

CHAPTER 1 FUNDAMENTAL IN APPLIED METHODOLOGIES FOR MATERIALS PROCESSING AND SIMULATION

Nor Akmal Fadil and Wan Fahmin Faiz Wan Ali

1.1 INTRODUCTION

Materials research is the cornerstone of innovation across virtually every engineering discipline (Wellmann, 2021). From semiconductors in electronic devices to advanced composites in aerospace, from bio-compatible alloys in medical implants to corrosion-resistant coatings in the oil and gas industry, the progress of modern technology hinges upon the ability to understand, design, synthesize, and optimize materials. At the heart of this endeavour are the methods employed to study and manipulate materials.

This book, *Applied Methodologies for Materials Processing and Simulation*, explores diverse yet interconnected experimental and computational methodologies that underpin contemporary material science and engineering. It brings together contributions from researchers across academia and industry, showcasing their work in areas such as electroless and electrodeposition, whisker growth phenomena, deep learning models for process prediction, and natural fiber composites. The aim is

to provide readers with both a theoretical foundation and practical insight into advanced techniques in materials research.

The following sections offer a thematic overview of the chapters presented in this volume and elaborate on how each contributes to the broader context of material science and engineering research.

1.2 MITIGATING TIN WHISKERS IN ELECTRONICS VIA ELECTROLESS DEPOSITION

The chapter examines electroless deposition as a key technology for metallizing electronic integrated circuit packaging. Unlike traditional electrodeposition, electroless plating does not rely on external electric current; instead, it uses a chemical reduction mechanism to deposit metals such as copper and nickel (Buylov, 2023). This process is especially suitable for high-aspect-ratio features, as it ensures uniform metal deposition on the entire via surface. It is scalable, low-cost, and compatible with sub-10-micron geometries.

A major focus of the chapter is on the reliability challenges posed by metallic whiskers, the microscopic filamentary growths that can lead to electrical short circuits. Historically observed in tin coatings, recent studies have shown similar concerns in copper-based metallization, particularly in high-density interconnects. The authors detail the fundamental theories of whisker growth, including:

- (1) Grain boundary diffusion: Where atoms migrate due to stress gradients.
- (2) Oxidation theory: Explaining how oxide layers act as barriers, leading to stress accumulation.
- (3) Recrystallization theory: Emphasizing the role of oblique grain boundaries.
- (4) Dislocation theory: Where dislocation climb and glide are hypothesized to cause atom movement.

The chapter also outlines experimental approaches such as environmental testing (varying temperature and humidity), micro-indentation for stress induction, and characterization tools like Field Emission Scanning Electron Microscopy (FESEM) and energy dispersive X-ray (EDX) spectroscopy. The electroless Ni underlayer is proposed as an effective mitigation strategy.

1.3 SINGLE BATH BRASS ELECTROPLATING FOR STEEL CORDS

This chapter bridges materials science with industrial manufacturing, particularly in the tire industry. Brass electroplating is a critical process in preparing steel cords that reinforce rubber tires (Polyakova, 2021). A single bath approach simplifies processing, reduces waste, and enhances cost efficiency.

- (1) The authors investigate the effects of several plating parameters:
- (2) Current density: Affects deposition rate and coating morphology.
- (3) Pyrophosphate concentration: Influences bath stability and metal ion availability.
- (4) Copper content modification: Alters alloy composition and mechanical properties.

The chapter includes multiple evaluation methods such as surface roughness measurement, grain size analysis, scratch tests, and rubber adhesion pull-out tests. These analyses are crucial in ensuring that the coatings provide optimal adhesion and fatigue resistance. The study emphasizes the balance between mechanical strength and ductility, and the role of electrochemical conditions in achieving uniform alloy composition. The authors present a comprehensive methodology that can be adapted in industrial plating lines.