SURFACE PROCESSING OF TOOLS AND COMPONENTS BY MEVVA SOURCE ION IMPLANTATION

W.L.Lin[1), J.M.Sang[2),X.J.Ding,[1)X.M.Yuan[2), J.Xu[2), H.X.Zhang[1), and X.J.Zhang[1)

1) Institute of Low Energy Nuclear Physics,Beijing Normal University,Beijing 100875, China

2)Beijing General Research Institute of Non–Ferrous Metals, Beijing 100088, China

ABSTRACT

Direct implantation of metallic ion species has been employed in surface processing of industrial components and tools with very encouraging improvements in recent years.In spite of high technical effectiveness, this new surface processing technique has not been extensively accepted by industries mainly because of high cost (capital and operating) compared with other competitive surface processing techniques.High current and large implantation area with eliminating the mass analyzer and the beam–scanning unit make metal vapor vacuum arc (MEVVA) source ion implantation versatile, simple and cheap to operate and well suited to commercial surface processing.

In this paper, the recent development of MEVVA source ion implantation technique at Beijing Normal University has been reviewed and the results of production trials of several industrial components and tools implanted by MEVVA source ion implantation have been presented and discussed.

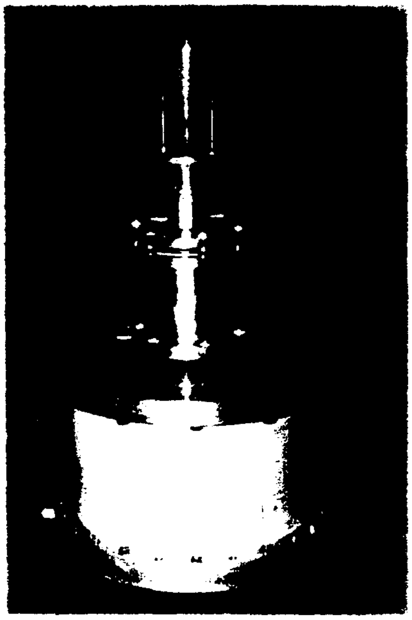
1.INTRODUCTION

In recent years, the direct implantation of selected ion species is widely recognized as a unique surface processing technique for modifying the surface properties of nearly all types of materials including metals, ceramics, polymers and composites in addition to semiconductors[1–4].Initially, implantation of non–electronic applications concentrated primarily upon energetic nitrogen ion beam to enhance wear resistance of mateials.More recently, metallic ion implantation has been demonstrated to be much more effective for improving the surface–sensitive properties such as tribological properties, chemical stability and enginering reliability [5–7].In spite of this, thene are also difficulties in the transfer of the technology from laboratory to production, the lack of suitable equipment to treat industrial components and tools at acceptable cost is generally the dominant reason.It is well known that an ion implantation facility suitable for commercial surface processing in non–electronic industries must fulfill the following criteria: (a)high current (> 10mA); (b)low cost (capital and operating); (c)high ion beam divergence to get large implantation area and to prevent overheating the substrate; and (d)reliability[8–10].

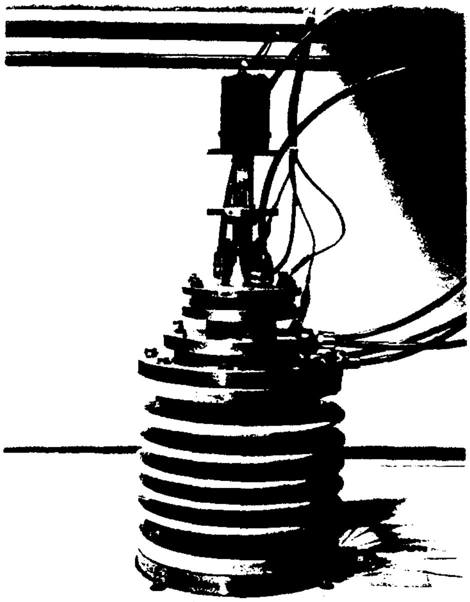
Metal vapor vacuum arc (MEVVA) source was initially developed for nuclear physics experiments by Dr I.G.Brown and co–workers[11, 12].Several different versions of MEVVA source ion implantors have been built for surface modification applications around the world[13–15].MEVVA ion source produces a pure metallic ion plasma form a solid bar (as cathode)of the selected metal.Metallic ions from the plasma are extracted and accelerated into a beam with high energy well switable for ion implantation.MEVVA source ion implantation has a number of unigue features imcluding (a) high current of more than 10 mA for most metallic species such as refractory, noble and rare earth metals and carbon as well; (b) mullicharged ion beams ; (c) sufficient ion purity without mass analysis magnets and ion beam scanning system ; and (d) divergent ion beam and large implantation area It is considered an innovative and cost effective metallic ion beam technology that is well suitable for commercial appications [16–19]. The studies on the economics of metal ion implantation by Dr J.R. Treglio et al indicated that with the advent of industrial scale MEVVA source ion implantation system the production costs have fallen from the order of US $ 1–10 per $cm^2$to as low as US $ 0.03 per cm^2[19]. In this paper the recent development of MEVVA source ion implantation technology at Beijing Normal University and the results of the production trials of components and tools have been reviewed.

2.EQUIPMENT

Several different versions of MEVVA source have been developed and used for metal ion implantation and other applications at Beijing Normal University in China since 1988[20–24].Fig.1 shows the photos of 2 versions of the source in which a stepping motor controlled movable cathode assembled so as to position cathode into the firing position when the cathode highly depleted. The source is operated in a pulsed mode with a pulse length of 1.2ms and the repetition rate typically in the range 0–25 pulses per second.



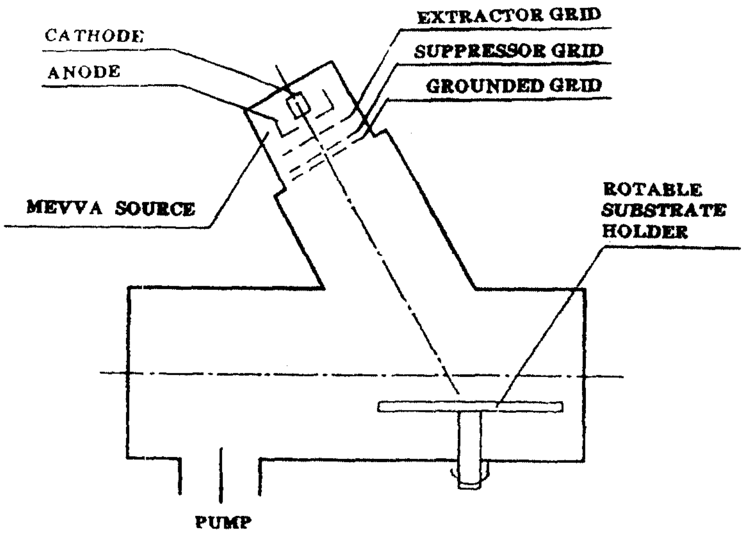
(a)



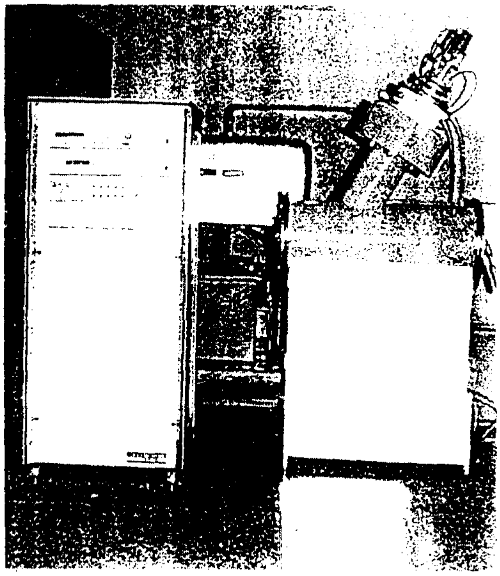
(b)

Fig.1 2 versions of MEVVA source: (a)MEVVA IIA–H source. (b)MEVVA IIB Source

Fig.2 shows a block diagram and an actual photo of a MEVVA source ion implantation system.Vacuum pumping is provided by an oil diffusion pump or an turbopump with a backing pump that can evacuate the chamber to $2x10^{-3}$pa in about 60 min.The extract voltage and time–averaged ion beam current in a circular spot on the target with 200mm diameter can be up to 80kV and 50mA respectively.The design and performance characteristics of the equipment have been described elsewhere[21, 25].In MEVVA source ion implantation, various fixtures are required for handling diferent geometries of workpieces and can be easily interchanged in the chamber in a short period of time. In recent years, computerized end–station systems have been developed to optimize the implantations of complex–shaped targets around the world[26] .In order to obtain optimum and reproducible improvements and avoid overheating of implanted workpieces, It is necessary to accurately control implantation parameters such as ion species, ion dose, ion beam density,ion energy and temperature rise during implantation.



(a)



(b)

Fig.2 MEVVA Source ion implantation system: (a)block diagram (b)photograph

3.APPLICATION IN METAL CUTTING TOOLS

Endurance of metal cutting tools represents a very rigorous application of ion implantation.The wear of metal cutting tools is a complex process in which one or more of adhesive or abrasive wear, surface fatigue, corrosive and / or oxidation wear seem to be the principal contributors to the tooling wear.It is often the case that the user is difficult of specifying what type of wear the tools are subjected to .In order to be successful with surface processing of metal cutting tools by ion implantation, it is very important to do simulation tests carefully before deciding optimal implantation parameters for industrial tools.

The first example of metal cutting tools implanted by MEVVA source ion implantation is twist drills made of high–speed steel for making holes in mild–carbon steel and stainless steel.A lifetime improvement of drills by over a factor of 7 was obtainged with titanium plus carbon dual ion implantation.And markedly lowered materials pinck up was observed as well.Furthermore, a substantial lifetime improvement of treated drills remains after regrinding.Fig.3 is a photograph of implanted drills.

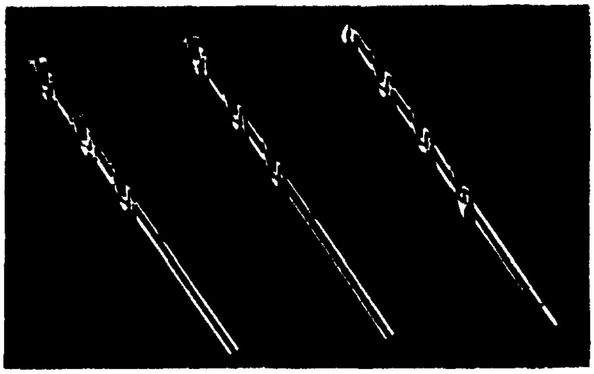
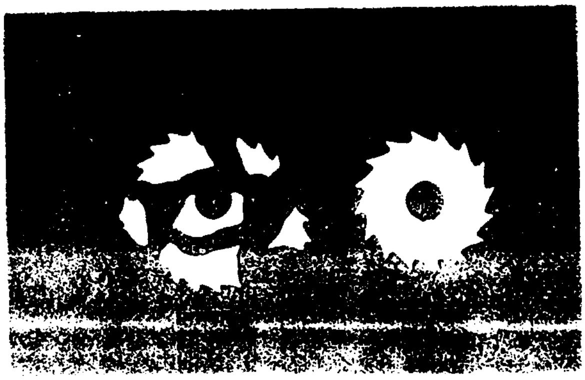


Fig.3 Photograph of high–speed steel twist drills suface–trated with MEVVA source ion implantation

Disc cutters for stainless steel cutting is the second application that can be improved significantly by Ti+C dua implantation.The cutters are also made of high–speed steel hardened to more than HRC60.The number of grooves on stainles steel workpieces cut by the unimplanted cutters is around 4, whereas implanted disc cutters have finished 72 grooves without failure.Ion implantation siginficantly reduces materials pick up during operation and the patches of debris on the surfaces of disc cutters and improves the surface finish of the products, Fig.4 shows a photograph of implanted and uninplanted disc cuters.



(a) (b)

Fig.4 Photograph of disc cutters(80mm diam).

(a)Unimplanted, broken into pieces after working 2 grooves in stainless steel workpiece

(b)Implanted, after working 72 grooves without failure.

The third example of metal cutting tools treated by Ti ion implantation is 3–lip–keyway cutters made of high–speed steel, which outlast unimplanted 3–lip–keyway cutters by a factor of 8 for making keyways in stainless steel workpieces, and by a factor of 7 for mid–carbon steel workpieces.Fig.5 is a photograph of 3–lip–keyway cutters.

Fig.5 Photograph of three–lip–keyway cutters implanted by MEVVA source ion implantation.

4.APPLICATION IN EXTRUSION DIES

A extrusion die typically has a series of fine holes.Ion implantation has been proved to successfully protect the walls of the fine holes of mamy types of dies against wear, adhesion, erosion and corrosion. Ti+C dual implantation has been used for processing some hot extrusion dies (made of H13 steel) for the aluminium shaping industry with siginficant improvemets in endurance up to 30 times and in reduction of extrusion force (or power) by about 20% due to the reduction of aluminium pick up of implanted dies. Fig.6 shows a photograph of a hot extrusion die to produce aluminium alloy shaping material for making bicycle rim.

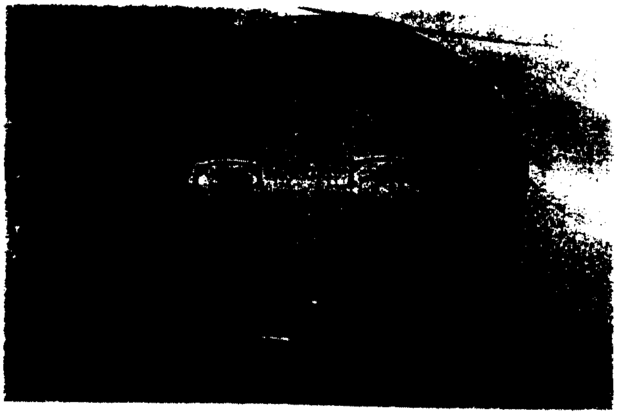


Fig.6 Photograph of Ti+C dual implanted hot extrusion die for shaping aluminium alloy bicycle rim material.

We have also treated cobalt–cemented tungsten carbide dies with Ti+C or Ta+C ion beams for the aluminium can industry by MEVVA source ion implantation. The results of in situ tests showed that implanted dies outlast the untreated ones by a factor of 2–4, and reduce the short can failure.

5.APPLICATION IN RELAY CONTACT COMPONENTS

Precise relay contact components, made of such specialized alloy as silver–based alloys, are good candidates for industial applications of MEVVA source ion implantation.These components usually have amall and simple geometries suitable for batch processing.The failure of these precise devices may have serious consequences.In our experience, some metallic species, e.g. rare earth elements Y or Ce, refractory metal Mo, implanted into relay contact components at doses ranging from $1x10^{17}$to $3x10^{17}$ions / cm^2at extract voltages up to 50 kV , have been effective for both wear resistance and welding resistance without noticeabiy increasing contact resistance.

6.APPLICATION IN CRITICAL COMPONENTS OF SOPHISTICATED EQUIPMENT

Minimizing the power supply of the off–gas pump in returnable artificial satelite is of key importance. Fig.7 shows the rotor and stator (made of GB TIOA carbon tool steel)of an off–gas pump mounted on a returnable artificial satelite for scientific experiments. In aerospace application of off–gas pump which has a tight demensional tolerance , no liquid lubricants can be utilized and no other conventional coating technique is suitable.Ion implantation provides an ideal surface processing for this application.After ion implantation of the rotor and stator of the pump with Ti to a dose of 3×10^{17}ions / cm^2at 50 KV extract voltage by using MEVVA source ion implantation facility, current consumption of the pamp was decreased by more than 25% compared with untreated components.This surface porcessing has been accepted as a regular technique by the manufacturer of these components.

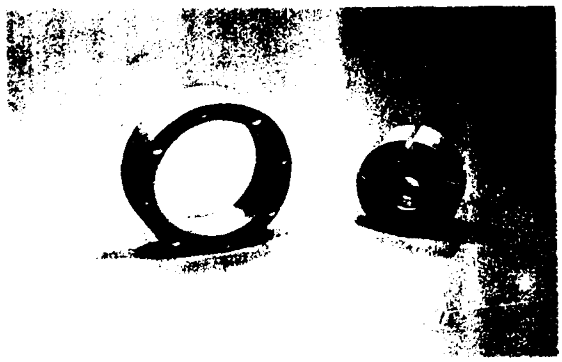


Fig.7 Photograph of the rotor(a) and stator(b) of an off–gas pump for aerospace application.

Another example is the coupling unit consisting of a cam and a holding chuck made of high alloy steel in precise gyroscope.Their tight demensional tolerance makes them good candidates for ion implantation.The operation performance of the coupling unit has been extremely ımproved by Ti+C dual implantation for holding chucks and Ta+C dual implantation for cams respectively.

7.CONCLUSIONS

With the advantages of producing pure, multicharged, divergent and high current metallic ion beams without complicated and costly mass analyzer and ion beam scanning unit, MEVVA source ion implantation is a uniquc and cost–effective ion beam processing technique for both scientific research and industrial applications.

In our experience, siginificant improvements in operation performance of several types of critical tools, sensitive devices and precise components have been obtained by using MEVVA source ion implantation. It is anticipated that MEVVA souce ion implantation will play a much more important role as a surface processing technique for various precision, critical, high–technology and high value–added industrial applications.

ACKNOWLEDGMENT

This work has been supported by the National Advanced Materials Committee of China (NAMCC).

REFERENCES

1. C.J.Mc Hargue, Inlernational Metals Reviews, Vol.31, No.2(1986)49.
2. J.S.Williams, Rep.Prog.phys.49(1986)491.
3. K.O.Legg and H.Solnick–Legg, Nucl.Instrum.Methods, B 40 / 41 (1989)562.
4. G.K.Hubler and F.A.Smidt, Nucl.Instrum.Methods, B7(1985)151.
5. J.K.Hirvonen, Mater.Sci.Eng.A116(1989)167.
6. P.Sioshansi, Mater.Sci. Eng., 90(19887)373.
7. P.Sioshansi, Nucl.Instrum.Methods, B37 / 38(1989)667.
8. F.A.Smidt, B.D.Sartwell and S.N.Bunker, Mater.Sci. Eng., 90(1987)385.
9. C.A.Straede, Nucl.Instrum.Methods, B 68(1992)380.
10. J.R.Treglio, Adv, Mater.process., 12(1989)49.
11. I.G.Brown, J.E.Galvin and R.A.Mac Gill, Appl.phys.Lett., 47(1985)358.
12. I.G.Brown, J.E.Galvin, B.F.Gavin and R.A.Mac Gill, Rev.sci.Instrum., 57(1986)1069.
13. J.R.Treglio, Nucl, Instrum.Methods, B40 / 41(1989)567.
14. I.G.Brown, M.R.Dickinson, J.E.Galvin, X.Godechot and

R.A.Mac Gill, surf. coat .Technol., 51(1992)529.
15. J.R.Treglio, G.D.Magnuson and R.J.Stinner, surf.coat. Technol., 51(1992)546
16. A.I.Ryabchikov, Rev.sci.Instrum., 61(1990)641.
17. S.Humphries, C.Burkhart, S.Cofey, G.Cooper, L:K.Len, M.Savage, D.M.Woodall, H.Rutkowski, H.Oona and R.Shurter, J.Appl.Phys., 59(1986)1790.
18. J.R.Treglio, A.Tian and A.J.Perry, surf.Coat. Technol., 62(1993)438.
19. J.R.Treglio, A.J.Perry and R.J.Stinner, surf.coat. Technol., 65(1994)184.
20. W.L.Lin, X.J.Ding, H.X.Zhang, J.M.Sang, J.Xu and Z.Y.Wang, surf.Coat. Technol., 51(1992)534.
21. X.J.Zhang, H.X.Zhang, F.S.Zhou, S.J.Zhang, Q.Li and Z.E.Han, Rev.Sci. Instrum., 63(1992)2431.
22. W.L.Lin, X.J.Ding, J.M.Sang, J.Xu, Z.Y.Wang, S.Y.Zhou and Y.L.Li, surf.Coat.Technol., 56(1993)137.
23. W.L.Lin, X.J.Ding, T.Lu, Y.H.Qian, J.M.Sang, Z.Y.Wang.J.Xu, S.Y.Zhou and Y.L.Li, Mater.Lett., 13(1992)212.
24. H.X.Zhang, X.J.Zhang, F.S.Zhou, S.J.Zhang and Z.E.Han, Rev.Sci.Instrum., 6(1990)574.
25. W.L.Lin, X.J.Ding, J.M.Sang, J.Xu and X.M.Yuan, J.Mater.Eng.per. form., Vol.3 No. 5(1994)587.
26. B.Torp,P.Arahamsen, S.Erisen and B.R.Nielsen, Surf, Coat, Technol., 51(1992)556.