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Electrical properties of MXene thin films prepared from non-aqueous polar aprotic solvents

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For sustainable energy technologies, MXenes offer unique properties such as high electrical conductivity, hydrophilicity, excellent thermal stability, large interlayer spacing, easily tunable structure, high surface area, and microporous structure that facilitate faster ion transfer. To address limitations of aqueous MXene suspension, Ti_3C_2-type MXene thin films are prepared from non-aqueous suspensions in *N*,*N*-dimethyl formamide (DMF) and *N*-methyl-2-pyrrolidone (NMP) using solvent exchange method followed by spin coating or drop casting on gold interdigitated electrodes (IDE) and ceramic substrates and their electrical properties are compared. Electrical properties investigated by impedance spectroscopy (4 Hz to 8 MHz) and four-point probe (FPP) measurements show that DMF-MXene layers exhibit higher electrical conductivity than MXene deposited from NMP. The material technology and electrical properties of MXene thin films prepared from non-aqueous solvents may thus be promising for possible use of MXenes in hybrid photovoltaic devices as charge-transporting layers.

Introduction

Over the last decade, MXenes have attracted increasing attention due to their unique properties such as two-dimensional (2D) microstructure, metallic conductivity, surface hydrophilicity, and prospective applications from biology to energy harvesting and storage [1]. MXene represents a new class of 2D materials that can be named with the general formula $M_n+1X_nT_x$, where M is a transition metal, X is carbon or nitrogen, and T is a surface functional group (–OH, –O, and/or –F) [2]. MXenes exhibit excellent electrical and mechanical properties compared to other low-dimensional materials [3]. Recent studies of Ti_3C_2-type MXene have shown the highest electrical conductivity (15,000–20,000 S/cm) obtained so far for any 2D suspension-processed material [4, 5]. MXene films, in particular $Ti_3C_2T_x$, have higher electrical conductivity than exfoliated graphene, metal sulfides/hydroxides, etc. [6]. Due to their high conductivity, MXenes have a significant advantage over other nanomaterials, including reduced graphene oxide, for the production of conductive nanocomposites [7–9]. The electrical conductivity of MXenes also depends on the morphology. MXene nanoparticles or flakes have a typical 2D lamellar structure. Ultrathin, compact MXene films with highly aligned flakes exhibit very high electrical conductivity. Grain boundaries can also affect the behavior of electron hopping, smaller flakes correspond to more particle boundaries, and thus more interparticle contacts, resulting in lower electrical conductivity of the films. This is best evidenced by the much higher conductivity of flakes produced by a spin coating method, which produces more compact films with easier electron hopping transport.

Functional groups on the surface make MXenes hydrophilic and stable when stored as highly concentrated suspensions in water [10]. Abundant data are available in the literature on the colloidal properties of MXenes in water, but studies evaluating MXene thin films cast from different solvents are very limited so far [11]. The study of electrical conducting properties and structural features of MXene thin films prepared from polar non-aqueous solvents is important given their prospective use in organic or perovskite solar cells. Recent studies [7, 12] revealed