UNIVERSITI TEKNOLOGI MARA

ELECTRICAL AND CONDUCTIVE PROPERTIES OF EPOXY BASED CONDUCTIVE INK FILLED WITH GRAPHITE AND CARBON BLACK

NUR DIANA NASUHA BINTI MOHAMAD KAMSANI

Thesis submitted in fulfilment
of the requirements for the degree of
Master of Science
(Applied Chemistry)

Faculty of Applied Sciences

October 2025

ABSTRACT

This study addresses the global rise in electronic waste by developing an environmentally friendly, carbon-based conductive ink free of metal content. The objective was to formulate a conductive ink using epoxy resin as a binder and Carbon Black (CB) and Graphite (GP) as conductive fillers, investigating both their individual and combined effects to optimize electrical conductivity and adhesion properties. A series of ink formulations with varying CB and GP concentrations (0–25%) and combinations of CB-GP conductive ink in varied ratios were prepared and screen-printed onto polyethylene terephthalate (PET) substrates. Key characterization techniques included X-ray diffraction (XRD), UV-Visible spectroscopy, Fourier-transform infrared spectroscopy (FTIR), and field emission scanning electron microscopy (FESEM) to assess material structure, filler interaction, and dispersion quality. The findings revealed that while individual fillers provided moderate conductivity, the synergistic combination of CB and GP significantly enhanced performance. The epoxy composite with 20% CB achieved a conductivity of approximately 3.66×10^{-3} S/m, and 15% GP alone reached 3.77×10^{-3} S/m, as measured by Electrochemical Impedance Spectroscopy (EIS). However, the optimized ink at a CB:GP ratio of 1:2 exhibited a peak conductivity of 3.87×10^{-3} S/m, confirmed through EIS, with consistent results from two-point and four-point probe measurements. FESEM imaging showed a uniform dispersion of CB and GP particles forming a dense, interconnected conductive network within the epoxy matrix, facilitating efficient electron transport pathways. FTIR analyses confirmed the physical integration of fillers within the epoxy matrix, indicating good compatibility between components and contributing to the network's stability. Adhesion testing demonstrated excellent ink-substrate compatibility. The optimized 1:2 CB-GP ink showed a wettability contact angle of 36.8°, indicating good surface affinity, while pull-off tests recorded a strength of 0.41 MPa, confirming robust mechanical interlocking. Cross-cut adhesion tests further validated the coating's integrity without delamination or fragmentation. Theoretically, this study advances understanding of the synergistic role of filler morphology and dispersion in polymer-based conductive systems. Practically, it presents a sustainable, cost-effective conductive ink suitable for printed electronics applications such as RFID tags, sensors, flexible displays, and electrical circuits. This work offers a promising approach for e-waste upcycling through innovative conductive ink formulation.

ACKNOWLEDGEMENT

First and foremost, I would like to express my deepest gratitude to Ts. Dr. Zuliahani Ahmad, my supervisor, for their invaluable guidance, unwavering support, and constructive feedback throughout this research journey. Their expertise and encouragement have been instrumental in the completion of this thesis. I extend my heartfelt thanks to UiTM Perlis Branch, USM, UNIMAP, and HCMUT for providing the necessary resources, facilities, and opportunities to carry out my research. I am sincerely grateful to Dr. Solhan Yahya and Ts. Dr. Azniwati Abd Aziz for their insightful suggestions and critical input, which greatly enriched the quality of this work. I also extend my gratitude to other lecturers who contributed by sharing their expertise and valuable thoughts, which were immensely helpful in this research. Special thanks go to my colleagues and peers in the Araucat Postgrad Group for their camaraderie, discussions, and moral support, which made this journey less daunting. I would also like to acknowledge UiTM for the Geran Insentif Penyeliaan (GIP), which provided the financial support that made this research possible. On a personal note, I am deeply indebted to my family and friends for their constant encouragement, understanding, and patience during challenging times. Their love and belief in my abilities have been my greatest source of strength. Lastly, I express my gratitude to everyone who contributed to this work, directly or indirectly, and helped make this achievement possible. Thank you all.

TABLE OF CONTENTS

CHAPTER 1
INTRODUCTION

1.1 Research Background

The fabrication of electronic devices such as displays, sensors, current-collecting grids, and radio frequency identification (RFID) tags using low-cost, high-throughput, eco-friendly solution-processed electronics has drawn considerable attention as an alternative to conventional manufacturing methods (Liu et al., 2021). Printing technologies enable the deposition of conductive inks onto substrates to create customized electrical patterns on a variety of materials, including polymers, silicon, textiles, and paper (Htwe & Mariatti, 2021). Compared to traditional techniques such as copper etching, printing offers a purely additive process, minimizing material waste and simplifying production steps. However, despite these advantages, the development of high-performance conductive inks faces several unresolved challenges that limit their broader adoption in commercial applications. One major issue is the difficulty in formulating inks that simultaneously achieve high electrical conductivity, mechanical robustness, and environmental sustainability. The trade-off between these properties remains a critical barrier. For instance, while metallic fillers like silver offer excellent conductivity, they are costly and prone to oxidation. Meanwhile, carbon-based fillers are more sustainable but tend to suffer from agglomeration, resulting in poor dispersion and reduced electrical performance. Achieving a homogeneous conductive network remains a technical hurdle, especially in carbon-based formulations. This persistent challenge motivates research into synergistic combinations of filler such as graphite and carbon black to enhance particle dispersion, interconnectivity, and ultimately, electrical performance. Addressing this gap is essential for advancing eco-friendly printed electronics. Conductive inks typically comprise solvents, binders, and conductive fillers, where the binder plays a key role in dispersion and adhesion, and the filler contributes to conductivity (Saad et al., 2021). Thermoset binders such as epoxy, polyurethane, and silicone have been widely used due to their mechanical strength and compatibility with conductive nanoparticles or microparticles of highly conductive materials such as silver, copper, zinc, or carbon (Saad et al., 2020). An ideal conductive ink should exhibit good printability, low viscosity, high conductivity, strong substrate