Sol-gel derived Nb$_2$O$_5$ thin films for photonic applications

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The fabrication and optical characterization of thin Nb$_2$O$_5$ films, obtained by spin coating of Nb sol on silicon substrate are presented. The Nb sol is prepared by sonocatalytic method using niobium chloride as a source for Nb and ethanol for solvent. The structure and morphology of the films are inspected through XRD and SEM measurements. Refractive index, extinction coefficient and thickness of the films are determined from measured reflectance spectra using non-linear curve fitting method. The impacts of ageing of the Nb sol, the duration of sonocatalytic treatment and post deposition annealing on the optical properties and thickness of the films are investigated. The possibility for fabrication of one dimensional photonic crystals using Nb$_2$O$_5$ and SiO$_2$ as high and low refractive index materials is discussed.

Keywords: sol-gel materials; Nb$_2$O$_5$ films; optical properties; optical characterization; spin-coating

INTRODUCTION

In recent years there is an increased scientific interest in Niobium pentoxide (Nb$_2$O$_5$) material because it is thermodynamically most stable as compared to other stoichiometries of niobium oxide and shows excellent chemical stability and corrosion resistance in both acidic and alkaline media [1]. Most often Nb$_2$O$_5$ was studied from the application in smart windows point of view and hereof the investigations of its properties are mainly devoted to optimization of its electrochromic behavior [2,3]. However, due to its interesting photoelectric and photocatalytic properties [4,5] Nb$_2$O$_5$ films may find application in different devices such as batteries and nanocrystalline solar cells [6,7], sensors [8], or transparent conductive electrodes [9].

A number of novel applications of Nb$_2$O$_5$ films rely on the ability to deposit high quality films with relatively simple and inexpensive techniques. Among various deposition techniques used for production of thin films from Nb oxides, the sol-gel method emerges as an attractive deposition method because of its versatility, low cost and low temperature processing [6]. Two types of precursors are currently used for formation of sol-gel Nb$_2$O$_5$ films: metal alkoxides (Nb ethoxide) [1] or metal salt-NbCl$_5$ [10]. The last one is preferred because of the lower price and weaker sensitivity to moisture as compared to the organic one.

For development of film application areas and implementation of Nb$_2$O$_5$ sol gel films in optical devices it is essential to characterize and optimize film properties (refractive index and extinction coefficient) and to be able precisely to control the film thickness. However, according to our knowledge there are only few studies on optical properties of sol-gel Nb$_2$O$_5$ films mainly concerning the determination of optical band gap and optical absorption [1,10,11].

The present paper studies the optical properties of thin sol-gel Nb$_2$O$_5$ films obtained by spin coating and their dependences on the duration of sonocatalytic treatment, time of sol ageing and post deposition annealing. The possibility of fabrication of one-dimensional photonic crystals is discussed.

EXPERIMENTAL DETAILS

The Nb sol was prepared by sonocatalytic method using NbCl$_5$ (99%, Aldrich) as a precursor according to the recipe in [12]. Briefly, 0.400g NbCl$_5$ was mixed with 8.3 ml ethanol (98%, Sigma-Aldrich) and 0.17 ml distilled water. The solution was subjected to sonification for 30 min and aged for 24 h at ambient conditions prior to spin coating. Transparent and stable sol was obtained easily and without additives.

Thin Nb$_2$O$_5$ films were deposited by dropping of 0.3 ml of the coating solution on pre-cleaned Si substrates and spin-on at a rate of 2500 rpm for 30 s. After the deposition, the films were annealed in

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