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Review

Advances on potential-driven growth of metal crystals from ionic liquids

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ABSTRACT

This article highlights the electrodeposition of metals, in crystalline or amorphous form, that are momentous in the present era of science and technology. Available literature related to nucleation and growth of metal crystals has been reviewed to gain insight into the mechanism and kinetics. The progress made in the electrodeposition technique, using an ionic liquid (IL) medium, has been detailed for selected metals using different ILs for achieving the controlled growth mechanism driven by electrochemical potential. Theoretical models for nucleation and growth of crystals by electrodeposition have been explained and the effect of crystallization overpotential on the growth of crystal growth has been discussed. Finally, the factors affecting the growth process and the mechanism have been identified and critically analyzed based on the available literature, fundamental knowledge-base, chemistry of ILs, and electrodeposition.

1. Introduction

The exploitation of metals with desirable morphology through controlled growth and structure-property correlation paved the way for widespread industrial applications, which is responsible for the modern world we live in today [1]. The advent of nanotechnology has radically expanded the scope and the properties of metals leading to manifold applications in science and technology [2]. To exploit the full potential, the nucleation and growth, the crystallinity, the mechanism and kinetics for growth of metals need to be explored to optimize for shaping metals with desirable morphology for task-specific applications including electronics, optics, sensors, automotive, catalysis, aerospace, etc. [3].

The growth of metals is in principle a 'bottom up' approach [2]. The controlled synthesis, growth, or transfer of metals more often as thin films on a substrate is referred to as growth or deposition. A thin film is a layer of metals that ranges in thickness from fractions of a nanometer to several micrometers. Depending on the growth condition, the final deposit can be amorphous, polycrystalline, or crystalline. Growth in an orderly repeating pattern extending in all three spatial dimensions forms crystalline whereas the absence of a repeating ordering pattern of the constituent metals results in amorphous growth. Epitaxial growth is a term used to describe deposition procedures that result in crystalline material [2]. If a seed nucleus is not added intentionally for inducing further growth, the nucleation may be homogeneous or heterogeneous.

A variety of techniques have been used to deposit solid metals from precursor materials, which include: physical vapor deposition (PVD)

[4], chemical vapor deposition (CVD) such as ultra-high vacuum CVD (UHCVD), CVD parylene deposition, plasma enhanced CVD (PECVD), low pressure CVD (LPCVD) [4], thermal oxidation [4], atomic layer deposition (ALD) [4], molecular beam epitaxy (MBE) [4], thermal spraying [3], hot dipping [5], sputter deposition [3,5,6], roll binding, self-propagating high-temperature synthesis (SHS) [7,8], and electrodeposition/electroplating or electrochemical deposition (ECD). The technique to be used relies on the metal to be deposited, desired characteristics, and tolerance of the substrate for temperature. The quality of the deposit, in particular, morphology and crystallinity as well as functionalities immensely depend on the techniques of preparation. Despite success in many cases to deposit a wide range of metals, other techniques are not suitable for large scale applications except electrodeposition due to their high cost resulting from the requirements of ultra-high vacuum or high temperature, set-up, and limited tunability in addition to the toxicity to humans as well as to the environment [3].

Deposition of metals using electrochemical methods in the electroplating industry dates back well over 100 years [9,10]. Formation of metal particles in electroplating may be both spontaneous and non-spontaneous. The latter can be driven to occur by applying electrochemical potential, called electrodeposition, that is, the deposition via the reduction of ions dissolved in a liquid medium by applying electric potential/current energy (vide infra). In this technique, the growth of metals onto the substrate takes place and the liquid medium in which ions are dissolved must be sufficiently conductive. Electrodeposition has been considered to be a very efficient and superior preparation method

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