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# Energy gradient carbon embedding in the magnetic media for improved tribological performance

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ABSTRACT

A technique of energy gradient carbon embedding using the filtered cathodic vacuum arc technique in the top layer of the magnetic media is evaluated for its tribological properties. Cobalt is used as the magnetic material. The embedded layer is obtained by using ion energies of 60 eV and 90 eV successively to embed carbon in the top layer of the magnetic media and seal the Co/C mixed layer with a few mono-layers of carbon. Auger electron spectroscopy and transmission electron microscopy are used to characterize the modified surface in terms of its thickness, structure and chemical composition. Ball-on-disk wear tests and atomic force microscopy based scratch tests are conducted on the bare cobalt and modified cobalt surfaces to characterize the wear resistance. It is observed that the wear life and scratch resistance of the cobalt surface improved considerably after the surface modification.



## 1. Introduction

To meet the ever-increasing demand in the storage capacities of hard disk drives, it has become necessary to reduce the magnetic spacing between magnetic media and active surface of the head read/write elements [1]. One of the ways to achieve this reduction is by decreasing the thickness of the overcoats that are applied on the magnetic media to protect it from corrosion and wear. To achieve storage capacities beyond 1 Tbit/in$^2$, the overcoats have to be thinner than 1 nm [2–8]. By decreasing the thickness, the conventional coating materials/methods such as diamond-like carbon (DLC) coatings deposited by sputtering or chemical vapor deposition methods ($CH_x$ or $CN_x$ films) will not be able to function effectively. When thinner than 2 nm, these films will not be continuous and mechanically tough to protect the surface against wear and corrosion. Hence, new surface modification technologies in terms of deposition techniques and the materials used have to be continuously developed without adversely affecting the tribological and anti-oxidation capabilities of these ultrathin overcoats.

In our previous studies we have developed a novel method of carbon embedding as a surface modification process which has been shown to be very effective in reducing friction and improving the anti-oxidation properties of the media surface [9–11]. In this technique, cobalt was selected as the material for the magnetic media and its surface was directly bombarded with $C^+$ ions at ion energy of 90 eV, resulting in the formation of a mixed layer in the outermost surface of the media without the formation of a carbon overcoat. The mixed layer demonstrated excellent tribological properties such as reduced coefficient of friction (~0.4) when compared with that of the bare cobalt surface (~0.7). Moreover, tribological tests conducted under the same conditions on commercial media disks which have a ~2–3 nm of carbon film with an overcoat of ~1–2 nm of lubricant showed a coefficient of friction of ~0.42 in comparison with the cobalt surface with a ~1–2 nm of mixed layer of embedded carbon, hence demonstrating the excellent tribological performance of the developed mixed layer. However, an Auger electron spectroscopy (AES) analysis performed on the wear track produced on the commercial media showed that even though the friction in this test was ~0.42, the carbon overcoat was completely removed and the magnetic material exposed. This implies that while the carbon overcoat (~2–3 nm) and lubricant layer (~1–2 nm) of the commercial disk were not able to survive the test conditions, the cobalt surface embedded with carbon at ion energy of 90 eV could survive and protect the surface effectively. In order to further improve the tribological properties of the protective mixed layer developed by the shallow ion embedment method, an ultrathin (<1 nm) Si buffer layer was deposited on Co magnetic film and bombarded with energetic $C^+$ ions to form a Co/Si/C mixed layer. While formation of strong covalent bonds between the mixed layer and magnetic film improves the adhesion of the protective layer to the surface, formation of a Si–C network in the bulk of the mixed layer and C–C bonds on the top surface enhanced the wear resistance of the mixed layer and resulted in a coefficient of friction of less than 0.2 [12].

Hence, looking at the potential of the above developed methods and the scope of further improvement in terms of wear resistance and

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reduced friction, the present study was undertaken whereby the main objective is to embed carbon into the media surface and seal the top surface by forming of a few mono-layers of carbon by using different $C^+$ ion energies. The energy gradient embedding process involved the bombarding of the media surface initially with $C^+$ ions at a lower ion energy followed by bombarding the same surface with $C^+$ ions with higher ion energy. In doing so, the higher energy atoms were embedded in the already formed shallow mixed layer of cobalt and carbon, which had been created after the bombardment of the media surface with the lower energy $C^+$ ions. This process results in formation of a denser mixed layer with higher amount of carbon atoms in the shallower regions (very top layers) which may lead to better tribological and corrosion protection.

The lower ion energy selected in the present study for bombarding the cobalt surface was 60 eV and the higher energy was 90 eV. In our previous study it was observed that the lower ion energy of 20 eV resulted in the formation of an ultra-thin overcoat [9]. Thus, in order to avoid the formation of a pure overcoat (only overcoat) on one hand and to prevent the deep implantation of the ions on the other, a lower ion energy of 60 eV was selected for this study. Moreover, the ion energy of 90 eV was selected for the higher energy embedding because of its excellent performance in terms of lower friction and anti-oxidation properties [9–12].

Prior to conducting the experiments, simulations were carried out using the Transport of Ions in Matter (TRIM) software to calculate the depth profiles of the implanted ions (distribution of embedded ions) in a substrate at any ion energy. Fig. 1 shows the results from the TRIM simulations.

Fig. 1 shows the distribution of the embedded $C^+$ ions in the cobalt surface when bombarded only with ion energies of 60 or 90 eV or when bombarded first with ions of 60 eV followed by 90 eV. It should be noted that in all these experiments, the Co surface is subjected to the similar total number (ion dose) of the impinging ions. Because of their low energy, $C^+$ ions of 60 eV are not able to embed themselves very deep into the surface and most of them are stopped in regions near the surface. This results in formation of a sharp profile near the surface with maximum intensity at a depth of about 4 Å. In contrast, at 90 eV, the ions are implanted to deeper regions with less number of atoms stopped near the surface. In this case, the distribution profile of the embedded ions is much broader with an intensity peak covering a range of about 5–7 Å. In other words, the top surface of the sample bombarded with $C^+$ ions of 60 eV is expected to have higher number of C atoms as compared to the 90 eV case. Presence of more carbon near the top surface is desirable to lower the friction and protect the surface against wear and corrosion. However, according to our previous findings and as it has been reported by many other researchers, the optimum tribo-mechanical properties of the carbon films are achievable at ion energy of about 100 eV. In order to get the advantage of both the cases, in the third simulation, the Co surface is first treated by $C^+$ of 60 eV and then bombarded by $C^+$ with energy of 90 eV. As can be seen in Fig. 1, the distribution profile of carbon atoms in this case has the desirable features of both the cases i.e. a deep and broad mixed layer with a peak near the surface (denser mixed layer near the surface).

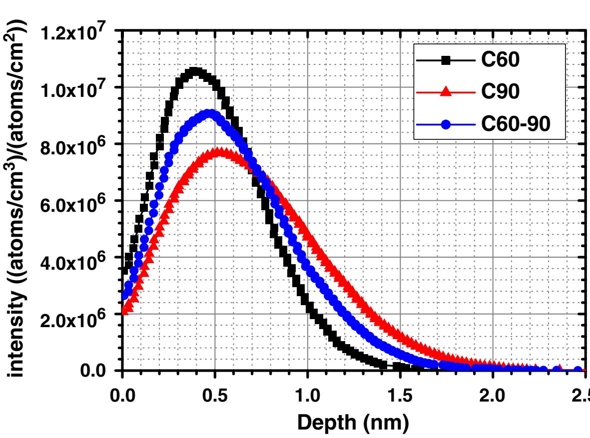


**Fig. 1.** TRIM simulations showing distribution of embedded $C^+$ ions in cobalt surface at 60 eV (C60), 90 eV (C90) and first at 60 eV followed by 90 eV (C60/90).

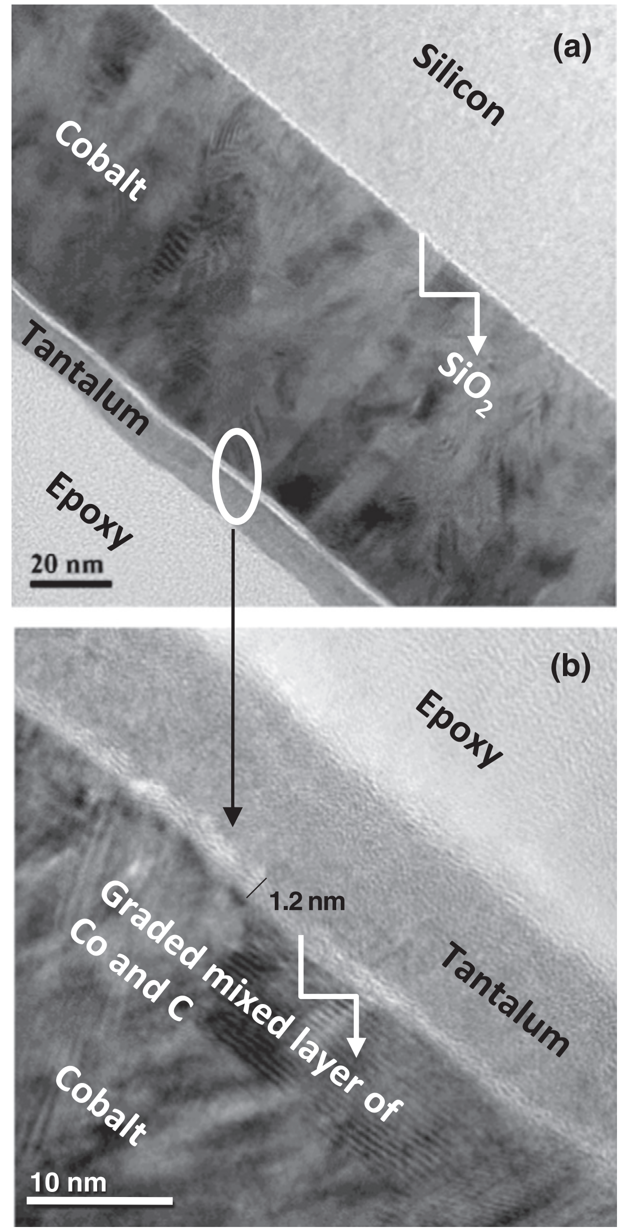


**Fig. 2.** TEM image of the cobalt surface (a) bombarded by carbon ions of 90 eV for 50 s and (b) bombarded with $C^+$ ions with a lower ion energy of 60 eV for 25 s followed by bombardment with a higher ion energy of 90 eV for 25 s.

## 2. Experimental section

### *2.1. Energy gradient embedding process using the filtered cathodic vacuum arc (FCVA) technique*

Square silicon samples were coated with 100 nm of cobalt films using magnetron sputtering under a base pressure of $1 \times 10^{-8}$ Torr. Prior to loading the samples into the FCVA chamber, they were cleaned thoroughly with isopropyl alcohol and acetone respectively, and then dried with nitrogen gas. After deposition of Co film the samples were