Electrochemical Synthesis and Nanofabrication of Materials for Magnetic and Ultrasound Sensors Application

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Abstract- We present the new approach to synthesize materials and nanostructures with application for magnetic field and ultrasound sensing. Our results indicate that electrodeposition at the nanoscale electrode geometry (nanocontacts) is an effective process that can deliver the ferromagnetic metal/oxide materials with desired composition and properties. These materials are the essential part of the nanocontact based device architecture which is investigated as the model system for magnetic filed sensor application. As an opposite process to electrodeposition, the dealloying i.e. a selective metal dissolution is used as fabrication process to create a high surface to volume ratio nanoporous metal structures. These structures are used as capacitive transducer for ultrasound sensor application. We present the preliminary results which demonstrate that thin layer – of nanoporous metal electrodes can be used as an inexpensive sensing device for ultrasound in electrolytes.

I. INTRODUCTION

In the last several decades the processes occurring at the electrochemical interface were proven to be the enabling phenomena behind the train of nanotechnology enterprise. There are many examples where the electrochemical fabrication is used today as convenient if not “the only” approach to deliver the desired structures, materials or surfaces [1]. The traditional fields of electrochemical research like corrosion, or electrodeposition, are rapidly being involved in different contemporary scientific disciplines where the word “nano” is frequently used prefix.

II. Ni-Fe(OH)3 PHASE SEPARATED MATERIALS FOR MAGNETIC FIELD SENSORS APPLICATION

During the electrodeposition of the ferromagnetic metals and alloys, the hydrogen co-deposition occurs in parallel resulting in the depletion of the hydrogen ions at the electrode/solution interface. This effect can lead to nucleation and precipitation of insoluble metal hydroxides at the growing deposit surface. Our recent results show that metal hydroxide incorporates in the magnetic deposit as completely separate phase [2]. The hydroxide incorporation rate is equal to the hydroxide flux achieved through the nucleation/precipitation process and this phenomenon can be used to electrodeposit ferromagnetic materials with controlled amount nonmagnetic oxide phase [2].

![Fig. 1 Vol % of Fe(OH)3 vs. [Fe3+] for electrodeposited Co40Fe60 films. Solution: pH=2, [Fe2+] = 0.1 M, [Co2+] =0.05 M, H3BO3 = 0.4 M, NH4Cl = 0.3 M, Deposition parameters: j = 3.8 mAm-2, current efficiency = 0.12, ω = 300 rpm [2].](image)

In Figure 1 the vol % of Fe(OH)3 incorporated in the Co40Fe60 matrix during CoFe alloy electrodeposition process is shown as a function of the Fe3+ concentration in the solution. The red line represents our model fit to the experimental data. As one can see, the vol % of hydroxide phase as high as ~ 40 % could be achieved for particular concentration of Fe3+ ions. The same approach is used to introduce the Fe(OH)3 phase in electrodeposited Ni nanocontacts. The deposition conditions for Ni are chosen to be such that Ni single crystal growth in nanoconfined electrode geometry is obtained [3], but with addition of Fe3+ ions in the solution, the incorporation of Fe(OH)3 occurs as well. The Ni matrix with ~ 30 % vol of Fe(OH)3 represents the material comprising the critical part of our nanocontact device which is used as the model system for spin polarized electron transport studies. In Fig. 2, we show the typical transfer curve for one of our nanocontact devices with the schematic of the cross section shown in the inset.
The measured values of $\Delta R/R$ of $\sim 40\%$ are comparable with today’s state of the art spin valve or TGMR based magnetic field sensors. These results indicate that the Ni-Fe(OH)$_3$ nanocontacts material represent the promising alternative for development of the future magnetic field sensors and materials for MRAM and biomedical application.

III. **Nanoporous Metal Structures by Dealloying for Ultrasound Sensing Application**

The inexpensive ultrasound sensors are in demand in many fields of medical research and diagnostics, in military arena, and in other areas of technological enterprise. In this talk we present our work investigating the design and fabrication of ultrasound sensors based on capacitive transducer concept. The nanoporous, high surface to volume ratio Au electrode is used as model systems where the novel approach for ultrasound sensor design is studied.

The nanoporous Au structures are produced by dealloying process [4]. The example of such electrode is shown in Figure 3B. As a source of an input ultrasound signal in the electrolyte, the ultrasound generator is used that creates periodic displacement/pressure wave of a broad frequency spectrum resembling a square wave profile with superimposed distortion. The electrochemical cell containing nanoporous Au electrode, 0.1 M HClO$_4$ electrolyte and the state of the art piezoelectric sensor is used to study the electrochemical interface as an ideal capacitive transducer converting directly mechanical perturbation into an electrical signal [5]. The output signals from the state of the art submersed piezoelectric transducer and our nanoporous Au electrode are presented in Figure 3A. The FFT of both signals indicates that electrochemical interface is sensitive to all frequencies in the incoming ultrasound spectrum and that fundamental and all other harmonics in the Furrier spectrum occur at the same frequencies for both sensors. The advantage of nanoporous electrode with large surface to volume ratio Au electrode is used as model systems where the novel approach for ultrasound sensing application is discussed in terms of possible ways to increase the signal amplitude demonstrating that sensitivity of the electrochemical interface can be easily adjusted by tailoring the dealloyed layer thickness i.e. the area of the interface, and by controlling the sensing potential. In conclusion, the complete derivation of the transducer equation is presented with the detailed phenomenological description of the sensing process.

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**REFERENCES**


