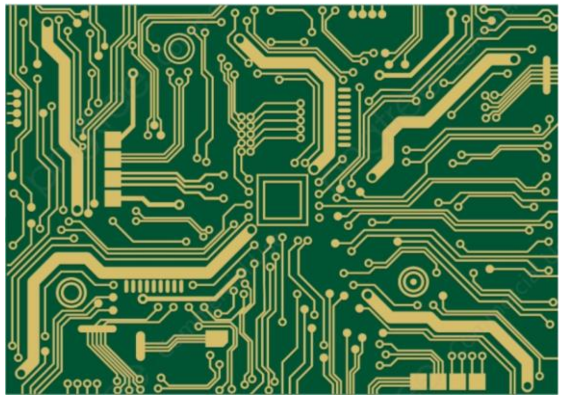
Printed Circuit Boards



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Outline

1. Abstract

In this document, we focus on Printed Circuit Boards. Printed Circuit Boards act as the skeleton to most of our electronics. Three topics surrounding PCBs will be covered: The board itself, efficiency, and environmental impact.

First, we understand what they are and their role, specifically in technology and electronics. PCBs are used in almost every aspect of our technology, connecting machine components via electrical signals. We look at factors that contribute to the overall efficiency of the board. Development in the etching process, microvias, and construction types all help maximize the board. Then, we look at the environmental impact of PCBs. The life cycle is examined, and find that the manufacturing process is responsible for much of the GHG emissions. Environmental impact (GWP) derives from three factors: laminate production, energy/water use, and chemical use. Then we end by looking at a possible alternative to traditional PCBs and find that paper-based electronics aren't quite up to date, but they are within reach and show a lot of promise.

2. Introduction

I will give a brief explanation of PCBs and their importance/usage in the market. Then, I will delve into the focus of the analysis, which is to seek the energy efficiency of the boards as well as the environmental impact they have. I will also share how the market is shaping the upcoming innovative boards.

3. Printed Circuit Boards

Printed Circuit Boards play an integral part in the technological realm. Before we get into the focus of the document, let us first breakdown, and understand what PCBs are. This section will entail an explanation of what PCBs are, the creation process, and the importance/usage of the boards.

3.1. What are they?

PCBs are boards that mechanically support and electrically connect electronic components or electrical components using conductive tracks, pads, and other features etched from one or more sheet layers of copper laminated onto/or between sheet layers of a non-conductive substrate. These boards have evolved significantly in the past few decades. They come in a wide range of sizes, each etched with an electric circuit designed for a sole purpose.

While researching the topic of PCBs, I came across a problem that many researchers like myself face when defining a PCB. The issue revolves around correct terminology; Printed Wiring Boards and Printed Circuit Boards are interchangeable. From my research, I found that the term PWB was the initial term for the boards. PWBs are the first stages of the PCB, so in a sense, they are the same thing, just that one evolved into the other, and we as an industry have adopted the term PCB.

3.2. How are they created?

Contemporary printed circuit boards consist of a compilation of layers mostly of fiberglass, laminate, multiple layers of circuit traces, the ground plane, and the power plane. Before the physical manifestation of a PCB can occur, you need to design the schematic in a software environment such as Allegro Cadence, PADS, or DesignSpark PCB. The process of board fabrication for the raw board is as follows: imaging, etching, layer bonding, drilling and plating, and surface finishing. It is also essential to know that there are different construction types of boards. This document will refer to two types: conventional multi-layering and high-density interconnect.

3.3. Importance and Usage

Printed Circuit Boards play an integral part in many of our lives. Whether we know it or not, PCBs act as the foundational hardware for most of our electronics. They give mechanical support to electronic components, which encapsulates our technology today. It's what provides the functionality to our mouse when we plug it into the USB port of our computer. The PCB in the mouse connects to the motherboard inside our machine and gives it functionality!

"Ranging from cell phones, consumer electronics, automotive, to sophisticated computer systems" (Nothdurft et al. 1). Any piece of hardware that has circuits printed and etched into the board is a PCB. With that said, we can quickly identify uses for PCBs: motherboards, graphics cards, SSD drives, any external hardware device, etc.

4. Efficiency

"The demand for PCBs has increased constantly, leading to an entrenchment of PCBs from the 1970s in nearly all branches of electronics. Since then, the electronic industry has experienced rapid developments" (Nothdurft et al. 1). As time has passed, the growing popularity of PCBs has created a demand for efficient and power-packed PCBs. The etching process, microvias, and construction types are the three factors that have contributed a significant portion to the efficiency of the boards.

4.1. Etching Process

The etching process is imperative to maximizing reliability and usage. The etching is the task of removing copper resist from the traces and pads to be soldered during assembly for all layers that will carry signals. As the miniaturization of electronic products continues, precision is now more critical than ever. With the advancement of thinner and more delicate copper coils coupled with the various layers, weak copper/epoxy joints are bound to occur. This tradeoff for efficiency has called for a need to promote adhesion between individual circuit board layers.

4.2. Microvias

Microvias are conductive holes that serve three purposes. One purpose for microvias is to penetrate all of the PCB's layers. Buried vias which sit in the middle of the PCB have no path to the exterior. Blind vias don't pass through the whole board but connect the PCB's surface to at least one interior layer. "According to IPC standards, buried and blind vias must be 150 micrometers in diameter or less. It allows them to connect the high-density layers of advanced PCBs" (Roettinger). Microvias are now standard practice in all types of PCBs; they allow for increased connection density due to tighter pitch features. This implementation of the boards helped with the miniaturization and efficiency.

4.3. Construction Types

We will discuss two types of construction: Conventional Multi-Layering (CM) and High-Density Interconnect (HDI). We will also look at the PCBA process and see how electrical components have impacted efficiency.

It's worth noting that the first boards were called Printed Wire Boards, and these boards only had one layer, the architecture was a lot simpler than the ones we use nowadays, and it was appropriate for the time.

4.3.1 CM and HDI

CM construction is known as conventional multi-layering and is the most common form found. The designs became multi-layered and ready to handle more than 20 voltage rails to optimize the interactive circuitry, as seen in Fig. 1. The miniaturization of layouts led to higher densities is vital to increasing efficiency and the overall proficiency of our electronics.

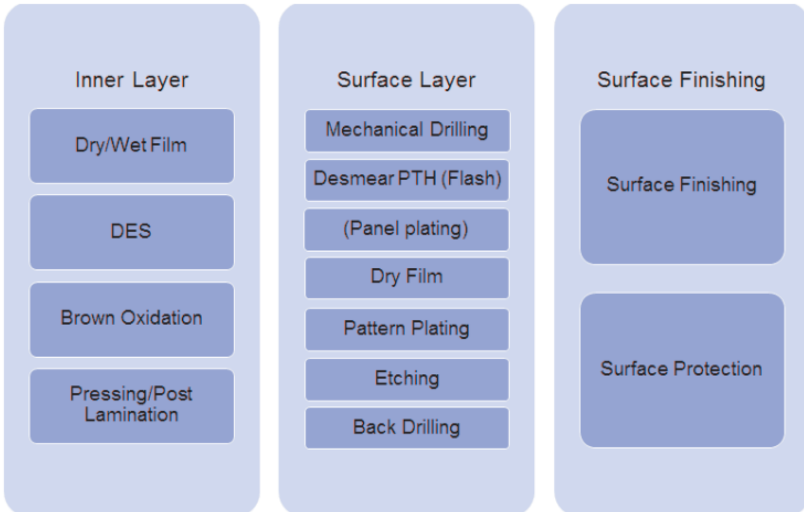

Fig. 1. Image is taken from (Erkko et al. 121).

Note: Conventional Multi-Layer fabrication process flow.

HDI Construction is a newer technology. HDI construction allows for board thinning, a decrease in layer count, and miniaturization of the device. Although the tradeoff for greater efficiency is the intricate design and use of material, as seen in Fig. 2. “One build-up layer in HDI for a four-layer board can provide the same number of connections as a 10-layer CM design. HDI construction can also lead to reduced area, upwards of 40% in some cases” (Alcaraz Ochoa et al. 5).

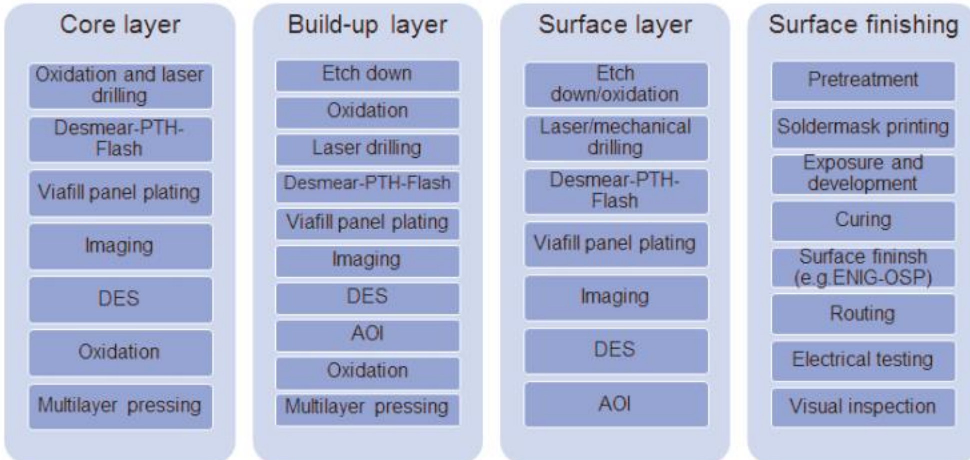

Fig. 2. Image taken from (Erkko et al. 122).

Note: HDI fabrication process flow.

4.3.2. PCBA

PCBA is the process of assembling components to the bare PCB on the surface layer. An example of a PCB is a motherboard. Every motherboard is a PCB, but not every PCB is a motherboard. Motherboards in the context of a computer system generally consist of BIOS and CMOS, I/O ports, IDE and SATA connectors, Power connectors, a CPU socket, Expansion card slots, and RAM slots. With the optimization of integrated circuits (IC), capacitors, resistors, and voltage regulator modules (VRM’s); the PCB can support each of these components and still perform at a high level even when the surface mount technology itself is advancing.

5. Environmental Effects

We examine the ecological effects of PCBs through the life cycle of the boards. We will explore two events of the life cycle: the manufacturing process of PCBs and the degradability of the boards (i.e., if the materials used can be recycled). Calculating the environmental effects from the manufacturing process is done through a GWP method, which examines how construction types and board size effect it. Calculating the degradability is done by reviewing the materials used to create the boards. We conclude by considering a feasible alternative to the traditional PCB.

5.1. Life Cycle

"Life cycle assessment (LCA) is an established approach used to determine environmental impacts such as the GHG emissions for a particular product, system, or population. For a product, it measures the emissions associated with the extraction of raw materials, production of materials and components that make up the product, sub-assembly and assembly, transportation and packaging, in-service operation, and end of life disposal" (Erkko et al. 120). Recent studies indicate that the manufacturing stage of electronics contributes a large portion of the emissions in a product's life cycle and that the fabrication process of PCBs is mainly responsible.

5.1.1 Manufacturing Effects

"As devices become more energy-efficient and consumer dependence on mobile electronics increases, the calculation of emissions becomes less important from a per-device inspection and more important to the cradle-to-gate including detailed studies of certain components" (Alcaraz Ochoa et al. 1). Since we've determined that PCBs are the root of almost all electronics, it is more intuitive to study the emissions from the manufacturing process of the bare boards rather than the many branches of electronics that use the boards. The global warming potential (GWP) is used to determine the environmental impact.

5.1.1.1. GWP Method

The introduction of the HDI construction within PCB manufacturing provides an opportunity to assess the ecological effects of PCBs as a function of design. The unit used to determine environmental impact is the global warming potential (GWP). The parameters used to calculate GWP are the laminate production, energy and water consumption in board manufacture, and process chemicals.

The Greenhouse Gases (GHG) impact is from emission factors caused by laminate manufacturing based on average component weight.

Electricity and water usage were measured via meters placed on a component level, with each component encompassing a defined set of manufacturing process steps (the inner layer, the core layer, the buildup layer, the outer layer, and the surface finish layer.)

The method used to calculate the GHG emissions of chemical use depended on the rate of chemical used by the consumption mass per component averaged over the square meter of produced material. (laminate/PWB).

5.1.1.2. Effects of Construction Type and Board Size

Data collection indicated that the total GWP emissions increase as the number of layers increases for both HDI and CM designs. Still, the amount of GWP increase depends on the type of layer added. The percentage of GWP did increase as the number of printed and etched layer pairs increased for both types. As for board size, the relationship between GWP and the area of the board is directly proportional.

It is important not to compare CM and HDI, as there are underlying factors that affect the GWP. As we now know, HDI fabricated boards are denser and thus more useful than CM boards, so comparing the two would not provide helpful insight. The same applies to the board size. It is not logically correct to compare a fixed size board of CM construction to an HDI construction because although the areas are the same, they do not perform the same function; as a result, skewing the GWP results.

5.1.2. Biodegradability

The PCB industry brings about potential environmental issues in the waste disposal and recycling stages. “It is estimated that globally, 20-50 million tons of waste electrical and electronic equipment (WEEE) are discarded annually” (Liu et al. 2). The waste from all kinds of WEEE contains many toxic substances, such as organic compounds, heavy metals, and brominated flame retardants. Each of these substances can cause severe damage if not disposed of correctly. “The consumption of copper in the PCB production as the life cycle of copper contributes the most to AP (45.15%), EP (63.56%), FAETP (89.52%), HTP (84.02%), TETP (85.09%), POCP (38.06%) as a result of the energy consumption and emissions (gas emissions such as CO2, SO2, NO2, and wastewater emission) in the mining and refining processes of copper” (Liu et al. 6).

5.2. New Science/Technology

Paper-based electronics have caught the eyes of many. Its unique characteristics, including flexibility, foldability, lightweight, degradability, and low-cost, are all sought after. Creating a paper-based alternative to PCBs has been thought of but never implemented. Everything explained is purely theoretical based on a prototype model that was made to compare the environmental effects to the traditional PCB.

5.2.1. P-PCB

The methodology used to create the prototype revolved around the LCA. “LCA results can provide us guidance of materials selection, product design, recovery mode, and even policy-making so that we can focus research efforts on minimizing the burdens of a product while maximizing its benefits.” (Liu et al. 2). The fabrication of the P-PCB is vastly different than that of traditional PCBs. The simple additive process used for the schematics is as follows: 3-D printing, inkjet printing, and screen printing. Another significant change is instead of using copper for the conductive filament; they use silver.

5.2.2. P-PCB vs. O-PCB

The comparison of P-PCBs and O-PCBs revolves around two factors. The environmental impact and the effectiveness of the boards.

5.2.2.1. Environmentally

The studies show that the ecological burdens of P-PCBs are two orders of magnitude less than those of O-PCBs. The result started by investigating the raw materials, the fabrication method, and the degradability of the boards.

The raw materials of the paper-based boards are simple and ecologically friendly, more than 80% of the raw material is cellulose paper, and the harmful substances account for less than 5% of the boards. Whereas, traditional PCBs use hazardous materials like epoxy resin, copper foils and filament, and glass fibers. In the fabrication process, P-PCBs have a more straightforward and less energy-dependent process, as opposed to the vast quantities of energy used and copper needed for O-PCBs. In Fig. 3. we see the difference in emissions from the two boards. Lastly, the high-content of paper in the P-PCBs makes it easy to recycle. On the other hand, the many harmful substances in O-PCBs are difficult to deteriorate, let alone dispose of safely.

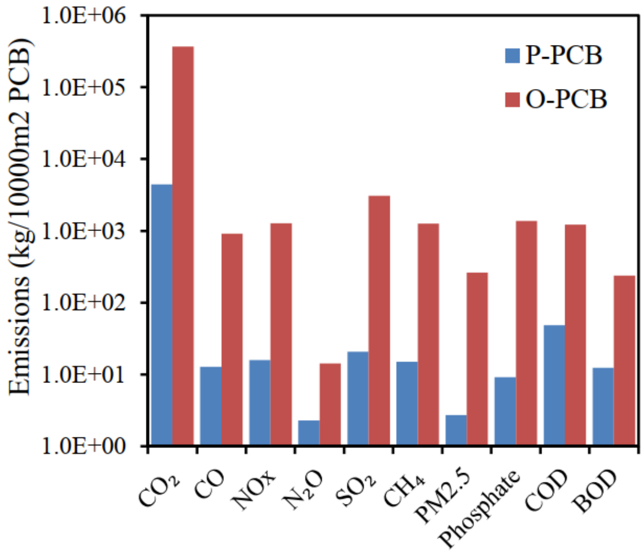

Fig. 3. Image is taken from (Liu et al. 6).

On paper, P-PCBs seem like the apparent change, but we must also look at the power output of both boards. It's without a doubt that minimizing environmental impact is essential, but we cannot overlook our necessity for power that we expect from our technology and electronics.

5.2.2.2. Proficiency

After testing both boards, the results came in favor of the O-PCB, but we cannot discredit the potential of the P-PCB. Both boards performed well when put through a temperature-humidity (85°C/85RH) and thermal-cycling test (-40~125°C) to determine their reliability. Downsides of the P-PCB that do effect proficiency is the line spacing, line width, and dielectric property (dielectric loss); they are inferior to that of O-PCBs. Although it is still enough to operate with low density and low-frequency PCB applications comfortably.

With the current development of paper-based technology, the P-PCB can only meet the needs of low-density applications. There are still many characteristics of the board that must develop before we can consider making the switch. That is without saying that many of the features like thermal conductivity, dielectric properties, fire-resistance, moisture resistance, and conductivity, can be feasible soon. Which would vastly change the environmental impact positively.

6. Conclusion

In conclusion, we have a solid understanding of printed circuit boards and their implementation in technology. We reviewed the creation process of the raw boards under two construction types. We investigated methods such as multilayers and HDI construction and understand how vital the etching process and microvias are to efficiency. The environmental impact that manufacturing PCBs at such a high-level proved to have some consequences, a GWP scale was used to determine its effects. GWP increased dependent on the board size and the strength of the board. Finally, we investigated a plausible future for PCBs in the form of paper to reduce adverse environmental impact. We noted that P-PCBs are indeed more environmentally friendly, but in terms of proficiency, they are not on par with O-PCBs.

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Grammarly notes: The word “microvias” may pop-up as an error when you submit my document through Grammarly. I added the word to my Grammarly library, so you should do the same. We spoke about this during office hours.

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