Polyhydroxyalkanoates for Biodegradable Printed Circuit Boards (PCBs): A Review for Bio-Microelectronics

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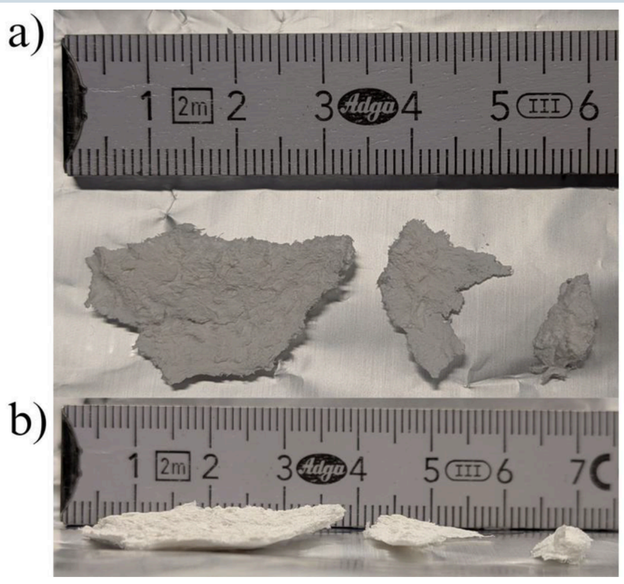


Figure 1: (a) Top view and (b) side view of some typical poly(3-hydroxybutyrate) (PHB) flakes. A millimetric ruler is included as a dimensional reference.

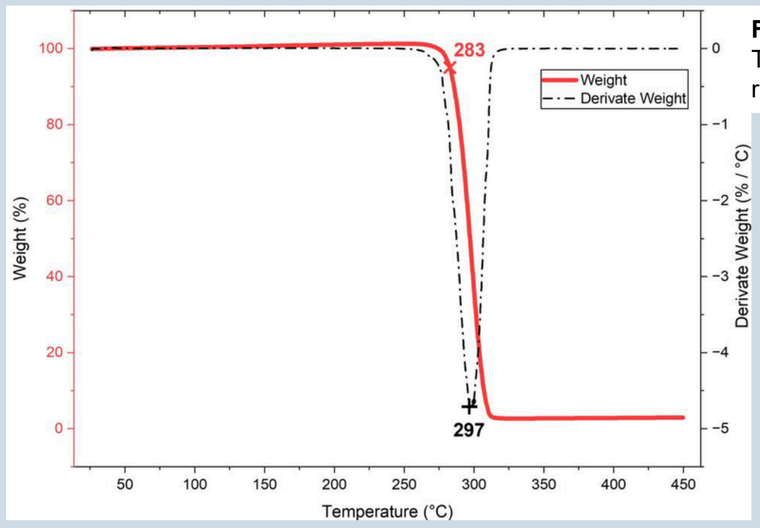


Figure 2:
Thermogravimetric analysis of PHB under nitrogen atmosphere with a heating rate of 10 °C/min: TGA (red) and DTG (black dotted) curves.

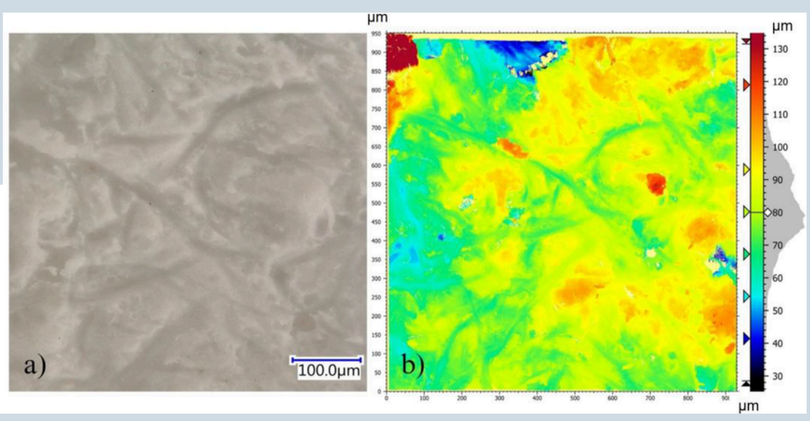


Figure 3: (a) Optical microscopy image of PHB surface at 500× magnification, showing irregular microstructure, localized inclusions, fine-scale crystalline domains and surface micro-roughness. (b) Three-dimensional surface topography obtained by optical profilometry 50× lens, presenting height distribution over a 950 µm × 950 µm area.

Physical-Chemical and Environmental Properties of PHB, PET and FR-4

	PHB	PET	FR-4
Density (g/cm^3)	1.25	1.30	1.96
Melting temperature (°C)	161	255	-
Glass transition temperature (°C)	-10	70	-
Superficial resitivity (MΩ)	-	10^8	4×10^7
Dielectric strength (kV /mm)	27	22	14.2
Tensile strength (MPa)	21	90	424
Water absorption (%)	0.7	0.07	0.4
Operating limit temperature (°C)	-	160	130
Global Warming Potential (kg CO2 eq.)	-3×10^{-1}	-	9.22×10^3
Human Health (kBq U235 eq.)	-2.2×10^{-1}	-	1.13×10^3

Table 1: Comparison of physicochemical and environmental properties of PHB, PET, and FR-4, highlighting the potential of PHB as a bio-based alternative for printed circuit boards. Sources [2-6]

Introduction

The insulating substrate of Printed circuit boards (PCBs) is typically composed of Flame Retardand 4 (FR-4), a fossil-based, flame-retardant material made of woven fiberglass reinforced with epoxy resin. FR-4 provides high mechanical strength, thermal stability, chemical resistance, and dimensional integrity; however, recycling is technologically complex and economically challenging. Consequently, mishandling of PCBs leads to the release of hazardous and persistent pollutants, posing severe risks to ecosystems and human health [1].

Redesigning electronic materials for improved end-of-life management is a priority. This work presents a structured evaluation of poly(3-hydroxybutyrate) (PHB) as a sustainable substrate material for bio-microelectronics.

The study integrates material processing strategies, additive manufacturing compatibility, physicochemical and thermal characterization, mechanical performance considerations, and eco-friendly recovery approaches to evaluate PHB as alternative material to FR-4 for biodegradable PCB.

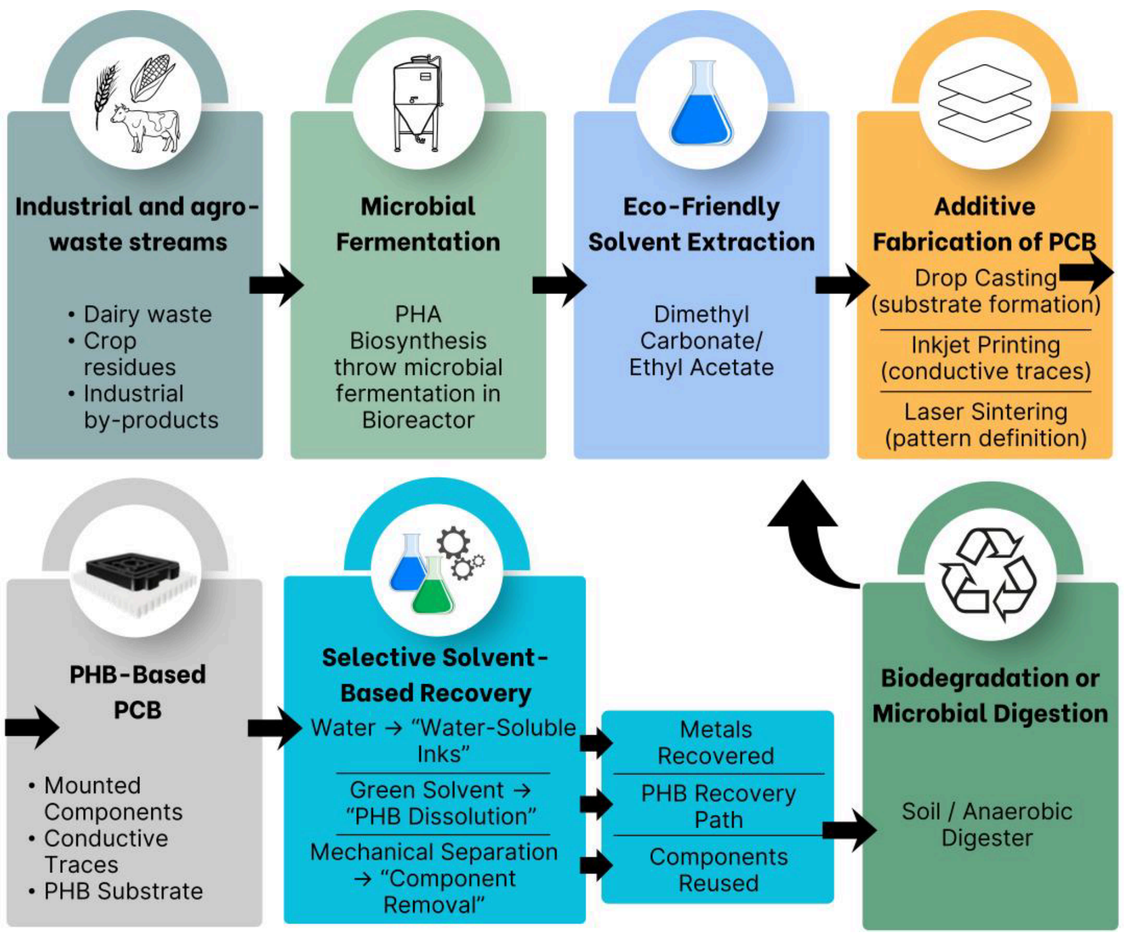
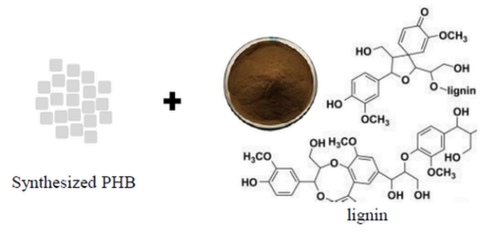


Figure 4: Scheme of key strategies for eco-friendly recovery in PCB manufacturing.

Process

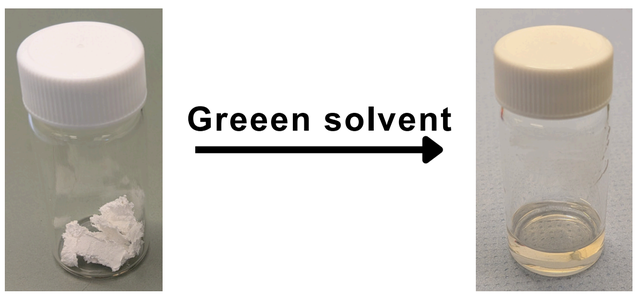
PHB extracted from *Cupriavidus necator* DSM 545 cells has been utilized for this study as flakes (Fig.1), after solvent extraction and oven drying. TGA and profilometry of the flakes are shown respectively in Fig.2 and Fig.3.

PHB samples have temperature resistance lower than traditional PCB's plastics; copolimerization and combination with other natural polymers can enhance their homopolymers properties.



Enhanced physiochemical stability (Melting temperature, Mechanical resistance)

- Lignin enhancement
- Formulation of solution with PHB in DMC
- Substrate formation from solution
- Conductive traces / mounted components



Challenges

Mechanical properties: Meeting industrial standards

Solvents recovery: Higher bio-polymer recovery and purity degree

Economic: High cost due to materials and fermentation processes

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