OVERVIEW OF POLYIMIDE PROPERTIES AND APPLICATIONS

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Abstract: *Polyimides are polymers obtained by sintering by simple polycondensation a one- or two-stage reaction between a diamine and a (aromatic) dianhydride in a polar aprotic solvent. From a chemical point of view, the polyimide is a polymer of imid monomers (CO-NR2). Polyimides have the following main properties: outstanding mechanical and electrical properties, high thermal stability, good biocompatibility and chemical resistance. Polyimides are used in biomedical, optoelectronic engineering, for microfabrication of MEMS and bio-MEMS devices.*
Keywords: *polyimides, polycondensation, bio-MEMS, photosensitive polyimide, fabrication*

1. INTRODUCTION

Because they meet certain technical requirements, polyimides (PIs or Kapton) are part of the "high performance" polymer class. They were invented by Dupont in the 1960s. Polyimides are polymers obtained by sintering by simple polycondensation a one- or two-stage (Step I: formation of polyamidic acid); Step II: conversion of polyamidic acid to polyimide) reaction between a diamine and a (aromatic) dianhydride in a polar aprotic solvent [17], [2], [5] (Fig.1). They contain in structure the functional group of molecules ($CO\text{-}NR_2$) called imide monomers. Essentially, from a chemical point of view, the polyimide is a polymer of imid monomers.
Polyimides can be classified, depending on the chemical structure of the backbone (Fig.2), according to the type

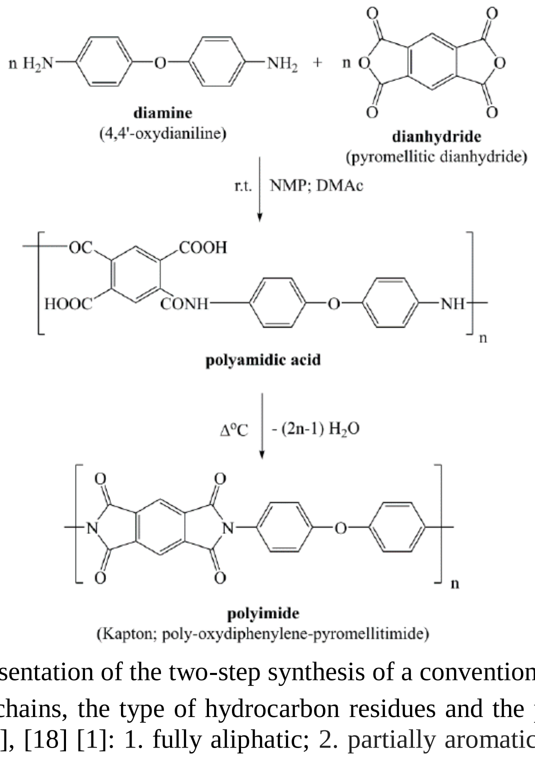

Figure 1: Schematic representation of the two-step synthesis of a conventional polyimide, after [1]

of interactions between the main chains, the type of hydrocarbon residues and the presence of other functional groups, in the following types [11], [18] [1]: 1. fully aliphatic; 2. partially aromatic; 3. fully aromatic (they are generally made from aromatic diamines and aromatic tetracarboxylic dianhydrides); 4. thermoplastic (pseudothermoplastic); 5 thermosetting. As monomers are combined in the polymer chain there are [16]: homopolymers (aromatic dianhydrides and aliphatic diamines; aliphatic dianhydrides and aromatic diamines) and copolyimides (various dianhydrides and aromatic / aliphatic diamines).
At polyimides, special inter- and intra-chain interactions are present. They derive from the imid moieties which are repeated [1].

At present, investigations are carried out mainly on aliphatic and aromatic polyimides, potential candidates for engineering and biomedical applications.

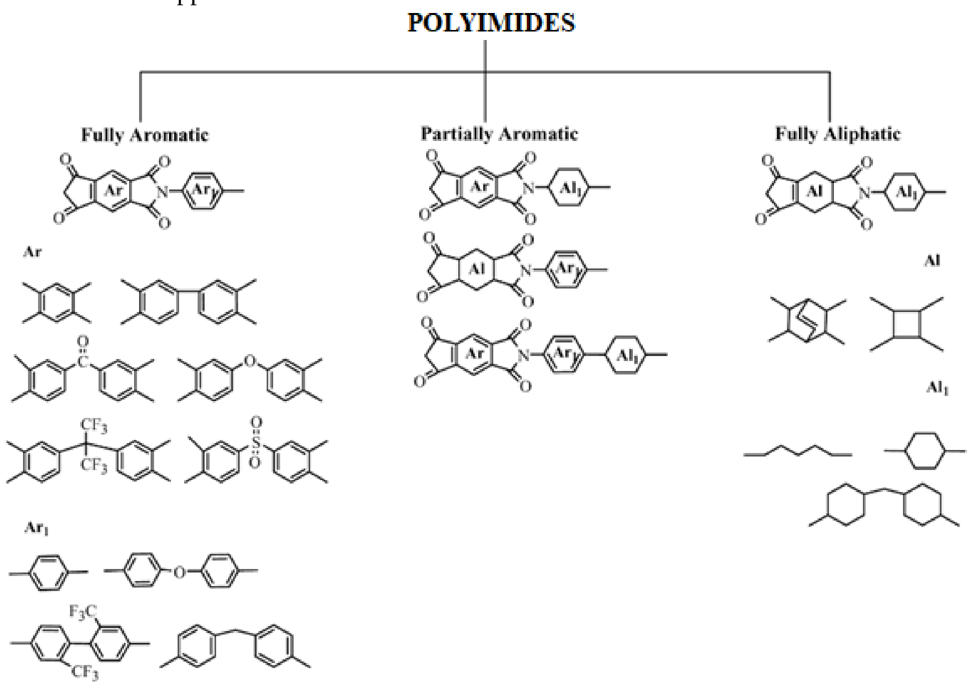

Figure 2: Classif ication of polyimides into 3 broad categories depending upon the chemical structure of the backbone, after [11]

2. THE PROPERTIES AND APPLICATIONS OF POLYIMIDE POLYMERS

Polyimides can be processed by several processes depending on the use of a variety of solvents [M]. Are characterized by the following properties: high thermal stability (due to its heterocyclic imide rings on the backbone, good biocompatibility, chemical resistance and solvent resistance, remarkable mechanical and electrical properties, low modulus, low moisture absorption etc. (Tab.1) [11], [1], [9]

Table 1: List of the electrical, mechanical, and thermal properties of polyimide, after [17], [15] [6], [9], [1], [17]

Property	Unit of measurement	Norm ASTM	Value
Mass density	[g/cm^3]	D792	1,3 – 1,7
Water Absorption (50% rh; %)		D570 / ISO 62-1	0,4 – 4,1
Possible thicknesses	[μm]		1 - 15
Young's modulus	[GPa]		2,5
Poisson ratio	to 23 [°C]		0,34
Tensile strength	[MPa]	D570 / ISO 62-1	231 at 23 [°C], 139 at 200 [°C]
Tensile module	[MPa]		8830
Flexural strength	[MPa]	ISO 178 / D790	42 – 170
Hardness (Rockwell)	-	D785	35 – 120
Coefficient of friction	-	D1894	0,17 – 0,77
Residual stress on silicon	[MPa]		35 to 5 [μm], on 8" wafer, 375 [°C] cure
Specific resistivity	[Ωcm]		> 10^{16}

Specific heat	[10^7 cm^2 /s^2 K]		1,13
Disruptive strength	[V/cm]		1,510
Melting point	-		Does not melt, Decomposes at 520°C
Thermal conductivity	[W/mK°C]		0,12
Thermal decomposition temperature	[°C]		> 550
Dielectric constant	[25µm, 1kHz]		3,4
Index of refraction		D542	1,2 – 1,9
Electrical conductivity	[e17 Ωcm]		1,5
Hydrophobicity	-		82 degrees
Chemical resistance	-		very good to excellent
Sterilization	-		autoclave, ETO, gamma, e-beam
Elongation	[%]		30
Loss factor	Tan δ		0,0013, at 1 [kHz]
Biocompatibility	Used in Bio-MEMS an implantable intracortical electrode array. Polyimide also provides an ideal surface for the selective attachment of various important bioactive species onto the device in order to encourage favorable long-term reactions at the tissue-electrode interface. Overall polyimide is a proven biocompatible material and an excellent choice for neuroprosthetic applications.		

Polyimide is commonly used in microfabrication as a flexible substrate (negative photoresist in a variety of fabrication techniques), as a sacrificial layer during MEMS fabrication or in independent structures released from the wafer [2], [14]. Microfabrication is the term used to describe a set of technologies or manufacturing techniques at the micrometer scale of electronic devices or MEMS (microelectromechanical systems) [3], [10], [14]. Polyimides have various applications in biomedical, optoelectronic, microelectronic engineering and in the manufacture of MEMS [7], [5], [14], [9], [4], [6], [12], [14].
The general properties of the polyimides (properties summary, fabrication overwiev, examples of applications and fabrication challenges) are summarized in Table 2.

Table 2: General properties of polyimides polymers, after [9], [14]

Properties summary	**Fabrication overview**	**Examples of applications**	**Fabrication challenges**
High thermal and chemical stability	Pattern photosensitive polyimides	Flexible microelectrode arrays	Poor adhesion onto materials
Low moisture absorption	Dry etching of using oxygen or fluorine chemistries	Capacitive Micromachined Ultrasonic Transducer (CMUT) sensor for aerospace applications	Significant shrinkage during imidization process
Tailorable film via chemical modification	Hot embossing capability	Microchannels; new and better devices, sensors (new type of ultrasonic sensor), and actuators	
Photosensitized formulations	Surface modification using plasma	Lab-on-a-tube technology	
Biocompatible	Excellent material for micro molds	Self-assembly via Imidization shrinkage	

Polyimide makes an excellent material for micro molds because they are easy to store and molded, they are durable and resistant to chemicals and thermal degradation. Through the use of thick polyimide sheets, high-ratio microelectronic devices can be obtained using the LIGA technique [14].

3. CONCLUSION

Polyimides can be classified in the following types: 1. linear polyimides (aliphatic); 2. semi-aromatic; 3. aromatic (they are generally made from aromatic diamines and aromatic tetracarboxylic dianhydrides); 4. thermoplastic (pseudothermoplastic); 5 thermosetting. Polyimide is commonly used in microfabrication as a flexible substrate (negative photoresist in a variety of fabrication techniques), as a sacrificial layer. Polyimides are used in microfabrication of flexible microelectrode arrays, microchannels; new and better devices, sensors (new type of ultrasonic sensor), and actuators etc.

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