

Lecture 49-Polyimides

Introduction to Polyimides in Polymer Process Engineering:

Welcome to the exploration of Polyimides in the realm of polymer process engineering. Before delving into the specifics of Polyimides, let's briefly recap what we covered in the previous lecture. Our discussion focused on the chemistry of epoxies, their ring opening mechanisms, properties, and touched upon phenoxes and silicones.

Overview of Polyimides:

Now, in this segment, we will dive into the world of Polyimides, exploring their functionalities, definitions, structures, and physicochemical properties. Additionally, we'll delve into their applications, particularly in the electronics industry, and explore the synthesis process of soluble Polyimides.

Topics to be Covered:

1. Definition and Structure of Polyimides
2. Physicochemical Properties of Polyimides
3. Applications, with a focus on Electronics
4. Synthesis of Soluble Polyimides
5. Two-Step Curing Processes
6. Polyamide Modification for Specific Applications
7. Photosensitive Polyimides

Polyimides: Definition and Structure:

Polyimides belong to the class of aromatic polymers characterized by the presence of amide (-CONH-) linkages in their molecular structure. Traditionally, they are formed through the condensation polymerization of dianhydrides and diamines. Examples of Polyimide applications include polyamide foams and electro-winding applications.

Polyimides: Definition

- Polyimides are a type of polymer that belongs to the class of aromatic polyimides, characterized by the presence of imide (-CONH-) linkages in their molecular structure.
- They are typically formed through the reaction of dianhydrides and diamines, which undergo a condensation polymerization process to form the polyimide polymer.



Polyimide Structure:

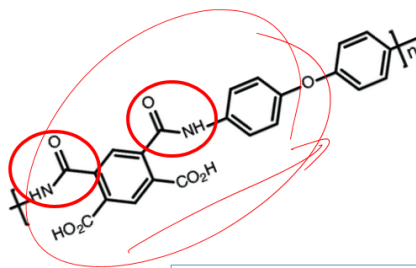
The structure of Polyimides features repeating units composed of aromatic dianhydrides and aromatic diamines, creating a robust and versatile polymer backbone.

In the subsequent discussions, we will explore the intricacies of Polyimides, including their physicochemical properties, applications in electronics, synthesis processes, curing methods, and modifications tailored to specific needs. Let's embark on this journey into the realm of Polyimides in polymer process engineering.

The typical structure of Polyimides reveals the presence of amide (-CONH-) linkages in the main chain, connecting aromatic rings of the dianhydride and diamine. The aromatic ring as the polymer backbone contributes to its inherent high thermal stability and rigidity, forming the fundamental structure of Polyimides.

Polyimides: Structure

- Polyimides have a repeating unit composed of an aromatic dianhydride and an aromatic diamine.
- The imide linkage (-CONH-) is present in the main chain of the polymer, connecting the aromatic rings of the dianhydride and the diamine.
- The presence of aromatic rings in the polymer backbone contributes to its high thermal stability and rigidity.



Physicochemical Properties of Polyimides:

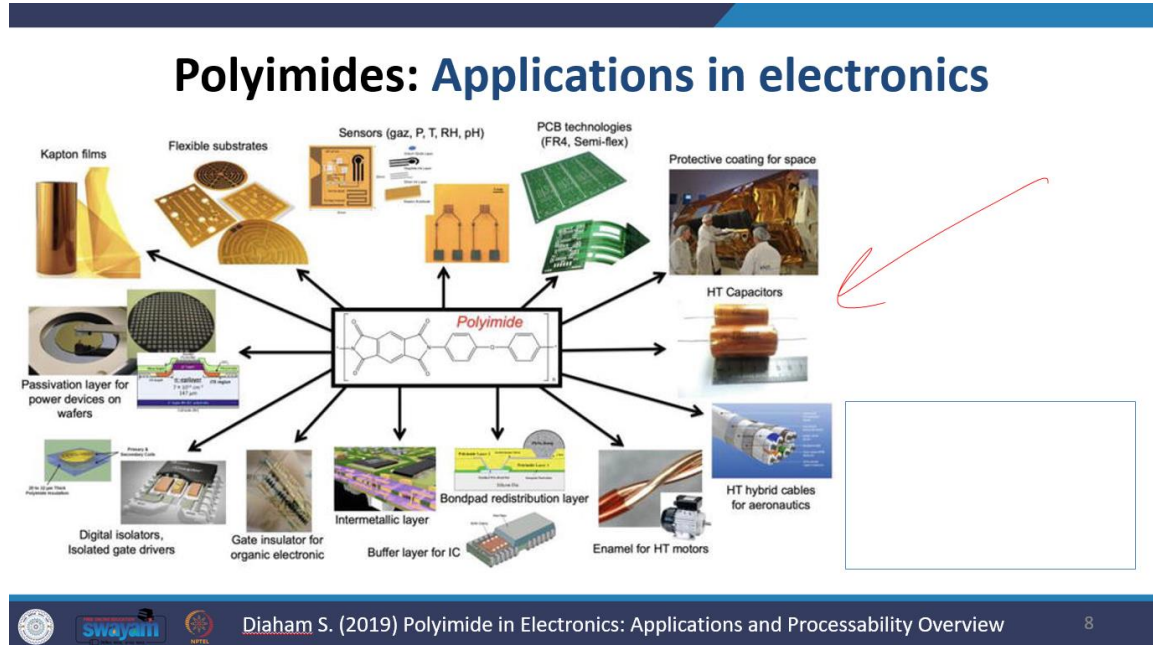
Polyimides exhibit a range of exceptional physicochemical properties, making them versatile in various applications.

1. **Excellent Thermal Stability:** Polyimides showcase remarkable thermal stability, withstanding continuous exposure to temperatures of 300 °C or above without significant degradation. This property makes them well-suited for applications demanding resilience under high temperatures.
2. **High Mechanical Strength and Tensile Strength:** Polyimides possess high mechanical strength, impressive tensile strength, stiffness, and dimensional stability. These qualities make them suitable for structural applications where robustness is crucial.
3. **Chemical Resistance:** Polyimides offer excellent chemical resistance, withstanding various chemicals, solvents, acids, and bases. This resistance ensures longevity and prevents degradation, making Polyimides ideal for applications in harsh chemical environments.
4. **Electrical Insulation:** In terms of electrical properties, Polyimides exhibit outstanding electrical insulation. This feature is particularly valuable in electronic applications where reliable electrical insulation is a critical requirement.

In summary, the unique combination of thermal stability, mechanical strength, chemical resistance, and electrical insulation makes Polyimides a versatile class of polymers

suitable for a wide range of applications, especially in environments with stringent performance requirements.

Polyimides in Electronics: Applications and Advantages:



Polyimides, with their exceptional properties, find extensive applications in the field of electronics, showcasing versatility and reliability.

1. **Low Coefficient of Thermal Expansion:** Polyimides boast a low coefficient of thermal expansion, leading to minimal dimensional changes with temperature variations. This property makes them ideal for applications requiring thermal stability.
2. **Applications in Electronics:**
 - **Kapton Film:** Used in various electronics applications.
 - **Flexible Substrate Sensors:** Utilized for developing sensors, offering flexibility, chemical resistance, and excellent dielectric properties.
 - **PCB Technologies:** Rigid substrates for PCBs providing mechanical support and electrical insulation for electronic components.
 - **Protective Coatings for Space:** Offers thermal stability, radiation resistance, and protection against harsh environmental conditions.
3. **Digital Isolators and Microelectronics:**

- Polyimides play a crucial role in microelectronics, serving as low-K intermetallic layers for ultra-large-scale integration. This reduces capacitance and enhances signal integrity.
- Bond pad redistribution and buffer layers in integrated circuits facilitate efficient signal routing and connection between different components.

4. Flexible Substrates:

- Polyimide films are utilized as flexible substrates in sensor development, offering flexibility, chemical resistance, and excellent dielectric properties.

5. PCB Technologies:

- Rigid polyimide substrates in PCB technologies provide mechanical support and electrical insulation for electronic components.

6. Protective Coatings for Space Applications:

- Polyimides act as protective coatings in space applications, offering thermal stability, radiation resistance, and safeguarding against harsh environmental conditions.

Polyimides in Various Energy Storage and Electrical Applications:

Polyimides exhibit diverse applications in the realm of energy storage and electrical components, addressing new challenges in emerging technologies.

1. High-Temperature Capacitors:

- Polyimide films are employed for high-temperature capacitors, offering exceptional electrical properties and stability at elevated temperatures. This is crucial in addressing challenges in new energy storage technologies.

2. Insulating Layer for Aeronautical Cables:

- Polyimides serve as insulating layers in the next generation of high-temperature aeronautical cables, ensuring reliable electrical insulation under extreme conditions.

3. High Thermal Class Enamel for Electrical Motors:

- In electrical motor applications, high thermal class enamel of polyimides provides excellent thermal endurance and electrical insulation properties, contributing to the overall efficiency and reliability of motors.

4. Passivation Layers for Power Electronic Devices:

- Passivation layers made of polyimides are utilized for surface insulation in high-voltage and high-temperature power electronic devices like Silicon (SI) and Silicon Carbide (SiC). This prevents electrical leakage, enhancing device reliability and stability.

5. Insulating Barriers for Digital Isolators:

- Polyimides play a crucial role as insulating barriers in digital isolators used in isolated gate drivers. This ensures effective isolation between high- and low-voltage circuits, contributing to enhanced safety in power electronics.

6. Gate Insulators for Organic Electronics:

- In emerging organic electronics, polyimides serve as gate insulators, facilitating charge transport and controlling device performance. This application contributes to the advancement of organic electronic devices.

Polyimides, with their high-temperature stability and exceptional electrical properties, find diverse applications in the evolving landscape of energy storage and electrical systems. Their role spans from capacitors to aeronautical cables, motors, power electronic devices, and emerging fields like organic electronics, showcasing the versatility of these polymers in addressing contemporary challenges.

Polyimides: Wire Coating and Mechanical Properties:

Polyimides serve diverse purposes, acting as wire coatings and molding components when fillers are added. The mechanical strength and flexibility of these polymers depend on the size of the oligomers, which, in turn, correlates with the degree of crosslinking during the curing process. Larger oligomers exhibit lower degrees of crosslinking, resulting in greater flexibility.

Structural Properties of Acetylene-Substituted Polymers:

- Fourteen acetylene-substituted polymers are described, emphasizing their thermal and electrical properties comparable to condensation-type polymers.
- Dielectric constants range from 2 to 3, showcasing favorable electrical properties.
- Long-term thermal stability ranges from 300 to 400 °C.

CHART I. Type 1 oligomers

X			SOLVENT	M.P. °C	T _g , °C OF CURED POLYMER *
>C=O	-	0	NMP DMF	>250	>400
>C(CF ₃) ₂	-	0	ACETONE	184-5 190-4	410
	-	0	ACETONE	122±2	312* 372**
	-	0	THF (ACETONE)	140	302
>C=O	-O-	1	ACETONE CHCl ₃	175-185	>400

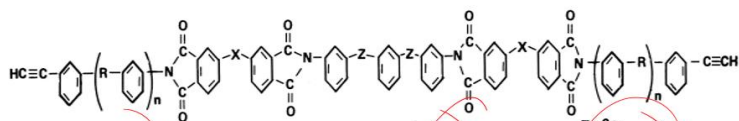
*AFTER 8 hr 370°C POSTCURE
**AFTER 24 hr 370°C POSTCURE



Oligomer Types and Their Properties:

- **Type 1 Oligomer:**
 - Different solvents used
 - Melting point and glass transition temperature of the cured polymer provided for reference.
- **Type 2 Oligomer:**
 - Glass transition temperature and relevant solvent listed.

CHART II. Type II oligomers



X	Z	R	n	SOLVENT	M.P., °C	T _g , °C OF CURED POLYMER	NOTES
$>C(CF_3)_2$	-O-	-	0	ACETONE	168 - 173	324 294	
	-O-	-	0	ACETONE	182 - 185	296	
$>C=O$	-O-	-	0	NMP, DMF	195 - 200	370	HR600
-CH ₂ -	-O-	-	0	THF	160	263	
-O-	-O-	-	0	THF (ACETONE)	150	253	
	-O-	-	0	THF (ACETONE)	134	212	
$>C=O$	-O-	-	0	NMP, DMF	200 - 210	CURE INCOMPLETE	PARA ETHYNYL
$>C=O$	-S-	-	0		175		
$>C=O$	-O-	O	1				HR650



Synthesis Methods:

Polyimides can be synthesized through two main polymerization processes:

1. Condensation Polymerization:

- Involves the reaction between two or more monomers with the elimination of a small molecule (such as water or alcohol) during the polymerization process.

2. Addition Polymerization (Step-Growth Polymerization):

- Another method for synthesizing polyimides.

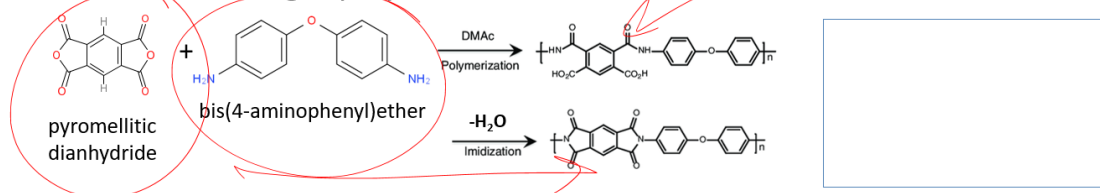
The choice of polymerization method influences the properties and characteristics of the resulting polyimide, offering flexibility in tailoring the material for specific applications.

Polyimides: Synthesis

A common procedure is to condense pyromellitic dianhydride with bis(4-aminophenyl)ether, as shown.

The reaction proceeds according to two steps:

1. The formation of an intermediate polyamic acid
2. Ring closure through the elimination of water to yield the high molecular weight polyimide



Polyimide Synthesis: Two-Step Process:

Polyimides are typically synthesized through a two-step process, involving the reaction of aromatic dianhydride with an aromatic diamine. This process results in the formation of an intermediate polyamic acid or polyamic ester precursor, often referred to as intermediates. The second step involves subjecting the polyamic acid to thermal or chemical imidization, leading to the formation of the final polyamide structure with amide linkages (CONH).

Synthesis Steps:

1. First Step:

- Aromatic dianhydride reacts with an aromatic diamine.
- Forms an intermediate polyamic acid or polyamic ester precursor.

2. Second Step:

- Polyamic acid undergoes thermal or chemical imidization.
- Acid and amine groups convert into amide linkages (CONH).
- The final product is a high molecular weight polyamide.

Common Procedure Example:

- Pyromellitic dianhydride reacts with bis 4-aminophenyl ether.

Reaction Steps:

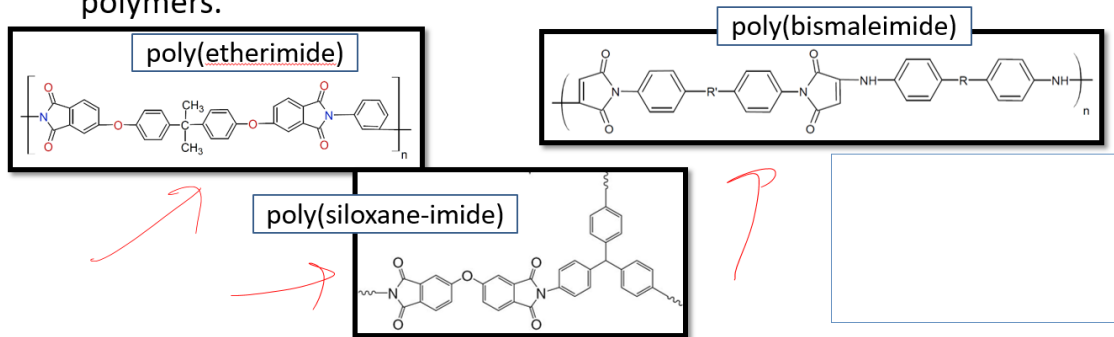
1. Formation of an intermediate or polyamic acid.
2. Ring closure through the elimination of water (condensation polymerization).
3. Cyclization or ring closer in polyamide synthesis.

Cyclization Process:

- Requires a minimum temperature of 120 to 150 °C.

Polyimides: **Synthesis**

- Examples of condensation polymerization-based polyimides include poly(etherimide), poly(bismaleimide), and poly(siloxane-imide) polymers.



Imidization for Completion:

- Achieving quantitative conversion from polyamic acid to polyamide requires a higher temperature (300 to 400 °C) for several minutes to an hour.
- The high temperature needed for this conversion restricts the use of polyimides to applications where such temperatures can be tolerated.

This synthesis process showcases the controlled formation of polyimides, highlighting the importance of temperature and reaction duration in achieving the desired properties of the final polyamide product.

Polyimide Formulations and Properties: Case Sensitivity:

The synthesis of polyimides is highly case-sensitive, tailored to specific applications based on the desired properties. Formulations using benzo guanine or S triazine have been developed, featuring more moderate baking temperatures ranging from 125 to 205

°C. These polymers, characterized by higher molecular weights, exhibit improved thermal stability attributed to the elimination of small molecules during the polymerization process.

Properties of Condensation-Based Polyamides:

1. Thermal Resistance:

- The presence of the amide (CONH) linkage in the polymer backbone contributes to excellent thermal resistance.

2. Mechanical Strength and Chemical Resistance:

- These polyamides, synthesized through condensation polymerization, showcase notable mechanical strength and chemical resistance.
- Examples include polythermide, polybismelamide, and polysiloxane amide.

Structural Representation:

- Structurally, these polyamides can be represented as shown.

Step-Growth Polymerization-Based Polyamides:

- Also known as addition polymerization-based polyamides.
- Synthesized through a step-growth polymerization process.

Monomer Preparation:

- In step-growth polymerization, dianhydride monomer preparation is required.
- Both dianhydride and diamine serve as the two precursors for this type of polyamide.

The choice between condensation-based and step-growth polymerization-based polyamides depends on specific application requirements, allowing for the customization of thermal, mechanical, and chemical properties.

Synthesis of Step-Growth Polymerization-Based Polyamides:

The synthesis of step-growth polymerization-based polyamides involves careful steps to create a dianhydride monomer and initiate the polymerization reaction. Here's a detailed overview:

1. Monomer Preparation:

- React a dianhydride compound (e.g., 3,3',4,4'-benzophenone tetracarboxylic dianhydride) with a diamine precursor (e.g., 4,4'-diaminodiphenyl ether) in a suitable solvent (e.g., N,N-dimethylacetamide).
- Conduct the reaction under controlled conditions, stirring the reaction mass at an appropriate temperature.
- Isolate the dianhydride diamine intermediate as a solid or solution, depending on the reactants and reaction conditions.

2. Polymerization Initiation:

- Add a suitable catalyst or initiator to the dianhydride diamine intermediate to initiate the polymerization reaction.
- Common catalysts include metal salts or metal alkoxides.

3. Polymerization Process:

- Promote the polymerization process by adjusting the reaction mixture, considering temperature and time.
- The polymerization temperature is typically around 200 °C or higher, resulting in a material with a high glass transition temperature.

4. Reaction Monitoring:

- Monitor the reaction's progress using various analytical techniques such as spectrophotometry and viscosity measurements.
- Continue until the desired degree of polymerization is achieved, influencing the final product's properties.

5. Polymer Film Formation:

- For polymer film formation, cast or spin coat the polymer solution onto a substrate to create a uniform film.
- Evaporate the solvent under controlled conditions, such as heat or vacuum.
- This process allows the polymer chains to align, leading to the solidification of the film.

Careful monitoring and control throughout these steps ensure the desired characteristics and properties of the final polyamide product for specific applications.

6. Polyamide Thermal Treatment: Immunization Process:

Following the polymer film formation, the next crucial step is the thermal treatment, involving a curing process known as immunization. This step converts the polyamic acid and intermediate into the fully immunized polyamide. The thermal treatment typically comprises a two-step process, including a low-temperature immunization step followed by a high-temperature curing step. The specific temperature and duration parameters are tailored to the polyamide system and the intended application.

Examples of Polyamide Synthesis:

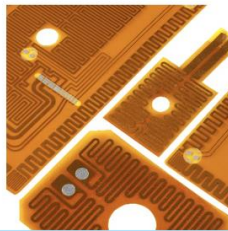
1. Kapton:

- An addition polymerization-based polyamide derived from pyromellitic dianhydride (PMDA) and 4,4'-oxydianiline (ODA).
- Exhibits excellent thermal stability and electrical insulation properties.
- Suited for various high-temperature applications.

Polyimides: **Synthesis**

Examples

- **Kapton:** A well-known addition polymerization-based polyimide derived from pyromellitic dianhydride (PMDA) and 4,4'-oxydianiline (ODA). It exhibits excellent thermal stability and electrical insulation properties, making it suitable for various high-temperature applications.



2. Dupont:

- Another addition polymerization-based polyamide frequently used as a flexible substrate in the electronics industry.
- Derived from biphenyl tetrachloride dianhydride (BPDC) and para-phenylenediamine (PPD).

- Offers good flexibility, mechanical strength, and thermal resistance.

Polyimides: **Synthesis**

- **Upilex:** Another addition polymerization-based polyimide, often used as a flexible substrate in the electronics industry. It is derived from biphenyltetracarboxylic dianhydride (BPDA) and p-phenylenediamine (PPD), offering good mechanical strength and thermal resistance.

<p>Base grade</p> <p>UPILEX-S</p>	<ul style="list-style-type: none"> ●Thermal properties: Outstanding heat resistance. Excellent heat shrinkage and dimensional stability. ●Environmental resistance: Low water absorption and hygroscopic expansion. ●Chemical resistance: Insoluble in all organic solvents and resistant to chemicals (acids and alkalis etc.). ●Smooth surface: Excellent surface smoothness allows fine pitch patterning.
<ul style="list-style-type: none"> ●Mechanical properties: High tensile strength and modulus. Demonstrates outstanding mechanical characteristics through a wide temperature range. ●Electrical properties: Excellent electrical characteristics over a wide range of temperatures and frequencies. 	

These examples highlight the versatility of polyamide synthesis, showcasing how tailored combinations of dianhydrides and diamines lead to polymers with specific properties, making them suitable for diverse applications. The thermal treatment ensures the desired characteristics, such as thermal stability and insulation properties, required for various high-performance applications.

Polyamide Properties and Two-Step Curing Process:

The base-grade duplex exhibits exceptional properties, showcasing high tensile strength and modulus, outstanding mechanical characteristics across a broad temperature range, excellent electrical features at various temperatures and frequencies, impressive thermal properties, environmental and chemical resistance, and a smooth surface conducive to fine pitch patterns.

Two-Step Curing Process and Photolithography:

1. Polyamide Coating:

- Substrate coated with polyamide, followed by a soft-bake (referred to as beta-staged) to eliminate the solvent and form a polyamic acid coating.

2. Photoresist Application:

- A layer of photoresist applied onto the polyamic acid coating.

3. Exposure and Development:

- The coated substrate exposed to a specific pattern using photolithography.
- Developed to dissolve the exposed areas of polymers using an alkaline solution like ammonium hydroxide.

4. Patterned Polyamide Formation:

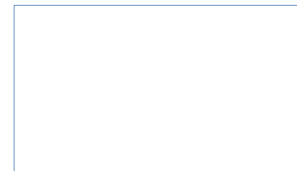
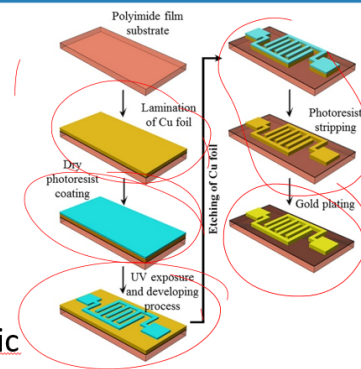
- Subsequent steps include substrate lamination, CO foil, dry photoresist coating, UV exposure, photoresist stripping, and gold plating.
- The photoresist is then removed, leaving behind a patterned polyamide.

5. Curing Process:

- The patterned polyamide undergoes a two-step curing process, progressing from the polyamic acid state to the fully polymerized state, sometimes referred to as the C stage.

Two-step curing process and Photolithography

- The substrate is coated with polyimide, which is subsequently soft-baked (B-staged) to eliminate the solvent and form a polyamic acid coating.
- A layer of photoresist is applied onto the polyamic acid coating, exposed to a specific pattern, and developed.
- The exposed areas of polyimide are dissolved using an alkaline solution, such as ammonium hydroxide.



This sequential process allows for the precise formation of an insulation layer with a well-defined rise. These insulation layers are applied in the production of thin film multilayer interconnect substrates, serving critical roles in advanced electronic applications.

Property Modification of Polymers:

- To address specific application requirements, the properties of polymers can be modified. The ability to tailor the characteristics of polymers allows for versatility and adaptability to diverse applications

Modification of Polyimide Properties through Structural Variations:

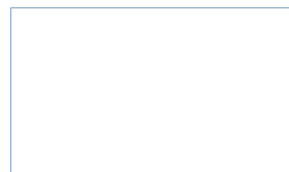
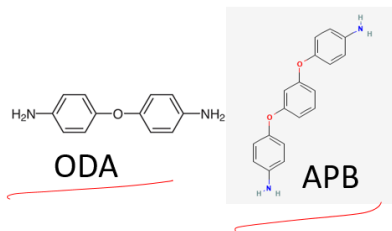
The chemical structure of polyimides can be tailored based on specific diamine and dianhydride monomers, leading to a variety of properties. Examples of structural changes include:

Modifying the properties of polyimides

Certainly! The chemical structure of polyimides can be altered based on the **specific diamine and anhydride monomers used**. Following examples illustrating the structural changes:

1. Diamine Variation:

- Using aromatic diamines like 4,4'-diaminodiphenyl ether (ODA) or 1,3-bis(4-aminophenoxy)benzene (APB) results in polyimides with rigid aromatic structures.

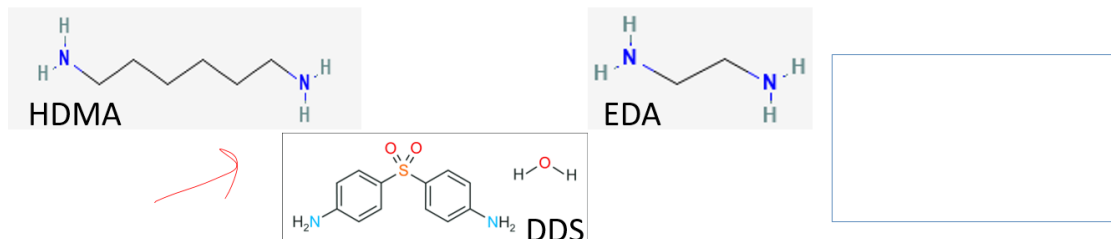


1. Diamine Variation:

- Aromatic Diamines (e.g., ODA or APB):**
 - Introduces a rigid aromatic structure to polyimides.
- Aliphatic Diamines (e.g., HMDA or EDA):**
 - Adds flexibility to the polyimide structure with alkyl chains.
- Diamines with Polar Functional Groups (e.g., DDS):**
 - Enhances solubility in specific solvents, improving versatility.

Modifying the properties of polyimides

- Aliphatic diamines such as hexamethylenediamine (HMDA) or ethylenediamine (EDA) introduce flexible alkyl chains into the polyimide structure.
- Diamines with polar functional groups, like 4,4'-diaminodiphenyl sulfone (DDS), can enhance the solubility of polyimides in certain solvents.



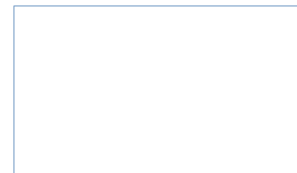
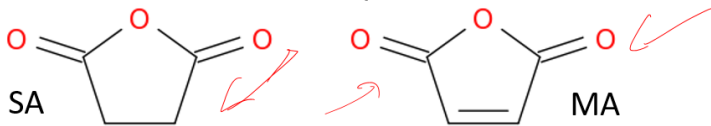
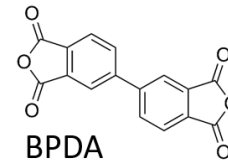
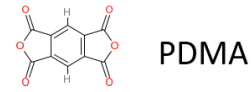
2. Anhydride Variation:

- **Aromatic Anhydrides (e.g., PMDA or BPDA):**
 - Introduces an aromatic structure into the polyimide backbone.
- **Aliphatic Anhydrides (e.g., succinic anhydride or maleic anhydride):**
 - Leads to more flexible and amorphous polyimide structures.
- **Anhydrides with Bulky Substituents (e.g., BTDA):**
 - Affects packaging and crystallinity of polyimides.

Modifying the properties of polyimides

2. Anhydride Variation:

- Using pyromellitic dianhydride (PMDA) or 3,3',4,4'-biphenyltetracarboxylic dianhydride (BPDA) introduces aromatic structures into the polyimide backbone.
- Aliphatic anhydrides, such as succinic anhydride or maleic anhydride, can lead to polyimides with more flexible and amorphous structures.



Examples of Structural Change:

1. ODA or PMDA Combination:

- Yields a highly rigid and thermally stable polyimide structure suitable for high-temperature applications.

2. HMDA or PMDA Combination:

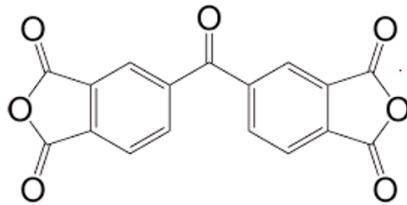
- Leads to flexible and transparent polyimides with improved mechanical properties.

3. DDS or BTDA Combination:

- Produces soluble and amorphous polyimides with good chemical resistance.

Modifying the properties of polyimides

- Anhydrides with bulky substituents, like benzophenone-tetracarboxylic-di-anhydride (BTDA), can affect the packing and crystallinity of the polyimide.



4. APB and BPDA Combination:

- Results in polyimides with a rigid and highly ordered structure, providing excellent mechanical strength and thermal stability.

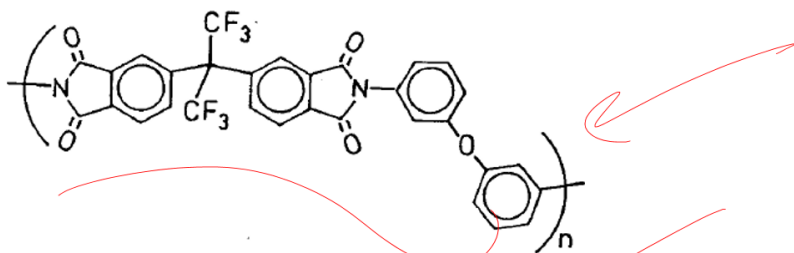
These examples showcase the versatility of polyimides, allowing for precise customization of properties based on specific applications and requirements. The ability to modify both diamine and dianhydride components provides a wide range of options for tailoring polyimides to meet diverse needs.

Examples of Polyimides Derived from Different Monomers:

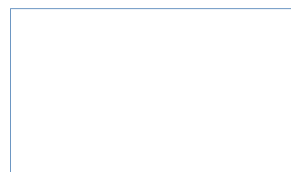
1. Polyimide from 2,2-bis(3,4-dicarboxyphenyl) hexafluoropropane 3,3'-oxydianiline diamine:

- Chemical Structure: *(Visual representation not provided)*
- This polyimide is derived from a complex structure involving 2,2-bis(3,4-dicarboxyphenyl) hexafluoropropane 3,3'-oxydianiline diamine, showcasing a unique and intricate molecular arrangement.

Examples



Polyimide derived from 2,2-bis(3,4-dicarboxyphenyl)hexafluoropropane 3,3'-oxydianiline diamine.



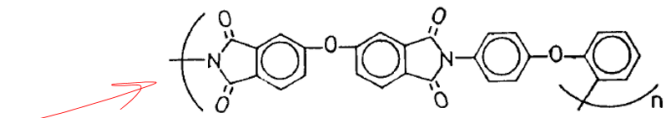
2. Polyimide derived from 4,4'-oxydiphthalic anhydride + 2,4'-oxydianiline diamine:

- Chemical Structure: *(Visual representation not provided)*
- This polyimide is synthesized from Polyimide derived from 4,4'-oxydiphthalic anhydride + 2,4'-oxydianiline diamine, demonstrating a distinct molecular configuration suitable for specific applications.

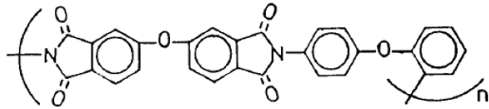
3. Polyimide from 2,2-bis(3,4-dicarboxyphenyl)carboxy dianhydride + diaminophenyl trimethyl indane:

- Chemical Structure: *(Visual representation not provided)*
- Representation of a polyimide derived from 2,2-bis(3,4-dicarboxyphenyl)carboxy dianhydride + diaminophenyl trimethyl indane, showcasing a tailored molecular design for desired properties.

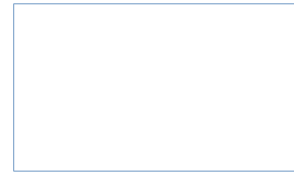
Examples



Polyimide derived from 4,4'-oxydiphthalic anhydride + 2,4'-oxydianiline diamine



Polyimide derived from 2,2-bis(3,4-dicarboxyphenyl)carboxy dianhydride + diaminophenyl trimethyl indane



Solvent-Soluble Polyimides:

- Solvent-soluble polyimides are designed to address limitations related to solubility in organic solvents, a crucial aspect in microelectronic applications.
- Modification involves incorporating bulky groups (e.g., trifluoromethyl or sulfone), bridging groups, and metal-linked diamines to enhance solubility and facilitate easy removal for reworking and component repair.

These examples highlight the diverse molecular structures achievable through variations in diamine and anhydride components, enabling the tailoring of polyimides for specific applications. The development of solvent-soluble variants enhances their usability in critical microelectronic applications.

Solvent-Soluble Polyimides: Advantages and Applications:

Material Properties	Polyimide (PI2555, Dupont)
Polymer type	Amorphous thermoset spin-coated
Thermal properties	
Glass transition temp. (T_g)	325
Melting temperature ($^{\circ}C$)	-

Thermal expansion coefficient at 25 °C, X 10⁵ (C⁻¹)	5.0
Barrier properties	
Water absorption (%)	N/A
Solvent resistance	N/A
Electrical properties	
Dielectric constant	3.4
Dissipation factor at 1MHz	0.0018
Other properties	
Young's modulus (GPa)	2.5
Optical Transparency	N/A
Biocompatibility	N/A

Advantages:

1. Stability and Shelf Life:

- Supplied as fully amidized or pre-polymerized, ensuring stability at room temperature and a long shelf life.
- Lack of water release during the curing process contributes to stability and reliability.

2. Thermal Crosslinking:

- Capable of undergoing thermal crosslinking at temperatures ranging between 200 to 350 °C.
- Forms dense coatings with minimal or no shrinkage during the curing process.

3. Chemical Resistance:

- Coatings exhibit chemical resistance to most organic solvents, enhancing their durability in various environments.

4. Controlled Viscosity:

- Precise control of polyimide viscosity allows the application of very thin coatings, ranging from 0.5 to 5 microns.

Applications:

1. Passivation Coating:

- Used as passivation coatings in electronic applications to protect surfaces and components from environmental factors.

2. Interlayer Dielectric:

- Applied as an interlayer dielectric in integrated circuits, providing electrical insulation between different layers.

3. X-ray Mask:

- Utilized in the fabrication of X-ray masks, contributing to precision imaging processes.

4. Planarization Coating:

- Used as planarization coatings to achieve a flat and even surface, crucial in certain manufacturing processes.

5. Alpha Particle Barriers:

- Applied as barriers against alpha particles in integrated circuits, preventing potential interference.

Properties (Example):

- **Polymer Type:** Amorphous spin-coated thermoset
- **Glass Transition Temperature:** 325 °C
- **Thermal Expansion Coefficient:** 5.0
- **Dielectric Constant (ϵ):** 3.24
- **Dissipation Factor (1 Megahertz):** 0.0018

Additional Considerations:

- Properties such as Young's modulus, optical transparency, and biocompatibility may also be important for specific applications.

Solvent-soluble polyimides offer a range of advantages and find specialized applications in the electronics industry, particularly in integrated circuits, where their stability, controlled viscosity, and chemical resistance play crucial roles.

Photosensitive Polyimides: Features and Applications:

Advantages:

1. Processability:

- Easily processed through techniques like spin coating, casting, and solution deposition, facilitating efficient fabrication processes.

2. Flexibility:

- Can be formulated to exhibit a high degree of flexibility, making them suitable for applications in flexible electronics and displays.

3. Chemical Resistance:

- Demonstrates resistance to a wide range of chemicals, including acids, bases, and solvents, enhancing their durability in various environments.

4. Thermal Stability:

- Exhibits excellent thermal stability, making them well-suited for high-temperature applications.

Disadvantages:

1. Limited Mechanical Strength:

- May have lower mechanical strength compared to other polyimides, restricting their use in structural applications.

2. Solvent Toxicity:

- Some solvents used in the dissolution of photosensitive polyimides can be toxic, requiring careful handling and proper disposal due to potential fire hazards.

Photosensitive Polyimides in Microelectronics:

• Patterning Through Photolithography:

- Capable of being patterned using photolithography, allowing for the precise formation of intricate structures in microelectronic circuits.

• High-Density Interconnect Applications:

- Applied in the fabrication of microelectronic circuits and high-density interconnects, where precision and miniaturization are essential.

Photosensitive polyimides play a crucial role in the semiconductor industry, enabling the creation of intricate patterns in microelectronics. While offering advantages in processability, flexibility, chemical resistance, and thermal stability, it's important to consider limitations such as mechanical strength and solvent toxicity in their application. Careful handling and disposal practices are necessary to address potential safety concerns.

Photosensitive Polyimides: Synthesis and Applications

Synthesis:

- **Photoinitiator Addition:**
 - Photosensitive polyimides are synthesized by incorporating a photoinitiator into the polyimide precursor solution.
- **Photoinitiator Function:**
 - The photoinitiator, sensitive to ultraviolet light, generates free radicals upon exposure.
- **Crosslinking Reaction:**
 - Free radicals initiate a crosslinking reaction, resulting in the formation of solid polyimide films.

Fabrication Process:

1. **Film Formation:**
 - Polyimide film is initially formed.
2. **Photolithography:**
 - Coating the polyimide film with a photoresist layer.
 - Exposure to ultraviolet light through a photo mask.
 - Chemically altering the exposed photoresist areas.
3. **Selective Removal:**
 - Selectively removing altered photoresist areas using a solvent.

4. **Etching:**

- Etching the underlying polyimide film with a suitable etchant to create the desired pattern.

Advantages:

1. **High-Resolution Patterning:**

- Achieves high-resolution patterning, enhancing suitability for microelectronic circuits and high-density interconnect applications.

2. **Process Compatibility:**

- Compatible with standard photolithography processes, ensuring ease of integration into existing fabrication methods.

3. **Chemical Resistance:**

- Exhibits excellent chemical resistance, making it suitable for use in harsh environments.

4. **Thermal Stability:**

- Demonstrates excellent thermal stability, allowing application in high-temperature environments.

Photosensitive polyimides offer advantages in precision patterning, compatibility with existing processes, chemical resistance, and thermal stability. These characteristics make them valuable in the fabrication of microelectronic circuits and other applications requiring intricate patterns and robust material properties.

Disadvantages of Photosensitive Polyimides:

1. **Limited Mechanical Strength:**

- Photosensitive polyimides may exhibit lower mechanical strength compared to other polyimides, restricting their suitability for structural applications.

2. **Cost Constraints:**

- Photosensitive polyimides can be more expensive than alternative polyimides, which may limit their application in certain contexts.

In conclusion, while photosensitive polyimides offer advantages such as high-resolution patterning, process compatibility, chemical resistance, and thermal stability, it's essential

to consider their limitations, including mechanical strength constraints and cost implications. The choice of polyimide type depends on the specific requirements of the intended application. The information provided covers various aspects of polyimides, including synthesis modes, applications, and different classes, with references for further exploration. Thank you for your attention.