to flat substrate
- Fluid spread evenly by centrifugal force
- Multiple layers can be coated for high aspect ratios
- Viscosity affects film thickness
- Film thickness (h) dependencies:
  - Rotation rate - f
  - Initial solids concentration - c
  - Constant - k (dependant on polymer/solvent system)

\[ h = k c^2 / f \]

Soft Bake

- Allows for evaporation of solvent
- Use level hot plate or convection oven
- 2-step temperature ramp between 65°C and 95°C
Exposure

- Polymerization of SU-8 by photolithography
  - LIGA (Lithographie Galvanoformung Abformung)
  - X-ray Lithography
- Leads to exposed areas cross-linking
- The thicker the film, the higher the exposure dose

UV-LIGA Photolithography
Post Exposure Bake

- Exposed area is cross-linked
- Two step ramp of temperature similar to Soft bake step
- Avoid rapid cooling (can lead to film damage)

Developing

- Immersion or spraying of surface with PGMEA (propylene glycol methyl ether acetate)
- Removes any unexposed or unpolymerized areas
Hard Bake

- Carried out at Temp. from 150°C to 200°C
- Can lead to increase in stress and cause cracks

Issues With Processing

- Varying $T_g$ with varying baking Temp.
- Shrinkage
- Resistant to chemicals (semiconductor industry)
Other Processing Techniques

- Nanoembossing
  - Silicon molds fab by e-beam lithography
  - Reactive ion etching used to mold the nanostructures
  - Molds from polymer pellets

References


POLYMER PHOTOVOLTAIC CELLS (PPC)

By Richard Kraude

WHAT, WHY, HOW???

- Photovoltaic cells (PCs) convert solar energy from the sun into electricity
- Renewable resource
- Third world countries
FIRST CELLS

- The first cells were made from silicon
- First sheet doped with phosphorous. This sheet of silicon is called N-type
- Second sheet doped with boron creates P-type. Instead of having free electrons, P-type silicon has a shortage of electrons, or “holes”, in its outer shell.

POLYMER PCS

- Polymer solar cells are a cost-effective alternative to silicon based solar cells
- Advantages of 'plastic' solar cells include low cost of fabrication, ease of processing, mechanical flexibility and versatility of chemical structure.
PROBLEMS

- The power efficiency of a polymer PC is low
- The excited states in PPC have a lifetime of only 1 ns, and diffuse on average only 10 nm³
- Efficiency is also hampered by poor electron transport in the film

IMPROVEMENTS

- Polymer blends with an electron acceptor, Fullerene were devised
- PPV:C₆₀ have power conversion efficiencies of up to 5 %, nearly four orders of magnitude better than devices made with PPV alone
The most basic plastic photovoltaic cells consists of a thin film (typically ~ 100 nm) of polymer such as poly(p-phenylene vinylene) (PPV) sandwiched between two electrodes of different work function. Indium-tin oxide (ITO) is generally used as the higher work function metal, as it is transparent, and either calcium or aluminum is used as the lower work function electrode. The cell is made by spin-coating the polymer layer from solution on top of an indium-tin oxide coated glass slide, and then depositing the top metal contact via vacuum evaporation.
Spin Coating Spray Coating

**SPIN COATING**

- **Stage One**: The first stage is the deposition of the coating fluid onto the wafer or substrate\(^1\)
- **Stage Two**: The second stage is when the substrate is accelerated up to its final, desired, rotation speed\(^1\)
- **Stage Three**: The third stage is when the substrate is spinning at a constant rate and fluid **viscous forces dominate** fluid thinning behavior\(^1\)
- **Stage Four**: The fourth stage is when the substrate is spinning at a constant rate and **solvent evaporation dominates** the coating thinning behavior\(^1\)
**KEY FACTORS IN SPIN COATING**

\[ h_f = k x_0 \omega^\beta \]

- \( x_0 \) = initial polymer weight fraction
- \( \omega \) = spin speed
- \( h_f \) = dry (final) film thickness
- \( k \) is a constant that depends on the concentration, solution viscosity, and other properties of the polymer and solvent

**INFLUENCES OF DEVICE PROCESSING CONDITIONS**

- The film thickness of conjugated polymers in photovoltaic cells is generally in the range of 50–200 nm
- The photovoltaic performance is dependent on the thickness of MEH-PPV : PCBM composite film. A maximal power conversion efficiency (2.07%) with a thickness of 180 nm was obtained
- \( O_2 \)-plasma-treated ITO substrate shows better photovoltaic performance than the cells with \( N_2 \) and \( Ar \)-plasma-treated substrates
- PEDOT was favorable for facilitating the hole transporting and collecting processes at the anode of polymer solar cell
- The photovoltaic performance of the PPC was directly related to the cathode configuration. The cell with Ca/Ag cathode shows better performance than the cell with other cathodes (LiF/Al, Al, and Ag)
**SPRAY COATING**

- Spin coating is problematic because large surfaces can’t be done
- Spray coating was shown to work and give equal energy convergence as spin coating\(^5\)
- Several companies uses this method

**COMMERCIAL PPC**

- Several companies produce PPC, including Nanosolar, XsunX, and Konarka\(^8,9,10\)
- Konarka’s unique photo-reactive materials can be printed or coated inexpensively onto flexible substrates using roll-to-roll manufacturing, similar to how newspaper is printed on large rolls of paper\(^9\)
REFERENCES


http://www.ksnakalotech.com/products.html
http://www.osmec.com/company-overview.htm
http://www.nanocell.com/about.htm

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Biosensors

Negar A. Monfared
Applications

- Glucose monitoring in diabetes patients
- Environmental applications (detection of pesticides and river water contaminants)
- Remote sensing of airborne bacteria (counter-bioterrorist activities)
- Detection of pathogens
- Determining levels of toxic substances before and after bioremediation
- Detection and determining of organophosphate
- Routine analytical measurement of folic acid, biotin, vitamin B12, etc. as an alternative to microbiological assay
- Determination of drug residues in food, such as antibiotics and growth promoters

Biosensor

- Sensitive
- Easy to use
- Small
- Robust
- Reliable
- Economical
**Biosensor**

**Immobilizing one reactant on a surface to be detected**

- Collective surface
- Transducer
- Detector

**Detection Methods**

**Based on:**
- Electrical properties
- Chemical properties
- Electrochemical properties
- Optical properties
- Piezoelectric properties
- Surface acoustic waves
- Thermal effects
Electrochemical Properties

- Amperometric biosensors
  - Ionization of immobilizes enzyme
  - Transfer of electron between redox center of enzyme and polymeric sensor
  - Ionic strength
  - pH
  - Hydration
  - Change in conductivity of polymer layer
    (Pt/GOₓ/GA composite as a glucose sensor)

Electrochemical Properties

- Change in Impedance, (EIS measurement)
  - Chemical reaction between sensor and enzyme
  - Insulating layer on a conductive substrate
    - Sensor layer degradation
    - Change in capacitance
      Poly(trimethylene) thin film to detect lipase
  - Conductive surfaces
    - Change in Impedance
      Röhm Pharma Eudragit S-100 (a copolymer of methyl methacrilate and methacrilic acid) to detect Urea
Optical properties

- Staining reactions
- Surface plasmon resonance technique
- Enzyme specific colorimetric assays
- X-ray photon spectroscopy (XPS)

Design of a polymer-enzyme composite biosensor for glucose

- Detection method
  - Amperometry
- Selecting materials
  - Glucose oxidase enzyme (GOx) (an isomer of the six carbon sugar, glucose)
  - Flavin adenine dinucleotide (FAD) (a coenzyme for many proteins including:
    - Monoamine oxidase
    - D-amino acid oxidase
    - Glucose oxidase
    - Xanthine oxidase
    - Acyl-CoA Dehydrogenase)
**Reaction with glucose**

\[ \beta-D-\text{glucose} + GO_x / FAD \rightarrow \]
\[ D-\text{glucono-}\delta-\text{lactone} + GO_x / FADH_2 \]  
(1)

\[ GO_x / FADH_2 + O_2 \rightarrow GO_x / FAD + H_2O_2 \]  
(2)

\[ H_2O_2 \rightarrow O_2 + 2H^+ + 2e^- \]  
(3)

Michaelis-Menten:

\[ J_{\text{gluc}} = \frac{J_{\text{max}}}{1 + \frac{K_m(G)}{[G]}} \]

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**Reduce oxygen effects**

- Using Pt electrode
- Using GO\(_x\) immobilized in poly(o-phenylenediamine)
- Using glutaraldehyde (GA) vapor to cross-link the enzyme
- Appropriate configuration of the Pt–GO\(_x\)–PPD design to minimize O\(_2\) interference
  - Suitability for neurochemical applications
  - Fast response time
  - Linearity over the relevant concentration range
  - Effective elimination of interference (endogenous reducing agents such as ascorbic acid)
  - Freedom from protein and lipid fouling
  - Stability in vivo
  - Ease of miniaturization
Sensor production

- Working electrode: Pt disc (D=1.23×10⁻⁴ cm²)
- Let the enzyme absorbs: Dipping Pt into GOₓ solution (5 min.)
- Dry the electrode
- Optimize loading of GOₓ on electrode: Repeat 4 times
- Cross-linking the enzyme: expos to GA vapor (20 min)

Processing issues

<table>
<thead>
<tr>
<th>Design</th>
<th>$J_{\text{max}}$ (μA/cm²)</th>
<th>$K_m$ (G) (mM)</th>
<th>Slope ($\mu$A/cm²)(mM⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pt₂/GOₓ/PPD–BSA</td>
<td>6.0 ± 0.8</td>
<td>14.7 ± 2.0</td>
<td>0.42 ± 0.09</td>
</tr>
<tr>
<td>Pt₂/PPD–BSA/GOₓ–GA</td>
<td>29.0 ± 3.3</td>
<td>6.4 ± 0.3</td>
<td>3.0 ± 0.3</td>
</tr>
<tr>
<td>Pt₂/GOₓ–GA</td>
<td>35.8 ± 7.0</td>
<td>5.0 ± 1.4</td>
<td>6.6 ± 1.9</td>
</tr>
<tr>
<td>Pt₂/GOₓ–GA</td>
<td>249 ± 34</td>
<td>9.0 ± 1.4</td>
<td>20.5 ± 1.6</td>
</tr>
<tr>
<td>Pt₂/GOₓ/PPD–BSA</td>
<td>15.8 ± 3.1</td>
<td>15.0 ± 1.0</td>
<td>0.82 ± 0.18</td>
</tr>
<tr>
<td>Pt₂/PPD–BSA/GOₓ–GA</td>
<td>128 ± 33</td>
<td>7.1 ± 1.1</td>
<td>10.5 ± 1.7</td>
</tr>
</tbody>
</table>
References


Proton Exchange Membranes

Nafion® ionic polymer membranes for use in fuel cells

Stephanie Bossé
August 17th, 2007
Polymer Processing
Fuel Cells
Chemical Energy $\rightarrow$ Electrical Energy


**Desired Properties**

- High H$^+$ conductivity
- Low electronic conductivity
- Low diffusion of H$_2$
- Polymer stability
  - Chemical
  - Mechanical
  - Electrochemical
- Easy fabrication
Nafion®
Thermoplastic
Sulfonated tetrafluoroethylene copolymer

Teflon Backbone
Stability
H₂ diffusion resistance
Hydrophobic

Sulfonic Acid Groups
Allows H⁺ to “hop” across the membrane
Hydrophilic

Proton Transport Across Membrane - I

Adapted from: http://www.doitpoms.ac.uk/tlplib/fuel-cells/pem_membrane.php
Proton Transport Across Membrane - II

Adapted from: http://www.doitpoms.ac.uk/tlplib/fuel-cells/pem_membrane.php

Proton Transport Across Membrane - III

Adapted from: http://www.doitpoms.ac.uk/tlplib/fuel-cells/pem_membrane.php
Proton Transport in Membrane - IV


Proton Transport in Membrane - V

PEM Geometry

- Efficiency of $H^+$ transfer from anode to cathode depends on:
  - Thickness of membrane
  - Surface area of membrane

- Currently processed into thin sheets
  $50 - 250 \, \mu m$

Processing of Nafion®

An extrusion-cast membrane
High speed & volume

Adapted From: http://www.cpchem.com/enu/docs_styrenic/tib_204.pdf
Processing Issues

Mechanical stresses and strains

*Leads to uneven hydration*

Steam forms air bubbles during processing

*Disrupts water filled channels*

Thin film does not yield much surface area

*Limits performance*

Problems with Nafion®

- **Must be well hydrated** – up to 50%
  - Operating temperature < \(\sim 80^\circ\)
    - *Automotive operating temperature* \(\sim 200^\circ\)

- **Non uniform expansion upon water uptake**
  - *Thickness change*: 10 – 14%
  - *Linear expansion*: 10 – 15 %

Next Week

How to improve hydration issues?

How to increase surface area?

New processing methods?

References

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tation&id=16665
• www.technologynewsdaily.com/node/4385
Polymers in Lieu of Mussels

The fabrication of biologically inspired polymer coatings

Kathryn Larned

Background

- Mussel anatomy
- Beard
- Mussel Adhesive Polymer (MAP)
  - Adhesion
  - Water resistance
  - Non-toxic
  - Fast bonding
  - Semi-permanent bonding

Applications

- Adhesives
  - Medical uses:
    - nerve reconstruction
    - wound closure
- Rustproof coatings
- Coatings for medical implants
  - Degradation
  - Acceptance by the body
- Drawback: excessive amounts are not obtainable from mussels

Alternative Polymers

- 1-3,4-dihydroxyphenyl-alanine (DOPA)
  - Adhesion to natural and synthetic surfaces
  - Resistant to degradation
  - Biological derivative- biocompatible

http://crops.confex.com/crops/wc2006/techprogram/P15278.HTM
Processing

- **Matrix assisted pulsed laser evaporation (MAPLE)**
- Deposits organic compounds without degradation by UV
  - Chamber deposition
  - Films of ~3mm²
  - Uses analogs of DOPA:
    - DOPA-PF68
    - DOPA-PF1274

- Surface Initiation Polymerization (SIP)
- Creates nanocomposites from an inorganic oxide nanoparticle, DOPA analog and monomer
  - Utilizes surface-initiated atom transfer radical polymerization (SI-ATRP)
  - Reacted for 28 h under argon atmosphere
  - Combined MMA and TiO₂-complex
  - Produces powders

Tem micrograph of PMMA-grafted TiO₂ nanoparticle after 20 h of SI-ATRP

SI-ATRP -- binuclear chelation is shown
**TiO₂ – Initiator Complex**

- DOPA is a catecholic amino acid
- Complex synthesized, which has a catecholic adhesive end and a bromine terminus to initiate ATRP
  - Reacted for 24 h
  - Washed repeatedly to remove unbound initiator

**Processing Considerations**

- **MAPLE**
  - Maintains structure of components
  - Controllable thickness, structure and stoichiometry
  - Testing only on small scale
  - No testing done yet on surfaces except silicon

- **SIP**
  - Anchoring of TiO₂ achieved
  - Repeated washing necessary to attain purity
  - Reaction requires more than two days
  - Testing only done on small scale
  - Molecular weight not controlled very well
## Bulk Production

- Modified polystyrene backbone
- Meant to mimic DOPA
- Created poly[(3,4-dihydroxystyrene)-**co**-styrene]
  - Reaction at -78°C under argon for 8 hr
  - Warmed to room temperature
  - Quenched after 20 hr

![Diagram of polymerization reaction](image)

## Summary

- Mussels produce MAP
- Medical implants and adhesives
- DOPA is a polymer mimic of MAP
- Processing possibilities:
  - MAPLE
  - SIP
  - Modified PS
References


Dendrimers as Drug Delivery Vehicles

Heather Paris
8/15/2007
Outline

- Background Information
- Application
- Drug Delivery System
- Product Geometry
- Materials
- Processing Methods
- Process Design Equations
- Issues

Background

Dendrimers are hyperbranched 3-D macromolecules comprising of multifunctional core, several branch points and outer surface.

Dendron (tree or branch)
Meros (parts)

Dendrimers are preferred because:
Monodispersity
Modifiable surface functionality
Highly definable size and structure
High biocompatibility
Application

Pharmaceutical and Biomedical applications

- Organosilane Castings
- Inks & Toners
- Light Harvesting
- Extraction & Phase Transfer Catalysis in SeCO2

DENDRIMERS

- Diagnostic
- Nano-composites
- Artificial Enzymes
- Sensor & Molecular Weight Standards

Application:
Pharmaceutical and Biomedical

Site-specific drug delivery for
- chemotherapy
- ocular adhesives
- anti-infective
- gene therapy
- Imaging

Example:
Cytotoxic drugs can be delivered directly to a cancerous tumor. This is achieved by attaching ligands to the surface that only active with tumor cells. This will kill the tumor while sparing the surrounds non-cancerous tumors.
Drug Delivery System

- **Encapsulation** of drugs uses the steric bulk of the exterior of the dendrimer or interactions between the dendrimer and the drug to trap the drug inside the dendrimer.
- Dendrimer-drug conjugates have the drug attached to the exterior of the dendrimer.

Product Geometry
Poly(amidoamine) PAMAM is the most common dendrimer used in gene delivery and is commercially available as Superfect®.

Polyethyleneglycol (PEG) is often conjugated to the surface of the dendrimers to create a hydrophilic shell around the hydrophobic dendrimer forming a unimolecular micelle.
Processing Methods

- They can be synthesized from almost any core molecules and the branches can be constructed from any bifunctional molecules (lysine or ornithine), while the terminal groups can be modified to achieve charged, hydrophilic or hydrophobic surface.

Process Methods

- 'Divergent' Dendrimer Growth
  - The dendrimer grows out from the core.

- 'Convergent' Dendrimer Growth
  - The dendrimer growth starts at what will be the surface.
Process Methods

- 'Hypercores' and 'Branched Monomers'

- 'Double Exponential' and 'Mixed' Growth

Processing Design Equations

- Methods to achieve controlled release include chemical or enzymatic reaction, diffusion through a matrix, or solvent activation.
Processing Design Equations

The drug A loaded within the bead is the transient source for mass transfer. The fluid surrounding the bead is the constant sink for mass transfer.

Assumptions:
• Unsteady state
• Radial symmetry with 1-D flux along r
• No degradation of the drug inside the bead \( (R_A = 0) \)
• \( C_{Ao} = 0 \) at \( r=R \)
• Constant bead radius \( R \)
• \( C_A = C_{Ao}, \ t=0 \)

\( A = \) water-soluble drug
\( C_{Ao} = \) Initial concentration of A
\( W_A = \) moles of Drug A release WRT time
\( R = \) outer radius
\( t = \) time

Processing Design Equations

Rate of drug release \( W_A \) (moles A/time) at the surface of the bead \( (r=R) \)

\[
W_A(t) = 8\pi R C_{Ao} D_{AB} \sum_{n=1}^{\infty} e^{-D_{AB} n^2 \pi^2 t / R^2}
\]

The fractional amount of drug A remaining in the bead at time \( t \).

\[
\frac{m_A(t)}{m_{Ao}} = \frac{\text{amount of A remaining}}{\text{initial amount of A loaded}}
\]

\[
\frac{m_A(t)}{m_{Ao}} = \frac{6}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{n^2} e^{-D_{AB} n^2 \pi^2 t / R^2}
\]
Processing Design Equations

• The degree (fraction) of branching (DB)

\[
DB = \frac{D+T}{D+T+L}
\]

- \(D\) = mole fraction of dendritic units
- \(T\) = mole fraction of terminal units
- \(L\) = mole fraction of linear units

Processing Issues

• Quality control
  – Incomplete growth Steps
  – Side Reactions
    • Disturbances in the radius, molecular weight distribution and drug concentration
      – Over dose
      – Under dose
References


