Magnetic and mechanical properties of electrodeposited Fe-W alloys

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Introduction

Recently, W alloys with iron group metals have emerged intensively as an alternative to replace electrolytic chromium, since such coatings have a unique combination of mechanical, corrosion and tribocorrosion properties, even at elevated temperatures. Furthermore, W alloys have been reported to present interesting magnetic properties, such as perpendicular and longitudinal anisotropy, high magnetic moment and low coercivity. In this context electrodeposition of Fe-W alloys could be targeted for fabrication of certain micro-/nanoelectromechanical systems (MEMS/NEMS), where the combination of pronounced magnetic properties and high hardness is needed.

Experimental

Fe-W alloys were deposited from recently developed glycolate-citrate bath having a following composition: 0.3 M citric acid, 1 M glycolic acid, 0.3 M Na_2WO_4, 0.1 M $Fe_2(SO_4)_3$. Deposits were obtained in the range of pH 5-8 at 20°C and 65°C, and constant cathodic current density was 15 mA/cm². The depth profiling analysis was carried out using the RF-GD-OES technique using power-voltage control mode.

Mechanical properties of obtained alloys were evaluated using nanoindentation technique on the cross-section of the specimens at 20 mN load, and the magnetic properties were studied using Vibrating Sample Magnetometer (VSM).

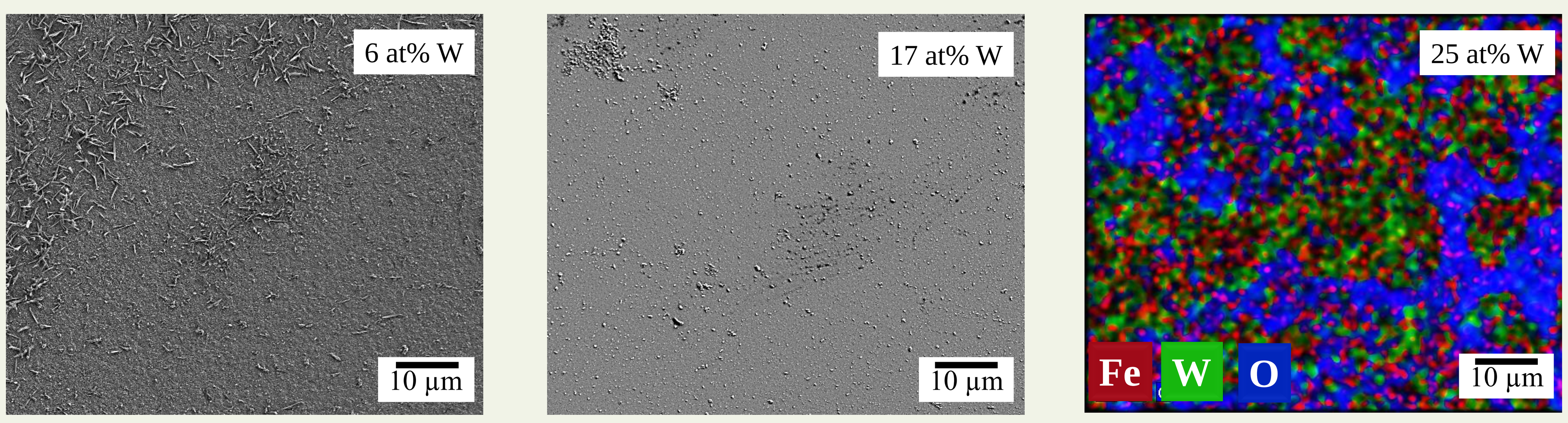

***Fig. 1.** SEM/EDX surface images of Fe-W alloys electrodeposited from glycolate-citrate electrolyte.*

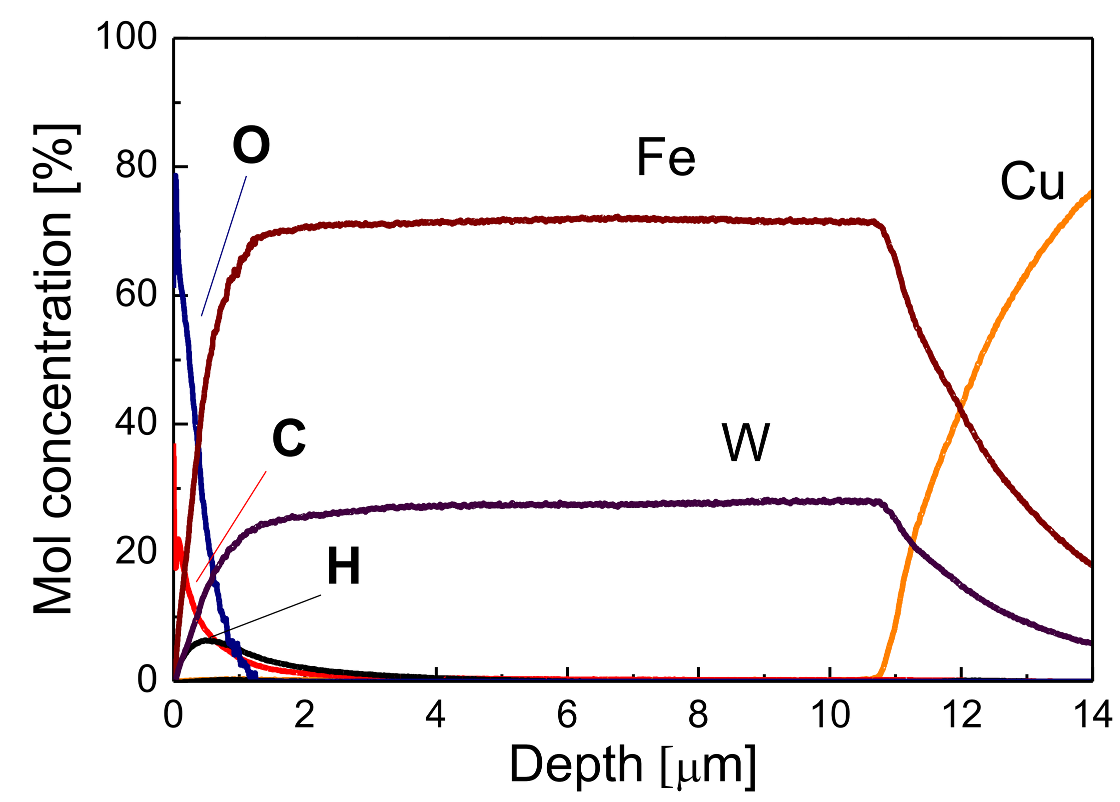

***Fig. 2.** GD-OES quantitative depth profile for electrodeposited Fe-25W coating.*

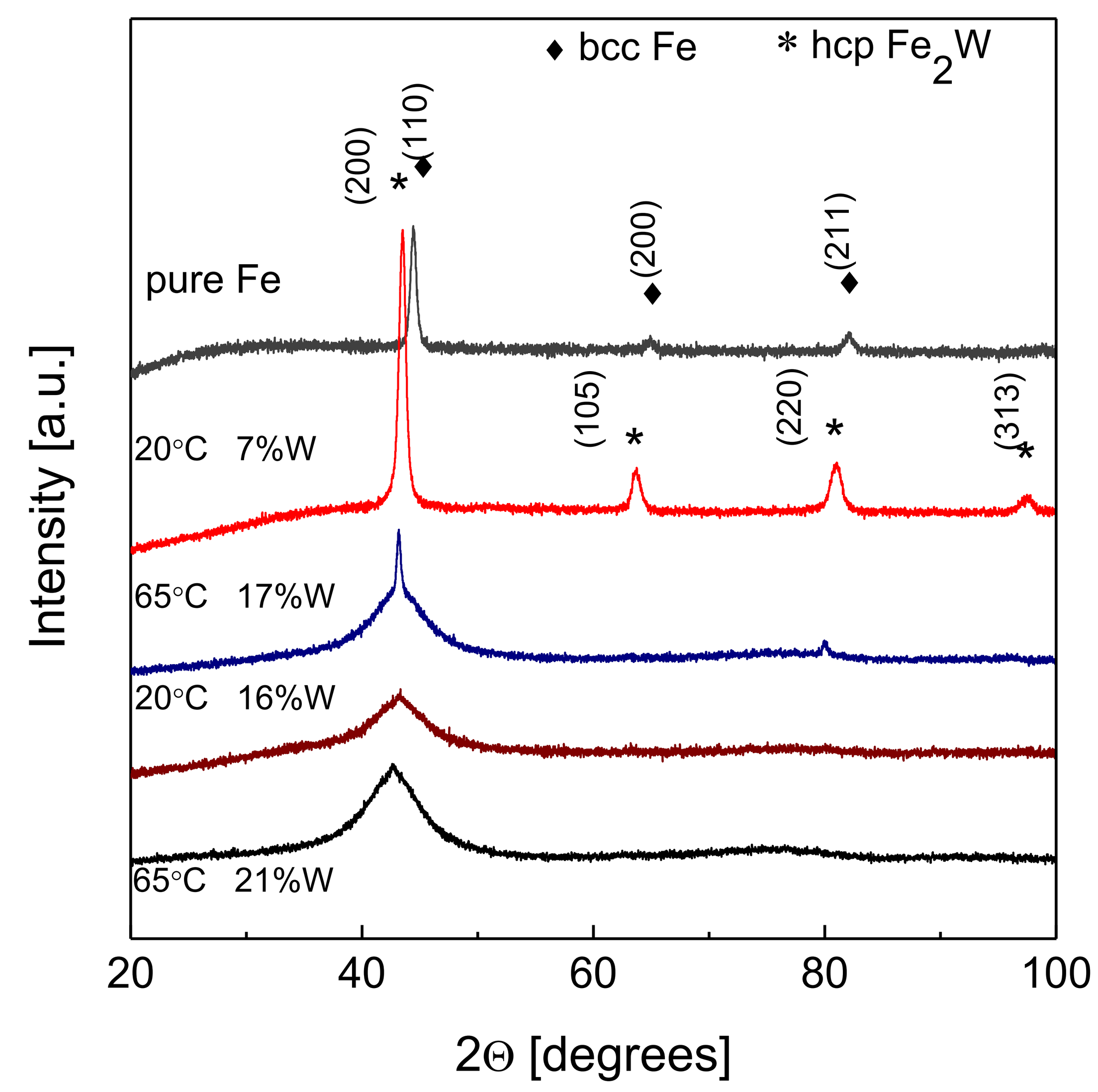

***Fig. 3.** X-ray diffraction patterns recorded on Fe–W electrodeposits at different W content and temperature.*

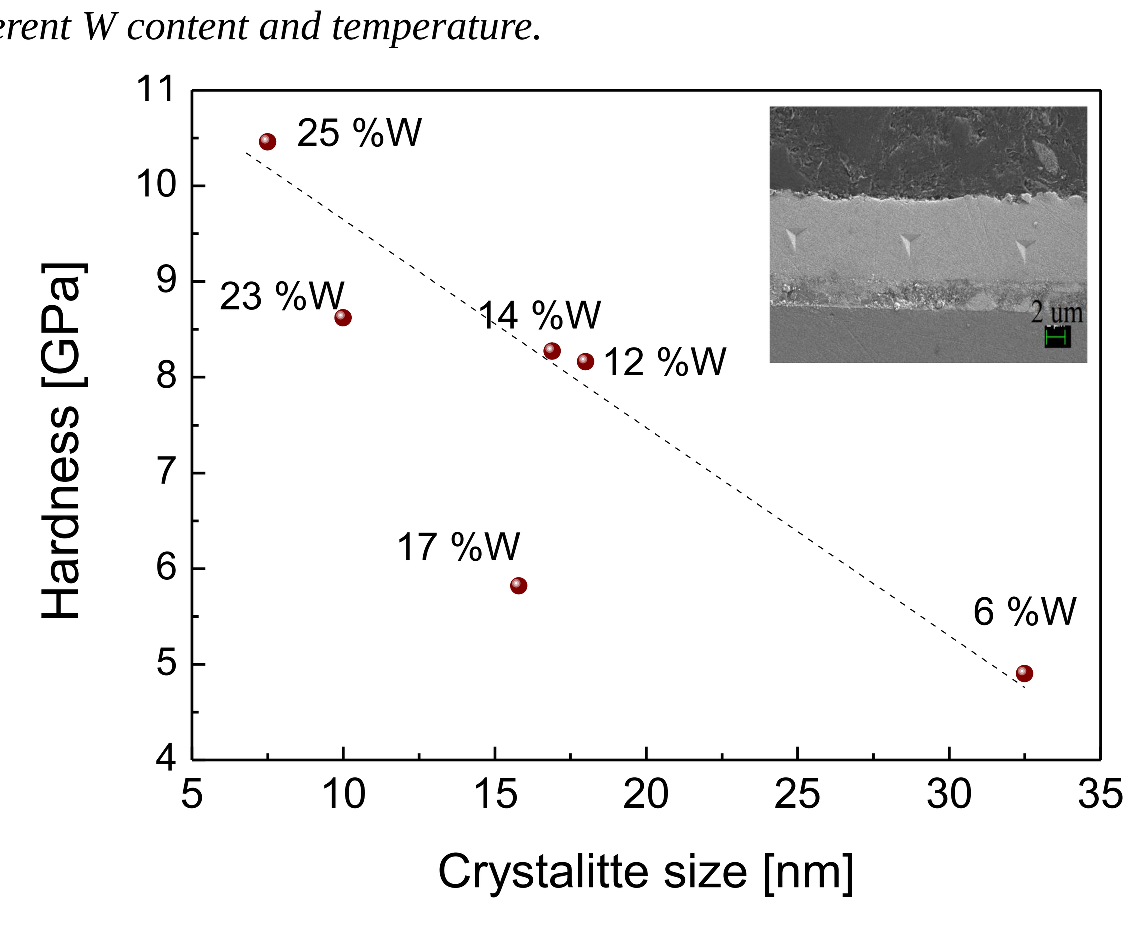

***Fig. 4.** Hall-Petch plot for Fe-W deposits of different composition. In insert the SEM image of typical indentation imprints.*

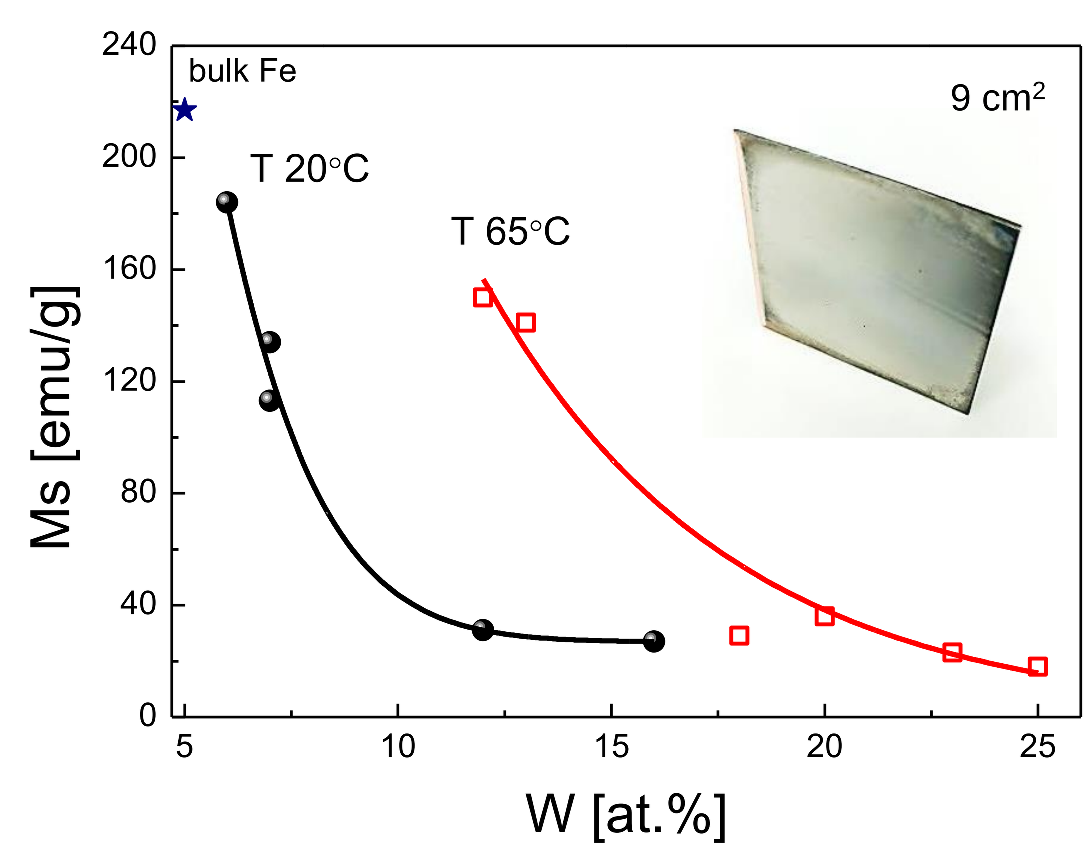

***Fig. 5.** Dependence of the saturation magnetization (Ms) of Fe-W coatings as a function of their composition. In insert the macro view of Fe-25W sample.*

Results and discussions

Composition of Fe-W deposits

The W content in deposits have been tuned from 6 at.% to 25 at.% by control of the deposition parameters. SEM/EDX analysis shows that Fe-W alloys typically contain a significant amount of O (Fig. 1). Composition GD-OES profiles confirm that O is present only in thin surface layer, while no O, C and H in the depth of the coating are found. Both Fe and W are distributed uniform along the entire thickness of the layer (Fig. 2).

Crystallographic structure

XRD patterns show that the structure of the films transforms from nanocrystalline to amorphous-like with increase in W content in the alloy. The shift of three peaks, characteristic for pure Fe to the lower 2Θ angles is caused by the formation of solid solution of W in bcc Fe. However, it is suggested that amorphous alloys can contain the mixture of solid solution and intermetallic phase Fe_2W. Remarkably, the threshold for formation of amorphous-like structured Fe-W alloys depends on the deposition temperature (Fig. 3).

Mapping of mechanical and magnetic properties

Incorporation of W atoms has great impact over mechanical and magnetic properties of the coatings. Fe-W alloy with 25 at.% of W exhibited the maximum hardness of 10.4 GPa, which is comparable to the hardness of electrolytic chromium. The hardening phenomenon followed the direct Hall-Petch relation, namely the strength increasing as the inverse square-root of grain size (Fig. 4).

The saturation magnetization tended to decrease with increasing in W from 184 emu/g for alloy with 6 at.%W to 18 emu/g for the alloy with 25 at.%.W. The soft magnetic properties of Fe-W alloys are observed with corresponding Hc values <200 Oe. Electrodeposition is highly recommended to perform at elevated temperature, since incorporation of light elements leads to magnetic signal reduction (Fig. 5).

SUMMATION. Fe-W alloys having 10-15 at.% of W are characterized by the combination of enhanced mechanical properties, high saturation magnetic moment and the low coercivity, thus meet the requirements for materials used in MEMS/NEMS fabrication.

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