Real-Time Early Warning Strategies for Corrosion Mitigation in Harsh Environments

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Abstract—Long period fiber gratings (LPFGs) were coated with iron (Fe) and exposed to oxidation in air and in water having different concentrations of sodium chloride (NaCl) to detect the formation of iron oxides and hydroxides. The process was monitored in real time by measuring the characteristics of the LPFGs attenuation bands. Thin films of Fe were deposited on top of silica (SiO₂) substrates, annealed in air, and exposed to water with NaCl. The composition of the oxide and hydroxide layers was analyzed by SEM/EDS and X-ray diffraction. It observed the formation of oxide phases, Fe₃O₄ (magnetite), and Fe₂O₃ (hematite) when annealing in air, and Fe₂(OH)₃Cl (hibbingite) and FeO(OH) (lepidocrocite) when exposed to water with NaCl. Results shows that Fe-coated LPFGs can be used as sensors for real-time monitoring of corrosion in offshore and in coastal projects where metal structures made of iron alloys are in contact with sea or brackish water. In addition, LPFGs coated with hematite were characterized for sensing, leading to the conclusion that the sensitivity to the refractive index of the surrounding medium can be tuned by proper choice of hematite thickness.

Index Terms—Fiber optic sensor, long period gratings, oxidation of iron, real-time monitoring of corrosion.

I. INTRODUCTION

THE consequences of the corrosion of iron and its alloys have become a problem of worldwide significance [1]. Corrosion causes plant shutdowns, waste of resources, loss or contamination of products, reduction in efficiency, endanger

safety and imposes expensive maintenance. The exploration of sea resources, such as deep sea mining and aquaculture, requires metallic structures, often made of iron alloys, which are exposed to corrosion [2]. In addition, activities such as dikes and the flooding of coastal marshland can produce brackish water pools for freshwater prawn farming. Brackish water is also the waste product of the salinity gradient power process [3]. In all these instances, the control and monitoring of corrosion processes can be of critical importance. A comprehensive review on major corrosion sensing schemes can be found in [4].

Optical sensors based on long period fiber gratings (LPFGs) including, sensing of strain, bending, temperature, chemical analysis, vapor detection, food quality control, and recognition of bacteria have been reported. A review on the fundamentals and on the main achievements obtained concerning LPFGs can be found in [5]–[7] and references therein.

The physical properties of LPFGs rely on coupling light from the core mode of a single mode fiber into forward propagating cladding modes, which translates in the appearance of attenuation bands in the transmission spectrum at specific wavelengths. The evanescent field of the cladding modes extends to the surrounding medium enabling refractive index (RI) measurements.

Sensors based on LPFGs over coated with different metal oxides were fabricated and characterized for RI sensing. It was reported that oxidation of metals as Zn, Ni, Ti, Al, and Cr into well-known oxide states can be monitored in real time by following the features of the LPFG attenuation band [8], [9]. These kind of gratings coated with metal oxides with specific properties leads to wavelength sensitivity enhancement when comparing to a bare LPFG.

Hematite, a thermodynamically stable Fe oxide with n-type semiconductor properties ($E_g = 2.1$ eV) under ambient conditions, is of great interest due to its cost effective and high resistance to corrosion. It has also been studied as an electrode material in photo electrochemical cells, catalyst, and sensing elements in gas sensors (such as formaldehyde) and humidity sensors [10].

This work reports a preliminary study on the real time monitoring of iron thin films subjected to oxidation in air and in water with different sodium chloride (NaCl) concentrations using LPFGs in a temperature controlled environment. Due to hematite chemical stability in aqueous environments, LPFGs coated with it were characterized for refractive index sensing.

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