

A NEW CLASS OF MATERIALS – AMORPHOUS METALS. PROPERTIES AND APPLICATIONS

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Abstract

This work presents the results of a cycle of scientific investigations and testing of physicochemical, physicochemical and electromagnetic shielding properties of both electrochemically and metallurgically produced thin amorphous and crystalline films of Fe, Co, Ni and their alloys and Cr.

Key words: microhardness, tensile strength, corrosion resistance, shielding

1. INTRODUCTION

The amorphous thin films have excellent physicochemical properties, such as microhardness, tensile strength, wear resistance, adhesion, etc. They are a suitable material for the repairing of precious critical threadbare parts of internal-combustion engines, transmissions, brakes, etc. of automotive and crawling vehicles. The amorphous thin films have also excellent physicochemical properties – both chemical activity and chemical resistivity. They are a suitable material both for catalytic systems used for decontamination of out-going gases of internal-combustion engines and for corrosion protection systems used in naphtha- and gas- pipelines, in high humidity atmospheres and in water- and aerosol-salt environments. Previous investigations in author's laboratory showed [1] some famous electromagnetic properties - $4\pi M_s$, B_r , H_c , μ , etc. - of electrodeposited amorphous thin films. Such properties may be obtained by thermomagnetic annealing of the metallurgical samples. The electrochemical production method of magnetic-soft materials is easier, accessible, inexpensive and highly efficient than any metallurgical one and it is unique and only possible for the articles they are made of plastics of ABS-copolymers. The development of the new class of materials - electrodeposited amorphous thin films allows an effective protection of computing and telecomm devices, apparatuses and components against both electromagnetic interferences (EMI) [5, 13] and high power electromagnetic pulses (HP EMP) [8].

2. EXPERIMENTAL STUDY

The microhardness H_v measurements are carried out using metallographic microscope NEOPHOT-2 with standard calibrated micro-indenter device. The tensile strength measurements of the stripped from substrate electrodeposited thin films are carried out using permanent velocity 1.5 mm/min deformation machine allowed an automatic recording of the diagrams. The corrosion resistant and corrosion prevention ability are studied both electrochemically and full- and half-dipping methods. The polarization curves are plotted automatically and the immersion tests results are evaluated visually using conventional templates, in accordance with ISO Standards. The corrosion process parameters are calculated from all experimental data. The electromagnetic attenuation as a measure unit for the EMI shielding ability of the electrodeposited thin films and of the rapid quenched strips is measured using ROHDE&SCHWARZ technique allowed an automatic recording of the diagrams and automatic scanning of the frequency band (10 kHz - 1000 MHz) in accordance with US military standard MIL-STD-461E/1999 [2]. The results are compared to the US FCC rules.

3. RESULTS AND DISCUSSION

The experimental results of the physicomechanical measurements are presented in Figures 1 and 2.

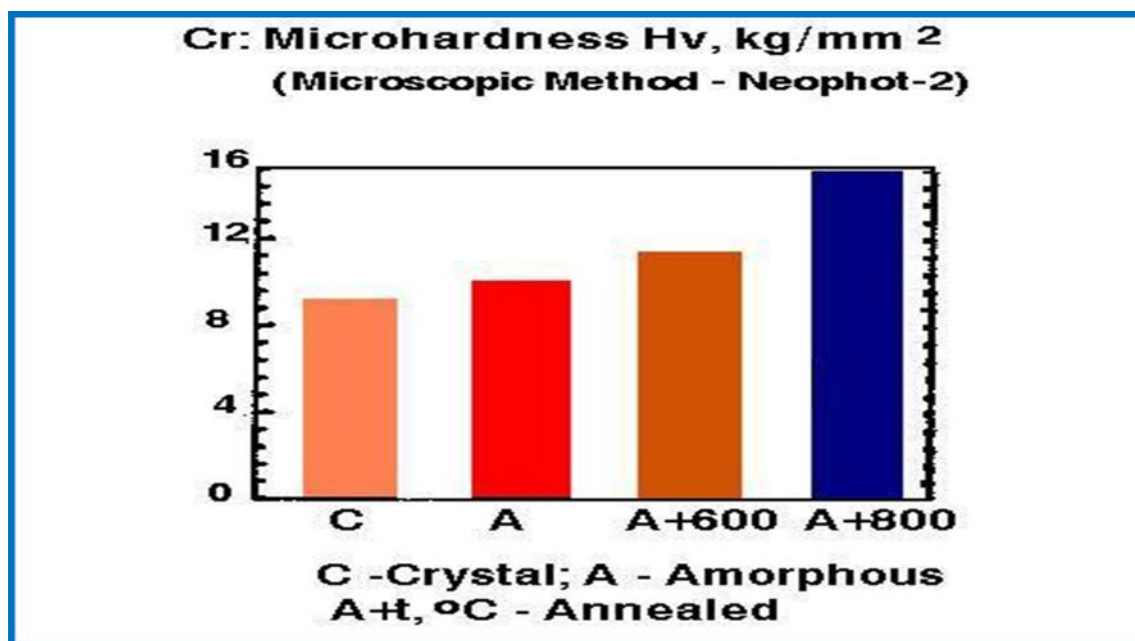


Figure 1. Microhardness H_v , kg/mm² of Cr electrodeposited films vs. their structure and treatment

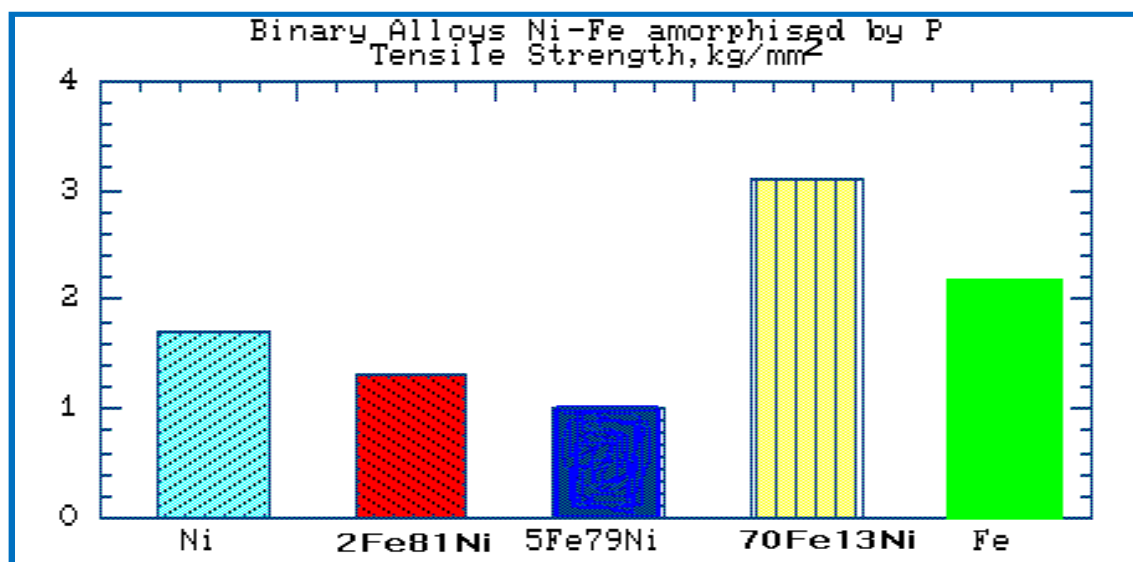


Figure 2 Tensile strength, kg/mm² of the amorphous electrodeposited films of Ni, Fe and their binary alloys vs. their phase composition

The values of the microhardness for the fine grain crystalline and amorphous Cr electrodeposited films are comparable. Up to 900°C thermal treating the structure is amorphous and the microhardness arises due to the homogenizing of the amorphous structure below the glassing temperature as the X-ray analyses showed.

The tensile strength of the amorphous Ni-Fe alloys depends on their phase composition and it is higher for higher Fe-containing alloys due to the additional amorphizing effect of Fe.

The experimental results of the corrosion investigations are presented in Figures 3 - 6. The corrosion resistance of the Ni and Fe films depends on the phosphorus contents, respectively on their degree of amorphization.

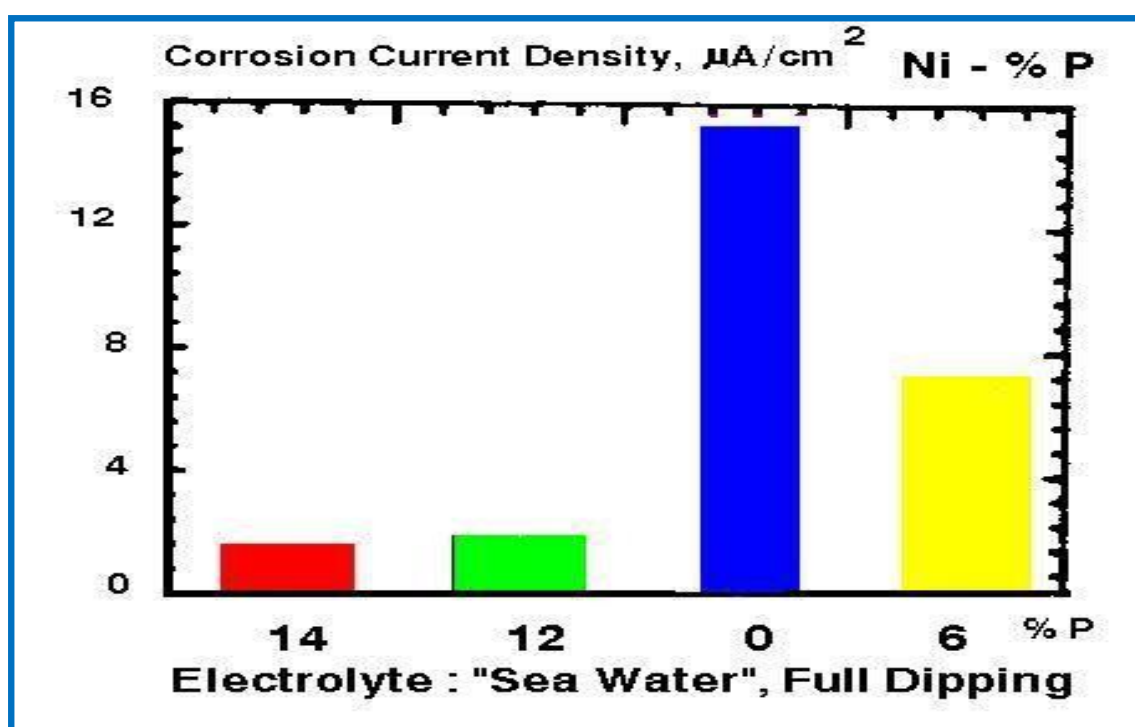


Figure 3. Corrosion current density, $\mu\text{A}/\text{cm}^2$ of the electrodeposited films of Ni vs. their phosphorus content

The highest corrosion resistance has the full amorphizing structures (Ni-14% P, Fe-10% P) and the high-annealed Cr films (due to the blocking effect of the uniformly distributed C content within the homogenized structure.)

The corrosion resistance of the amorphous Ni-Fe alloys depends on their phase composition and it is highest for 69Ni23Fe alloy. This irregularity can explain on the base of the synergetic effect both of Ni and of Fe on the main amorphizing agent – phosphorus.

The attenuation results obtained for rapid quenched; fully amorphized strips are in good accordance with the FCC regulation rules for electromagnetic emissions (Figure 7). The strips in wide 2-20 mm were used for cable shielding, but they did not meet the other functional requirements, such as physicomechanical characteristics. Some amorphous strips were implanted into fabrics, other samples were used as milled particles and powders for extruded composite plates, spread paint “wall-papers”,

etc. Nowadays the rapid-quenched amorphous strips have a short range of application only for some soft magnetic sensors and convertors.

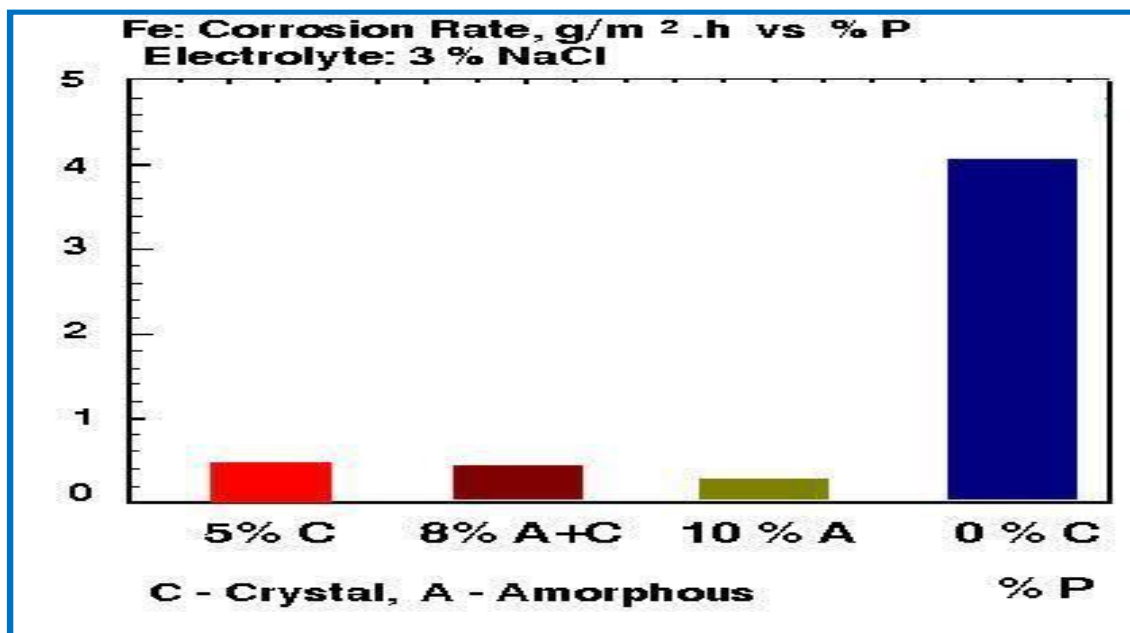


Figure 4. Corrosion rate, g/m².h of the electrodeposited films of Fe vs. their structure (respectively vs. their phosphorus content)

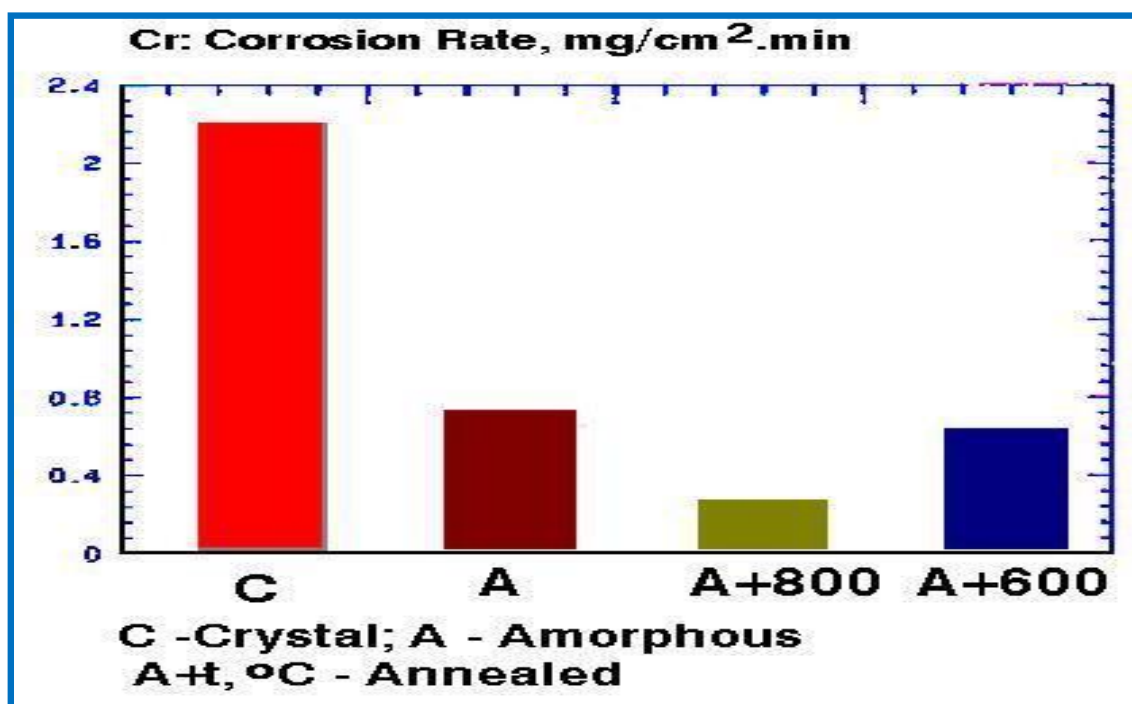


Figure 5. Corrosion Rate, mg/cm².min of the Cr electrodeposited films vs. their structure and treatment

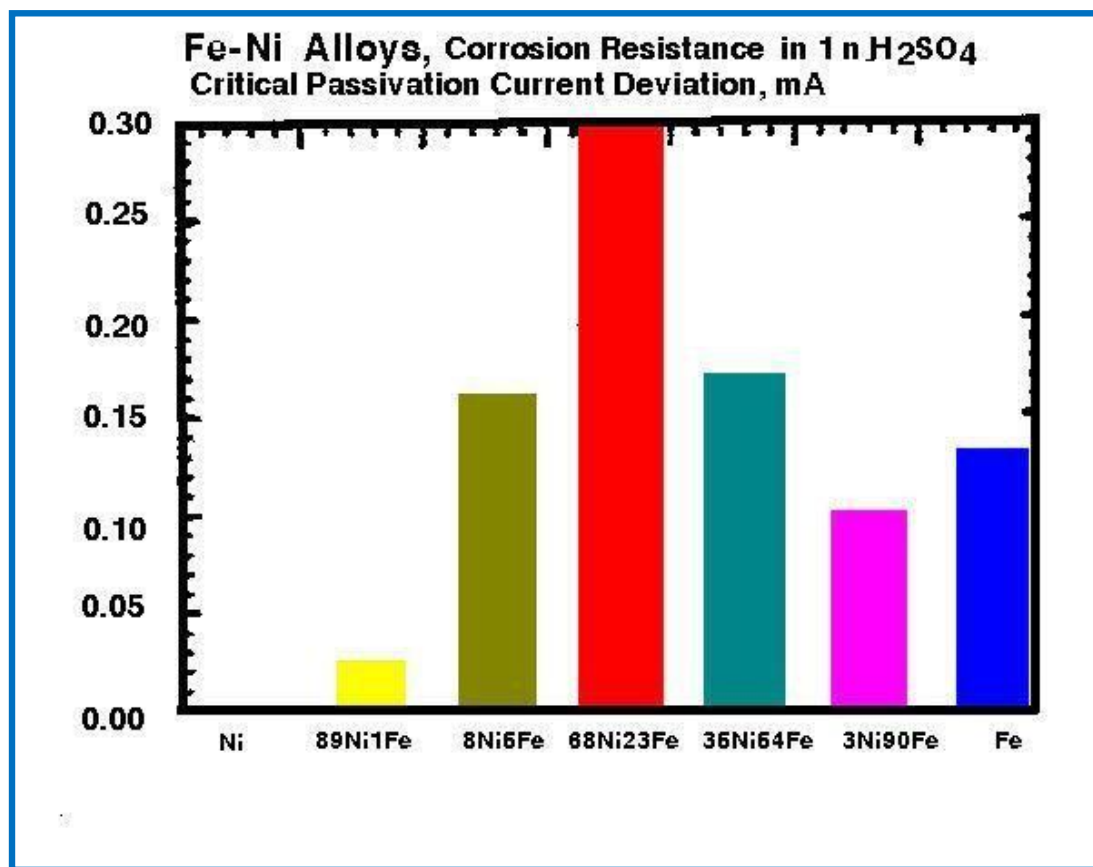


Figure 6. Critical passivation Current Deviation mA, of the amorphous films of Ni, Fe and their binary alloys vs. their phase composition

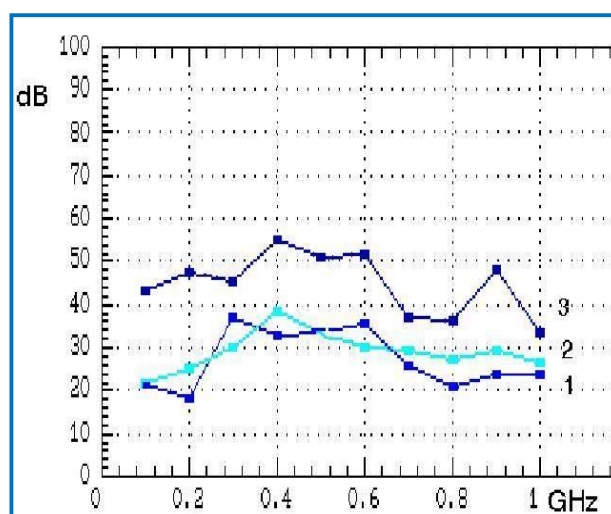


Figure 7. Attenuation for rapid quenched strips: 1 - 46Fe32Ni15B7Si, 2 - 48Fe20Ni10Co14B8Si; 3 - 4.5Fe2Mo68.5Co10B15Si

The main conclusion of the study of the rapid-quenched amorphous strips was the knowledge that both metallurgical and electrochemical methods for producing of the amorphous metals have the identical nature based on the same thermodynamic and kinetic principles [14]. The 2- and 3-component alloys can be amorphized easier than mono-component “pure” ones. Concerning the shielding ability properties of the alloys against EMI, the very important fact is that cobalt as one of the alloying components has the main role.

As reported earlier [1, 3-5], our experiments for application of the electrochemically deposited amorphous metal alloys were carried out using a wide range of samples, both laboratory models (self-made closed cases and boxes from different materials with suitable dimensions) and commercial products (PCs with various processor frequencies, HF, VHF, SHF and UHF transmitters, etc.)

The obtained results indicated that the shielding efficiency against the magnetic component of the field is 35-40 and 27-30 dB for field intensities of 0.2 and 2 Oe, respectively. Under the same conditions, the shielding efficiency against the electric component of the field is 50-80 dB in the frequency range from 10 kHz to 18 GHz.

As it was earlier shown in author’s laboratory [6], the amorphous electrodeposition processes of Fe, Ni, Co and their alloys require so strict experimental conditions – electrolyte composition, current density, temperature, etc. The results of our laboratory investigations of the experimental conditions of the electrodeposition were developed and incorporated as a new highly efficient technology for protective multilayer EMI shielding systems. The technology is adopted in the series production of “Telephone and Telegraph Technique” PLC, Sofia, Bulgaria, manufacturer of the improved telephone set Type TTT-100 for military and security application [7]. Figure 8 reports the attenuation results obtained for telephone set Type TTT-100.

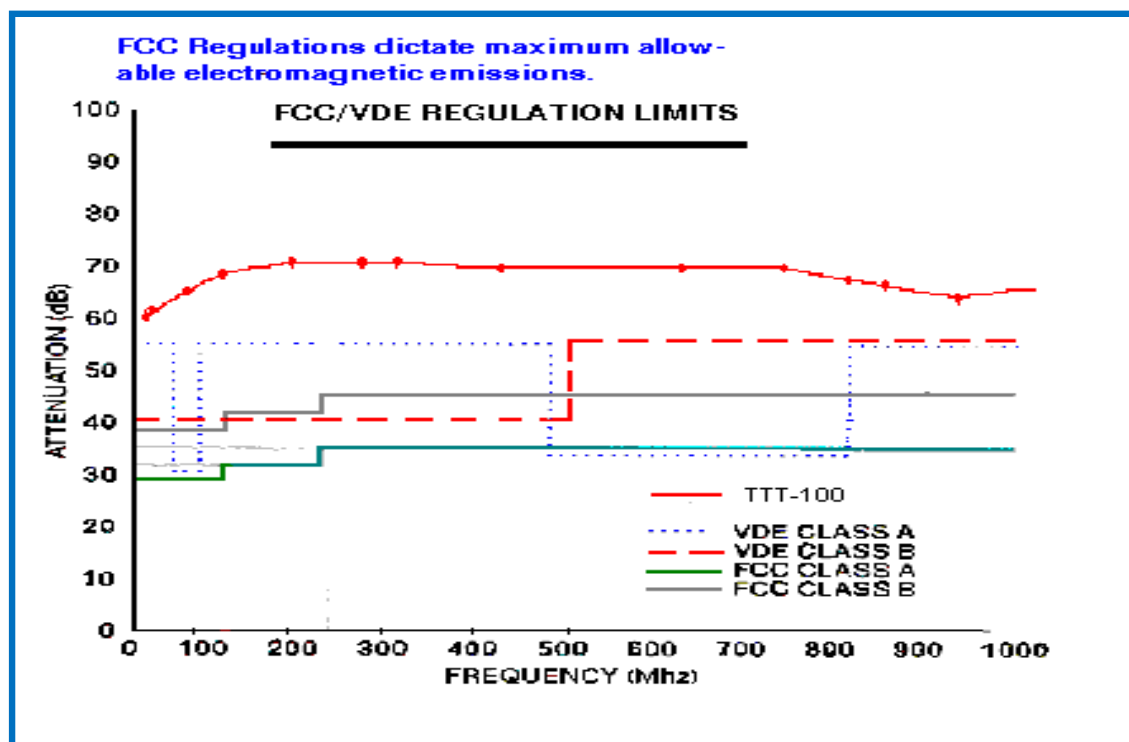


Figure 8. FCC rules for the maximum allowable electromagnetic emissions

The experimental results of the attenuation measurements are compared to the FCC regulation limits. It can be concluded that the electromagnetic protection of the telephone set TTT-100 provides attenuation over the maximum allowable emissions for all classes of equipment and applications, such as Surface Ships, Submarines, Aircraft - Army, Including Flight Line, Aircraft - Navy, Aircraft - Air Force, Space Systems, Including Launch, Vehicles, Ground - Army, Ground - Navy, Ground - Air Force, cited in the US DoD classification.



Figure 9. Photo of the phone set model TTT-100

The telephone set (Fig. 9) was presented at the Int. Conf. Defense Research and Technologies "Modernising the Forces - Cornerstone of the Bulgarian Way to NATO", Telecomm Exhibition Hall, Plovdiv, Bulgaria, May-June 2002. Its performance and quality were estimated very highly by Israeli and Romanian experts who, as a rule, are known to have severe requirements to the protection from non-authorized access to the data bases and voice transmissions, as well as to the protection against unintentional and/or directed hazardous electromagnetic pulses.

The combination of such properties as amorphous structure, phase composition and multilayer metal coating results in shielding effect, achieved by the laws of multiple inner diffusion scattering and

reflectance of the electromagnetic flow. Hence, the absorption of the electromagnetic flow, depending on the thickness of the protective system, is not a limiting factor for the shielding efficiency. In other words, the attenuation flow gradient under certain electromagnetic field conditions (intensity and duration) does not depend critically on layer thickness, but on the structure, number and composition of the layers [5, 14]. The synergetic effect of the absorption, multiple inner diffusion scattering and reflectance laws will be demonstrated later through the simultaneous application of the thickness, structure, number and composition principles of a shielding system for high power electromagnetic pulses (HPEMP) protection [15].

4. CONCLUSIONS

The results presented in this study allow the following conclusions to be drawn:

- The main physicochemical (microhardness, tensile strength), and physicochemical (corrosion activity, corrosion prevention ability) properties of the electrodeposited metal and metal alloys thin films depend on their structure (crystalline, amorphous) and phase composition.
- The second and third metal alloying component enhances the amorphizing effect of the main reducing agent (P, C, B, etc.).
- The thermal treatment (bellow the glassing temperature) of the as-plated amorphous thin film (if it is possible) homogenizes the structure, leads to a secondary distribution of the content of the amorphizing components within the homogenized structure and has an blocking effect on the active centers from “surface-active” compounds.
- The electrodeposited amorphous thin metal films are an excellent material for the repairing of precious critical threadbare parts of automotive and crawling vehicles industry due to their mechanical properties, as well as they are suitable for corrosion prevention purposes [9, 10] for more classes of devices and equipment in corrosion-aggressive environments.
- The electrodeposited amorphous thin metal films have famous electromagnetic properties which may be obtained so difficulty by other processes such as vacuum sputtering, thermomagnetic annealing, laser glassing, rapid quenching, etc. [11, 12].
- The electrodeposited amorphous thin metal films are an excellent material for protection of computing and telecomm devices, apparatuses and components against electromagnetic interference. The electrodeposition processes offer a simple for industrial implementation, inexpensive, highly efficient and reliable technology. It is highly competitive to other expensive, difficult, sophisticated, complicated technologies.
- The electrochemical technology is unique and only possible for EMI protection of computers, phone sets, etc. which cases and boxes are made of plastic ABS-copolymer materials.

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