ELSEVIER

Surface and Coatings Technology 84 (1996) 557–562

SURFACE & COATINGS TECHNOLOGY

Ion implanters for surface modification of metals

Bo Torp [a], Bjarne Roger Nielsen [a], Niels Jørgen Mikkelsen [b], Christen A. Stræde [b]

[a] *Danfysik A/S, Møllehaven 31A, DK-4040 Jyllinge, Denmark*

[b] *Tribology Centre, DTI Industry, Danish Technological Institute, Teknologiparken, DK-8000 Aarhus C, Denmark*

Abstract

Extensive experience has now been gained with respect to the application of ion implantation for surface modification of metals. Some implanters have been specifically developed to serve in research and development as well as in service implantation work within this field. This paper gives an overview of available ion implanters for surface modification of metals and their different design philosophies.

A special magnetic scanning and beam position control has been designed for our high-current implanter, capable of fast and efficient ion implantation of tools and components. Accurate magnetic steering of the ion beam by means of computer control allows high-current ion implantation to be performed on selected areas and patterns in the process chamber. In this way, only the important and relevant areas of the specimens are implanted. Thus, ion beam-induced heating of the specimens is decreased and the total process time is considerably reduced, making ion implantation a less costly commercial treatment for several tools and components.

Finally, future trends in equipment and technology have been touched upon.

Keywords: Ion implantation; Surface modification; Ion implanters

1. Introduction

During the last fifteen years it has been shown that in addition to nitrogen ion implantation, other ions, e.g. titanium, tantalum, chromium, boron and carbon, are needed to optimise the effects of ion implantation on the tribological and corrosive behaviour of materials [1]. Several high-current ion implanters have been developed to serve as service production machines, some only for gas or metal beams, others for all kinds of ions. However, the breakthrough of ion implantation as a widely accepted industrial technique has yet to occur.

Experience gained at the DTI Tribology Centre over the last seven years with commercial service implantation has shown that specialised and efficient equipment is required to ensure the success of ion implantation as an industrial process. It is also clear that some features have to be strengthened to allow for future growth of this technique within the industrial environment.

2. Ion implanters for surface modification of metals for ion beams

Most of the initial research and development work for ion implantation into metals has been carried out using laboratory accelerators, including electromagnetic isotope separators and home-made implantation machines [2]. Production implantation work was first performed with simple nitrogen implanters. Later, converted semiconductor implanters were used for a wider selection of ion species, and dedicated implanters for metals implantations were developed. Table 1 gives an overview of ion implanters in the energy range of 100–200 kV used for production implantation into metals.

The ion implanters can be grouped into five different categories, as shown below.

2.1. Non-mass analysed type with nitrogen ion source (A)

This type has been around for more than fifteen years. It is based on a bucket-type ion source directly attached to the target chamber. The ion source produces a broad beam covering the implant area and no scanning is applied. For large area implantation this causes some inhomogeneity of the dose. The advantage of this type of implanter is that the operation is simple, but the beam is limited to a mixture of N^+ and N_2^+ and therefore cannot be used in applications where metal

SSDI 0257-8972(95)02732-7

Table 1
An overview of machines (100–200 kV) used for production implantation into metals

	Non-mass analysed with nitrogen source	Non-mass analysed with metal vapour vacuum arc source	Mass analysed, semiconductor type; refurbished	Mass analysed, metal type with magnetic scanning	PSII
Advantages	Simple operation. Compact.	Simple metal beam production. Multi energy implant. Compact. Easy to change ion species.	Relatively low initial investment. Process parameter control (at low current).	Process parameter control. Large areas and components. More than one end-station. Versatile. Selected area implantation.	Not line-of-sight. Simple. No target manipulation.
Disadvantages/ problems	Line-of-sight. Only nitrogen beam. N^+/N_2^+ mix.	No pure gas beam. Line-of-sight. Multi energy implant. Metallic droplets.	Space charge effects (at high currents). Line-of-sight. End station. Beam current limitations. Not all elements may be available.	Line-of-sight. Large foot print. Complex.	Scale-up problems. Secondary electrons. Cooling of many small workpieces. No local treatment possible.
Examples of commercial suppliers	Tecvac. Zymet. ISC.	ISM.	Eaton. Varian. Spire.	Danfysik. Whickham.	

beams are required, such as for improving corrosion resistance. Fig. 1 shows a nitrogen implanter of this type.

2.2. Non-mass analysed type with a metal vapour vacuum arc source (B)

The layout of this type of implanter is similar to A [3]. The bucket source is exchanged for a metal vapour vacuum arc source, which uses a simple means of producing metal beams [4]. It is easy with this source to change between different metal ion species by turning a revolving wheel with different metal cathodes. The ion source produces ions of several different charge states, and with a fixed extraction energy this gives a set of discrete implantation energies. This can be an advantage since multi-energy implanting gives a broader implanted depth profile. However, it is not possible to control the charge state distribution and, hence, it is not easy to adjust the multi-energy implant, if necessary. Metallic droplets cannot be avoided from the ion source and this may cause problems [4]. This type of implanter does not allow implantation of pure gas ions and therefore cannot be used for the many applications using nitrogen implantation.

The two non-mass analysed machines are compact, since there is no mass analysing magnet, and no beam scanning or focusing facilities.

2.3. Mass-analysed converted semiconductor type (C)

This type consists of a slit extraction-type ion source, mass analysis, post acceleration and a target chamber, in some cases with a modified end-station with beam focusing and scanning [5]. The process parameter control is good at lower currents, but since these implanters use electrostatic lenses and beam scanning, controlling the beam at high currents is difficult owing to space charge effects. The semiconductor machines are mainly aimed at four different ions, i.e. B, P, As and Sb. Therefore, some elements might not be suitable. Being constructed from refurbished semiconductor implanters, the initial investment is relatively low, but more downtime can be expected.

2.4. Mass-analysed type with magnetic scanning (D)

This type of machine was developed specifically for high-dose, high-current implantation into metals with good process parameter control. The overall lay-out is quite similar to type C, but to avoid space charge effects the beam transport is all magnetic. This includes a magnetic quadrupole triplet and magnetic scanning in both horizontal and vertical directions in order to focus the high-current beam and scan it over large areas. Furthermore, the target chamber has been developed

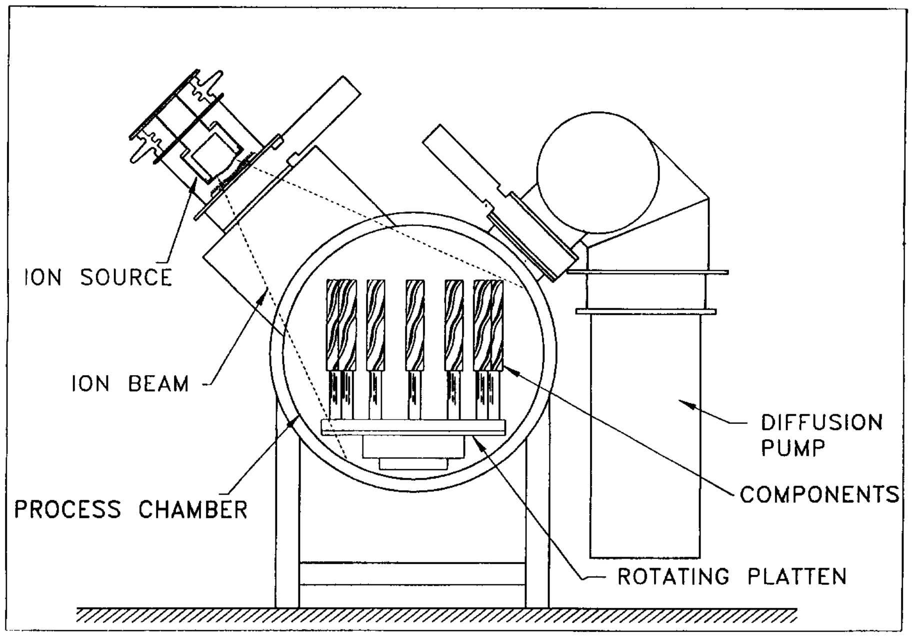

Fig. 1. Non-mass analysed nitrogen implanter (Implant Sciences Corp., USA).

specifically to allow manipulation of large tools and components [6,7]. An example of this type with switching magnet and more than one end-station, giving a better efficiency by minimising the pumping down and handling time, is shown in Fig. 2. This implanter has been manufactured in different configurations, the later ones including IBAD.

This type of machine is versatile and, therefore, complex, and has a relatively large foot print.

Implantation with machines of types A, B, C and D

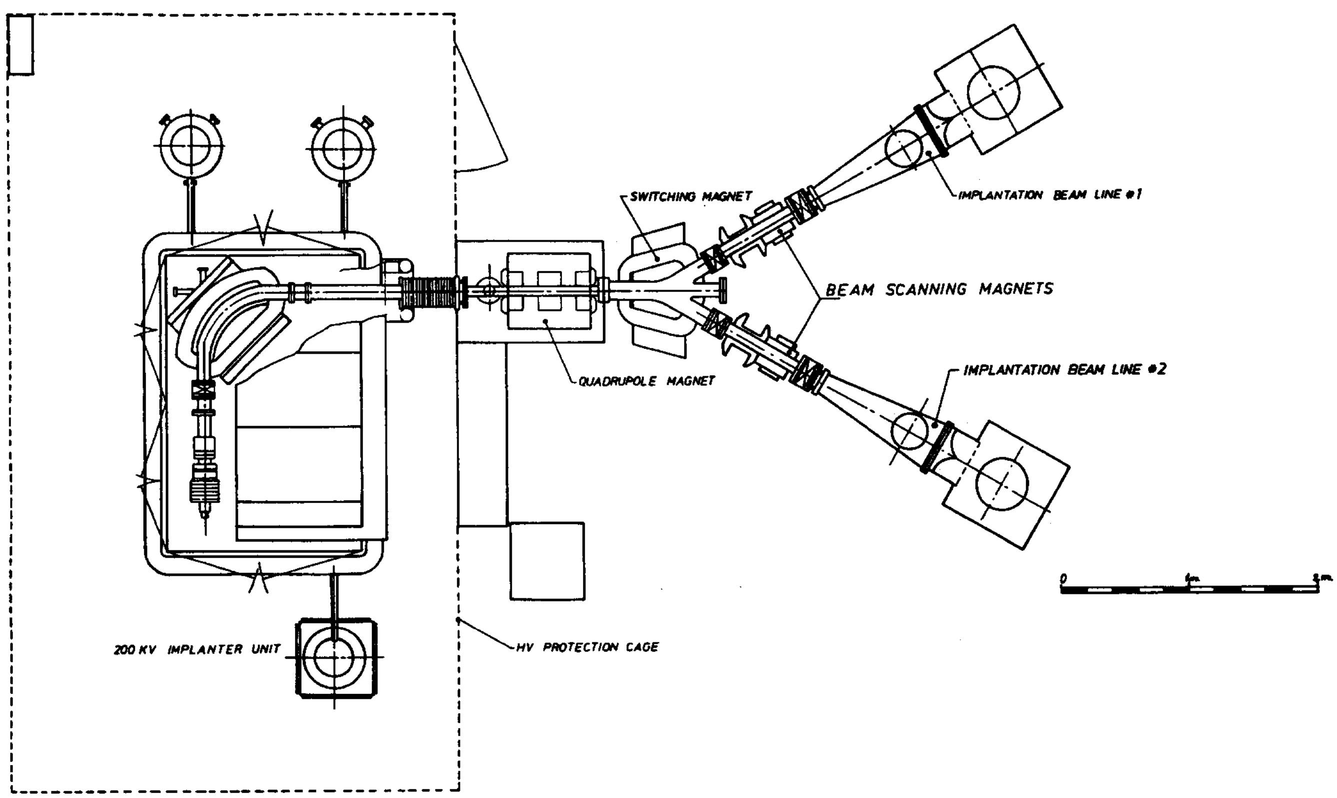

Fig. 2. High-current implanter with two implantation beam lines (Danfysik, Denmark).

is a line-of-sight process and therefore sample manipulation is required.

2.5. *Plasma source immersion implantation (PSII) (E)*

In PSII the stationary target is placed on an electrically isolated target holder embedded in a plasma enclosure. The implantation is done by pulsing the target potential to voltages in the 100 kV range. Since the plasma surrounds the sample this is not a line-of-sight process and no target manipulation is required [8].

This technique is quite promising for production work, but for large scale applications problems with plasma density, secondary electrons and cooling of many workpieces have to be overcome [9,10].

3. Computerised beam scanning and position control

Our high-current implanter was developed partly for service implantation work. Several ions can be produced with intensities of 5–10 mA, but some metal beams are more difficult to produce and may have many isotopes, resulting in useable beam intensities in the 1 mA range, only.

Therefore, in order to improve the efficiency of the implantations, a computerised beam scanning and position control was developed, as shown schematically in Fig. 3. The system is described in detail in Ref. [7].

The advantages of utilising the beam control and steering of the implanter are illustrated in the following example. At the DTI Tribology Centre, punch tools for tin-can production, like the one shown in Fig. 4, are frequently ion implanted. Although the tools are often large (diameters up to 30–40 cm), they may be implanted relatively quickly and cheaply with the new beam position control system. This is due to the fact that the critical area near the cutting edge is small, and by implanting this area only the process time is greatly reduced compared with that using a broad beam or rectangular beam scanning.

The tool is implanted by directing a focused beam (beam diameter ~1 cm, horizontally fixed and scanned 2 cm in vertical direction) onto the centre of the critical area of the rotating tool with the rotational axis held 45° from vertical. Several tools can be mounted in one batch, and the ion beam is made to shift frequently from tool to tool, as shown schematically in Fig. 5.

If three punches are implanted in one batch, the total area to be implanted is 534 cm^2. With a beam current of 5 mA and selected area implantation, the typical process time would be 1 h for the whole batch, and each tool is subjected to an average of only about 100 W beam power. Cooling the tools using the water cooled manipulator is therefore easy, even with relatively simple mounting fixtures.

If instead the same batch of tools were to be implanted using a broad stationary beam or a scanned rectangular beam, the situation would be quite different. This would require a broad beam diameter of about 45 cm, corre-

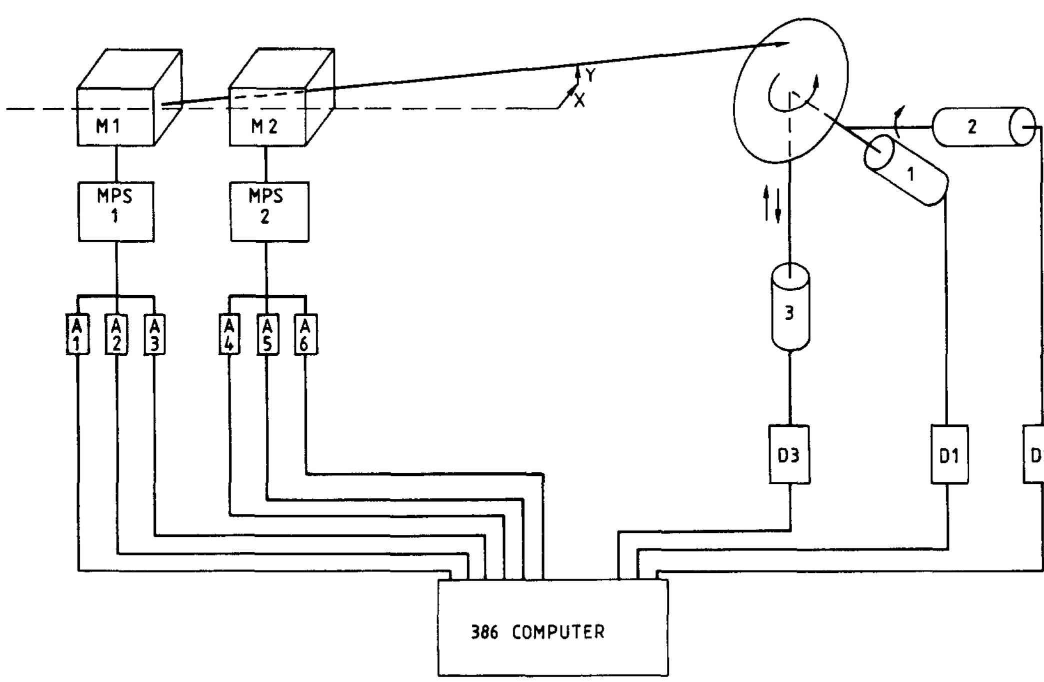

Fig. 3. The computerised end-station shown schematically. M1 and M2 are the two scanning magnets; MPS1 and MPS2 are the two magnet power supplies for the scanning magnets; A1–A6 are six analogue input signals for the power supplies; and D1–D3 are the three stepping motor drivers of the sample manipulator.

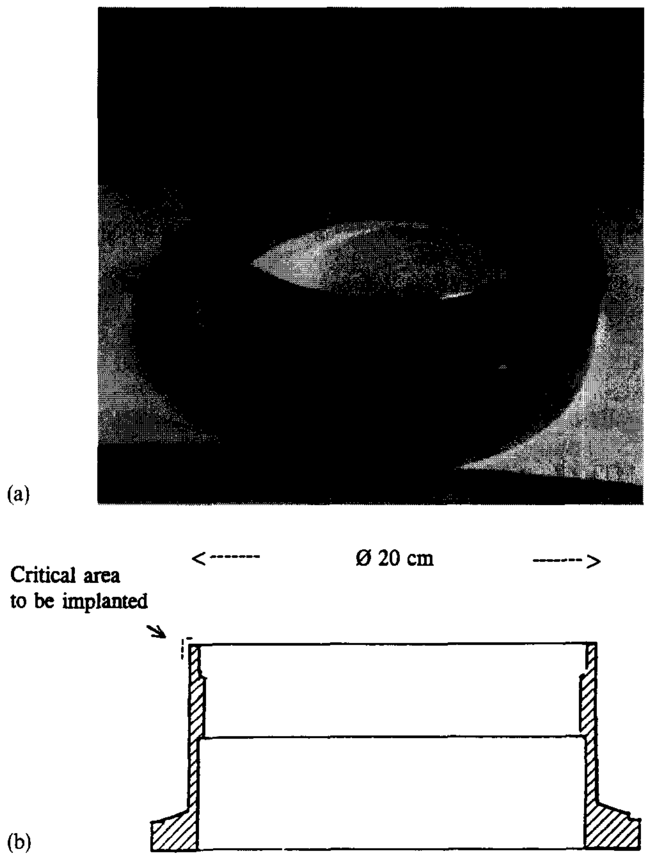

Fig. 4. A punching tool for tin can production. The lifetime of the tool was enhanced by a factor of nine by ion implantation (DTI Tribology Centre, Denmark).

sponding to a beam area of about 1590 cm^2. Owing to shadowing, the total area to be implanted is 7066 cm^2 when the tools are mounted at 45° relative to the beam. This area is approx. 13 times larger than the total implanted area in the selected area approach. In this case, with a beam current of 5 mA a process time of 13 h is needed. Alternatively, a beam current of 65 mA would reduce the process time to 1 h, but for such a beam current the total beam power would be approx. 4.9 kW. Thus, cooling the tools during the process may be very difficult or even impossible. In addition, running an ion source and an accelerator with such a high beam current is often troublesome and demands more servicing and refurbishment of the equipment.

In the case described above, but also when applied to many other tools, the selected area implantation technique will often result in a productivity gain of about ten times and a corresponding lowerering of the cost of ion implantation.

4. Future trends

Are higher beam currents needed? It has been stated that larger installations and consequently higher beam currents are needed to get the cost of broad beam ion implantation down to prices similar to PVD (physical vapour deposition) [11] for example, but this means that a large sample holder will be filled with large batches of tools or components requiring the same treatment every time. This is not always possible.

For the current applications at the DTI Tribology Centre using selected area implantation, 3–5 mA of nitrogen and chromium are sufficient and the prices are on the same level as PVD. Higher currents can give cooling problems. Therefore, we believe other more important elements in the process should be addressed to further enhance the commercial viability.

Low capital cost of equipment is important if the technique is to be further utilised by industry, and we believe that it is possible to reduce significantly the cost of the equipment.

It is important to have dedicated SMMIB equipment. Currently only a few ion species are required for production work at the DTI Tribology Centre. Therefore, the equipment does not need to be so versatile as that required for research and development machines. Furthermore, to make the treatment cost-effective we believe that selective area implantation is necessary.

The implanter should be fully automated and have process control so that a specialised technician easily can run the machine. The control system should incorporate data logging and remote trouble shooting.

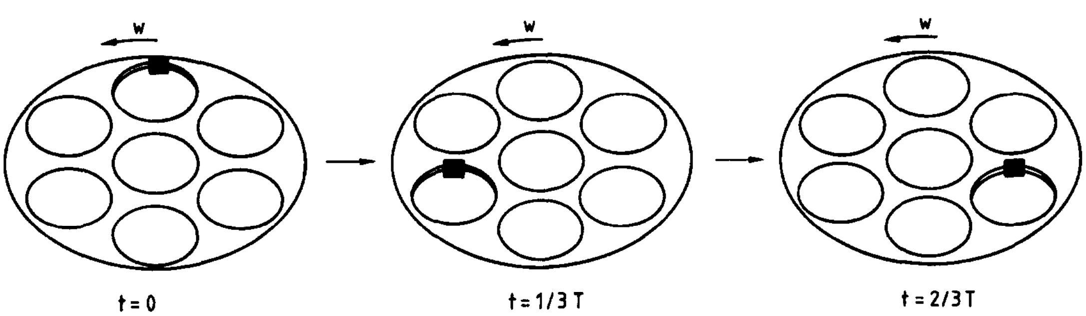

Fig. 5. Implantation of seven ring-shaped components on a disc using the selected area. The area of the ring being implanted is shown by the dark rectangles.

It is also important to keep the down time below 20% to reduce the overall running costs of the treatment.

If these improvements to the SMMIB equipment can be achieved in the future, we believe that the technique will be more successful.

Acknowledgements

This work was supported by the Danish Ministry of Industry under the Materials Technology Development Program (MTUP2).

References

[1] *Nucl. Instrum. Methods B, 19–20* (1987); *Mater. Sci. Eng., 90* (1987); *Nucl. Instrum. Methods B, 39* (1989).
[2] G.D. Lempert, *Surf. Coat. Technol., 34* (1988) 185.
[3] J.R. Treglio, G.D. Magnuson and R.J. Stinner, *Surf. Coat. Technol., 51* (1992) 546.
[4] I.G. Brown, *Rev. Sci. Instrum., 63* (1992) 2351.
[5] F.A. Smidt, B.D. Sartwell and S.N. Bunker, *Mater. Sci. Eng., 90* (1987) 385.
[6] B.R. Nielsen, P. Abrahamsen and S. Eriksen, *Mater. Sci. Eng. A, 116* (1989) 193.
[7] B. Torp. P. Abrahamsen, S. Eriksen and B.R. Nielsen, *Surf. Coat. Technol., 51* (1992) 556.
[8] J.R. Conrad, *Mater. Sci. Eng. A, 116* (1989) 197.
[9] D.J. Rej, J.R. Conrad, R.J. Faehl, R.J. Gribble, I. Henins, N. Horswill, P. Kodali, M. Nastasi, W.A. Reass, M. Shamim, K. Sridharan, J. Tesmer, K.C. Walter and B.P. Wood, *Mater. Res. Soc. Symp. Proc., 316* (1994) 593.
[10] B.P. Wood, I. Henins, R.J. Gribble, W.A. Reass, R.J. Faehl, M.A. Nastasi and D.J. Rej, *J. Vac. Sci. Technol. B, 12* (1994) 870.
[11] J.R. Treglio, A.J. Perry and R.J. Stinner, *Surf. Coat. Technol., 65* (1994) 184.