JMEPEG (1994) 3:587-590

High-Current Metal Ion Implantation for Industrial Applications

W.L. Lin, X.J. Ding, J.M. Sang, J. Xu, and X.M. Yuan

Ion implantation, as an efficient surface processing technique, has developed to include the implantation of various metallic ions for improving not only wear properties, but also such other surface properties as solid lubrication, fatigue, chemical stability, and engineering reliability. The high-dose metal ion implantation that can be accumulated in a short time over a relatively large implanting area makes metal vapor vacuum arc (MEVVA) source ion implantation well suited to practical surface engineering modification applications.

Keywords

industrial application, high-current, metal ion implatation, surface processing

1. Introduction

AS A SURFACE treatment technique for industrial application in non-semiconductor industries, ion implantation has the following advantages; (a) no thermodynamic constraints; (b) no noticeable dimensional change or shape distortion; (c) no delamination problem between the modified layer and the matrix; and (d) no requirement of refinishing or reheating.

In a series of papers, ion implantation of metallic species has been demonstrated to be effective for multipurpose modifications of surface-sensitive properties such as tribological properties, chemical stability, and engineering reliability (Ref 1-3).

Although numerous technical improvements have been obtained by metallic ion implantation, real commercial applications have emerged only in recent years. One of the main reasons for this has been the lack of suitable equipment for surface processing applications.

It is well known that an ion implantation facility suitable for commercial applications in non-semiconductor industries must fulfill the following demands: (a) high current; (b) low cost (capital and maintenance cost); (c) large implanted area; and (d) reliability (Ref 4-6).

Metal vapor vacuum arc (MEVVA) source ion implantation has some very attractive features: (a) high current of more than 10 mA for most metallic species; (b) multicharged ion beams; (c) sufficient ion purity without mass analysis magnets and ion beam scanning systems; and (d) divergent ion beam and large implanted area (Ref 7, 8). It is considered an innovative and cost-effective metallic ion beam technology that is well suitable for industrial applications (Ref 9, 10).

This paper presents some experimental results and successful examples of critical tools and sophisticated components implanted by using MEVVA source ion implantation.

2. Equipment

Several different versions of MEVVA source ion implantors have been built for surface engineering applications around the world (Ref 11-13). Four versions of this equipment have been installed at Beijing Normal University in China since 1988 and have been used for research and development investigations and for industrial service (Ref 14-18). Figure 1 shows a block diagram and an actual photograph of the equipment. Vacuum pumping is provided by an oil diffusion pump with a backing pump that can evacuate the chamber to 2×10^{-3} Pa in about 60 min. Pulsed, multicharged, sufficiently pure, divergent, and high-current ion beams of nearly all solid metallic species in the periodic table can be extracted from the source and then directly bombarded onto the target (specimens or industrial workpieces) without complicated and expensive mass analysis magnets or beam scanning systems. The extract voltage and time-averaged beam current in a circular spot on the target with a diameter of 200 mm can be up to 80 kv and 50 mA, respectively. In order to obtain reproducible improvements and avoid overheating of workpieces, it is necessary to accurately control implantation parameters such as ion species, ion dose, dose rate, energy, and temperature rise during implantation.

In MEVVA source ion implantation, target manipulations are required to implant all sides of the targets except planar ones. According to different geometries of industrial components, the target manipulation systems may consist of translation along one linear axis and rotation about one or more axes. In recent years, computerized end-station systems have been developed to optimize the implantation of complex-shaped targets around the world (Ref 19).

3. Implantation of Metal Cutting Tools

Endurance of metal cutting tools represents a very rigorous application of ion implantation, but little progress in this area had been made previously. The wear of metal cutting tools is a complex process in which abrasive wear, surface fatigue, and corrosive and/or oxidation wear seem to be the principal contributors to the tooling wear. It is often the case that the user is not able to specify what type of wear the tools are subjected to. In order to be successful with surface treatment of tools by ion

W.L. Lin and **X.J. Ding**, Institute of Low Energy Nuclear Physics, Beijing Normal University, Beijing 100875, China; **J.M. Sang, J. Xu**, and **X.M. Yuan**, Beijing General Research Institute of Non-Ferrous Metals, Beijing 100088, China.

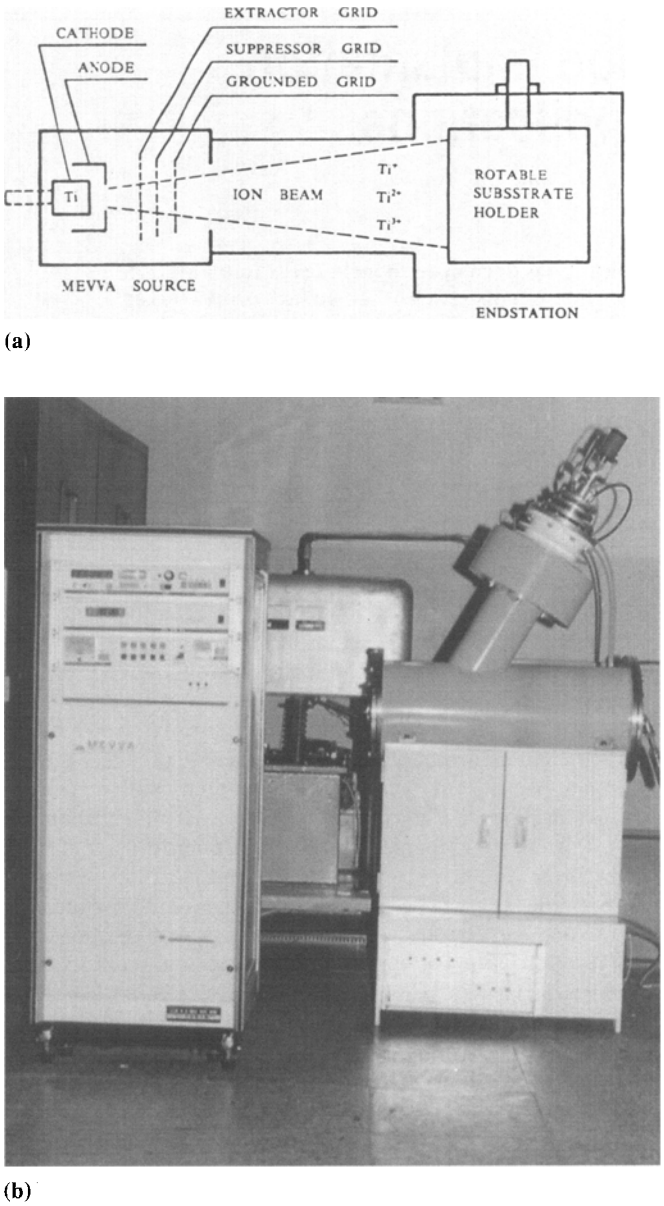

Fig. 1 MEVVA source ion implantation system. (a) Block diagram. (b) Photograph

implantation, it is very important to do simulating laboratory tests carefully before deciding optimal implantation parameters for industrial tools.

The first example of metal cutting tools implanted by using MEVVA source ion implantation is twist drills made of high-strength steel for making holes in mild-carbon steels and stainless steels. A lifetime improvement of drills by over a factor of 7 was obtained with titanium (3×10^{17} ions/cm^2 at 50 kv) plus carbon (2×10^{17} ions/cm^2 at 30 kv) dual implantation. Markedly lowered materials pickup was observed as well. Furthermore, a substantial lifetime improvement of treated drills remains after regrinding. Figure 2 is a photograph of implanted drills.

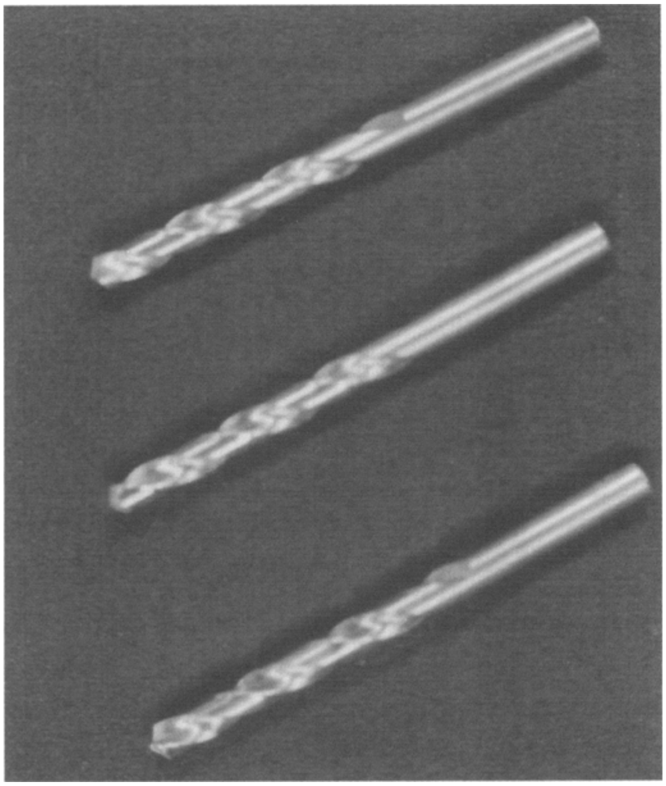

Fig. 2 Photograph of high-speed steel drills (8 mm diam × 73 mm) treated with MEVVA source ion implantation

Disc cutters for stainless steel cutting is another application that can be improved significantly by Ti + C dual implantation. The cutters are made of high-speed steel hardened to more than HRC 60. On an average, the number of grooves the unimplanted cutters can make is around 4, whereas implanted disc cutters have finished 72 grooves without failure. Ion implantation significantly reduces materials pickup of the cutters during operating and improves the surface finish of the products. Figure 3 is a photograph of implanted and unimplanted disc cutters.

4. Implantation of Relay Contact Components

High-precision relay contact components, made of such specialized alloys as silver-based alloys, are good candidates for industrial applications of MEVVA source ion implantation. These components usually have small and simple geometries suitable for batch processing. The failure of these devices may have serious consequences. In our experience, some species, for example the rare earth elements yttrium or cerium or the refractory metal molybdenum, implanted into relay contact components at doses ranging from 1×10^{17} to 3×10^{17} ions/cm^2 at extract voltages up to 50 kv, have been very effective for both wear resistance and contact welding resistance without noticeably increasing contact resistance. A few of these components are in pilot-scale production for MEVVA source ion implantation processing.

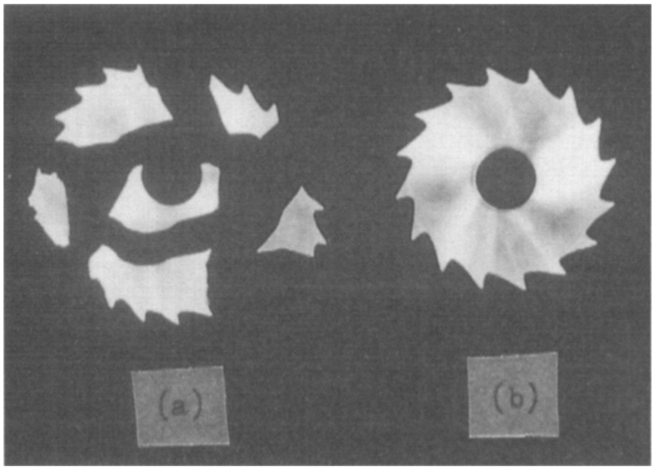

Fig. 3 Photograph of disc cutters (80 mm diam). (a) Untreated, after working 2 grooves in stainless steel workpieces. (b) Implanted, after working 72 grooves in a stainless steel workpiece

5. Implantation of Dies

A die typically has a series of fine holes. Ion implantation has been proved to successfully protect the walls of the holes of many types of dies against wear, erosion, and corrosion. We have treated some hot extrusion dies for the aluminum shaping industry with significant reduction of extrusion force (or power) due to the reduction in aluminum pickup by implanted dies.

We have also treated cobalt-cemented tungsten carbide dies with titanium and carbon ion beams for the aluminum can industry by using MEVVA source ion implantation. The results of in situ tests showed that implanted dies outlast the control samples by a factor of 2 to 4.

6. Implantation of Sophisticated Components

Minimizing the power supply of precision components of aerospacecraft is of key importance. It has been known for several years that either titanium implantation or Ti + C dual implantation into steels can give good wear resistance and marked reduction in coefficient of friction. This treatment seems to be a unique tool for improving precision components in artificial satellites, which can not utilize any liquid lubricants. Figure 4 shows the rotor and stator (made of GB T10A carbon tool steel) from an off-gas pump mounted on a returnable artificial satellite. After ion implantation with titanium to a dose of 3×10^{17} ions/cm^2 at 50 kv extract voltage by using a MEVVA source facility, current consumption of the pump was decreased by more than 25%, compared with that of the untreated component, and the manufacturer of these components has accepted the processing as a regular technique.

7. Conclusion

With the advantages of producing pure, multicharged, large-implanting-area, and high-current metallic ion beams without complicated and costly mass-analysis magnets and beam scanning systems, MEVVA source ion implantation is a unique and cost-effective ion beam processing technique for both research and industrial applications.

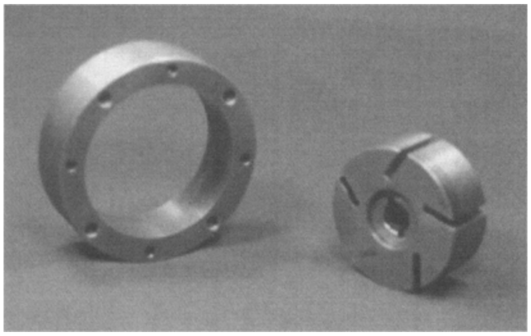

Fig. 4 Photograph of a rotor and stator of an off-gas pump for an artificial satellite

In our experience, significant improvements in operational performance of critical toolings, sensitive devices, and precision aerospace components have been obtained by using MEVVA source ion implantation:

- A lifetime improvement of twist drills by over a factor of 7 has been obtained by Ti + C dual implantation.
- Ti + C dual-implanted disc cutters outlast untreated disc cutters by a factor of over 17 and significantly reduce materials pickup.
- Yttrium, cerium, or molybdenum ion implantations have proved to be effective for improving wear resistance and contact welding resistance of relay contact components without noticeably increasing contact resistance.
- Ti + C dual-implanted WC-Co dies for the aluminum can industry outlast the control by a factor of 2 to 4 and reduce the short can failure.
- After titanium ion implantation of the rotor and stator of an off-gas pump mounted on a returnable artificial satellite, current consumption of the pump was reduced by more than 25% compared with that of unimplanted pumps.

It is anticipated that MEVVA source ion implantation will play a much more important role in surface treatments of various precision, critical, high-technology, and value-added industrial applications.

Acknowledgment

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

References

1. J.K. Hirvonen, *Mater. Sci. Eng.*, Vol A116, 1989, p 167
2. P. Sioshansi, *Mater. Sci. Eng.*, Vol 90, 1987, p 373
3. P. Sioshansi, *Nucl. Instrum. Methods*, Vol B37/38, 1989, p 667
4. F.A. Smidt, B.D. Sartwell, and S.N. Bunker, *Mater. Sci. Eng.*, Vol 90, 1987, p 385
5. C.A. Straede, *Nucl. Instrum. Methods*, Vol B68, 1992, p 380
6. K.O. Legg and H.S. Legg, *Nucl. Instrum. Methods*, Vol B40/41, 1989, p 562

7. I.G. Brown, J.E. Galvin, and R.A. MacGill, *Appl. Phys. Lett.*, Vol 47, 1985, p 358
8. H.X. Zhang, X.J. Zhang, F.S. Zhou, S.J. Zhang, and Z.E. Han, *Rev. Sci. Instrum.*, Vol 61, 1990, p 574
9. A.I. Ryabchikov, *Rev. Sci. Instrum.*, Vol 61, 1990, p 641
10. S. Humphries, C. Burkhart, S. Coffey, G. Cooper, L.K. Len, M. Savage, D.M. Woodall, H. Rutkowski, H. Oona, and R. Shurter, *J. Appl. Phys.*, Vol 59, 1986, p 1790
11. J.R. Treglio, *Nucl. Instrum. Methods*, Vol B40/41, 1989, p 567
12. J.R. Treglio, G.D. Magnuson, and R.J. Stinner, *Surface and Coatings Technology*, Vol 51, 1992, p 546
13. I.G. Brown, M.R. Dickinson, J.E. Galvin, X. Godechot, and R.A. MacGill, *Surface and Coatings Technology*, Vol 51, 1992, p 529
14. W.L. Lin, X.J. Ding, H.X. Zhang, J.M. Sang, J. Xu, and Z.Y. Wang, *Surface and Coatings Technology*, Vol 51, 1992, p 534
15. X.J. Zhang, H.X. Zhang, F.S. Zhou, S.J. Zhang, Q. Li, and Z.F. Han, *Rev. Sci. Instrum.*, Vol 63, 1992, p 2431
16. W.L. Lin, X.J. Ding, J.M. Sang, J. Xu, Z.Y. Wang, S.Y. Zhou, and Y.L. Li, *Surface and Coatings Technology*, Vol 56, 1993, p 137
17. W.L. Lin, X.J. Ding, T. Lu, Y.H. Qian, J.M. Sang, X.Y. Wang, J. Xu, S.Y. Zhou, and Y.L. Li, *Mater. Lett.*, Vol 13, 1992, p 212
18. T. Zhang, C. Ji, J. Yang, J. Chen, J. Shen, W. Lin, Y. Gao, and G. Sun, *Surface and Coatings Technology*, Vol 51, 1992, p 455
19. B. Torp, P. Arahamsen, S. Erisen, and B.R. Nielsen, *Surface and Coatings Technology*, Vol 51, 1992, p 556