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IMPLANTATION OF INTENSE PULSED METALLIC ION BEAM

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Abstract

The short-duration intense mixed metallic and gaseous ion beams, such as Ti^+ and N^+, produced by the multiplate chamber with central hole have been used for implantation. The compositions of titanium and nitrogen as a function of depth was determined using Auger electron spectroscopy PHI-550. It is proved that phase transitions of thin layer of steel bombarded by ion beams take place owing to the ion mixing and rapid cooling down of implanted area after melting by the pulsed beams with power density more than $10^7 W/cm^2$. The effective hardness increase is concluded from microhardness measurements. It is expected that the implantation with pulsed ion beam could open a new way for the significant industrial application.[1]

Introduction

As a result of the development of accelerator technology, ion implantation has been successfully used in the fabrication of semiconductor devices and large integrated circuit as a precise and versatile technique for introducting controlled amounts of dopant into semiconductor surface layers. In the early 1970's, the studies of ion implantation applied to the modification of the non-electric properties of material such as the mechanical and chemical properties of metals were initially carried out in the Harwell Laboratory and others.

New metastable alloys and compounds were unexpectelly formed by using ion implantation technology. An attempt to combine the ion implantation processes into a single step operation was demostrated experimentally to silicon doping by two different groups.[2] One group implanted phosphorus into P-type Si samples using a mechanically chopped ion beam produced in a conventional ion implanter. The pulse duration was of the order of a second, the ion current was several milliamperes and the ion energy was fixed at 100 keV. The other method, referred to as pulse implantation doping makes use of high-intensity pulses of plasma containing dopant atoms, generated by a powerful plasma gun. The duration of the ion beam pulse is within the range of one microsecond, the current density within the the range of several kA/cm^2, and the ion energy is of order of several keV.[3]

In our report, a new method of intense pulsed implantation by using powerful pulsed ion beam produced by multiplate chamber(MPC) is outlined. As a simple and efficient device, the MPC could provide a convenient tool to carry out pulsed implantation for wide application of material modifications.

Experimental procedure

As a variety of metallic ions, for instance, Al^+, Ti^+, Fe^+, Cu^+, Ag^+ etc. are evidently generated by MPC, it encourages us to carry out the experimental investigation of pulsed implantation with such a compact particle beam generator.

The specimens of virgin iron and carbon steel were chosen as implanted samples. After polishing, the pre-annealed substrates were placed on the positions outside the cathode hole of MPC.

It is well known that the chemical compounds of Ti_2N and TiN mixed with substrate carbon steel can significantly enhance the refractory and corrosion resistance and improve the behaviours of friction and wear of carbon steel, therefore, we take titanium and nitrogen mixed ion beams with ion energy about 50 keV for pulsed implantation.[4]

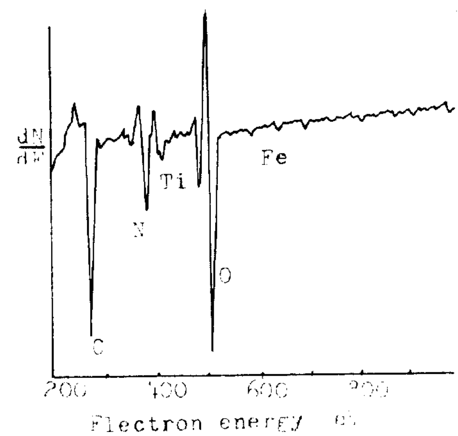


Fig. 1 Auger spectra of the implanted surface

Fig. 1 shows the components of implanted area of virgin iron specimen determined by using PHI-550 etcning revealed that the

The Auger depth profile of the components C, N, Ti, Fe by Ar etcing revealed that the titanium and nitrogen have similar depth profile, which could be explained by the high affinity of titanium and nitrogen (Fig. 2). Gaussian profiles of implanted titanium and nitrogen atoms response the theory of stopping range. Based on the melting model of intense pulsed ion beam for the doping process, the implanted atoms should be driven-in deeply into bulk of the substrate compared with the ion implantation of low DC current. One more witness of good affinity between titanium and nitrogen atoms is of the result of the linear electron scanning of bombarded

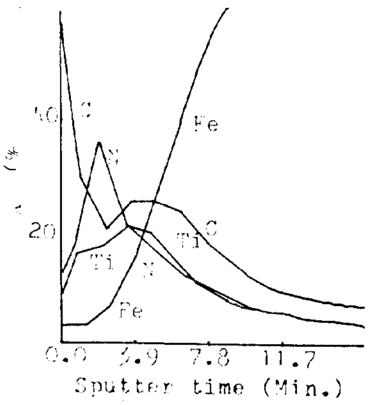


Fig. 2 The concentration of the com-components C, N, Ti, Fe versus sputtering time

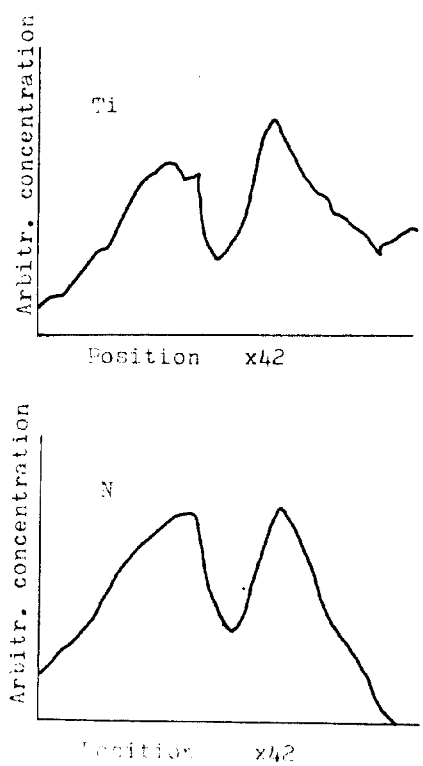
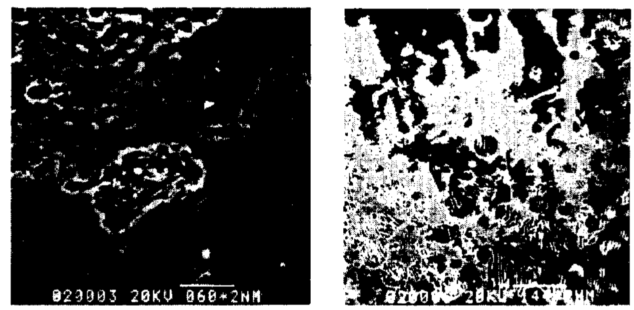


Fig. 3 The distributions of surface concentration of Ti and N by Auger electron linear scanning

region surface (Fig. 3).

For the observation of phase transformation, a specimen of 0.45 C carbon steel was implanted by mixed titanium and nitrogen ion beams. Rapid melting of thin layer on the sample surface took place under the bombardment of pulsed ion beams, therefore, the feature of "orange peel" appears on the polished surface of the sample due to the quenching effect induced by the pulsed powerful ion beams (Fig. 4). This could lead to a picture of an amorphous metal as highly disordered solid. In the boundary region of implanted surface, the pearlite of carbon steel



a. Implanted central and peripheral area of 0.45 C carbon steel specimen

b. Boundary area of implanted specimen

Fig. 4 Micrographs of the implanted surface

is partially covered by the disordered layer (Fig. 4, b). It is demonstrated that the processed samples exhibit much higher resistance to etch attack than substrate material.[5]

A pyramid population appearing in the ferrite region of the bombarded surface of 0.45 C carbon steel sample was observed by the scanning electron microscopy. It is believed that the formation of the pyramids should take into account in terms of the preferential sputtering of native, irradiation induced defect structures and differential atomic mobility of different ion species in substrate (Fig. 5).[6]

Microhardness indentations of the specimens were made under loads of 10 g for the unimplanted and implanted area. The hardness of the central implanted area of T8 steel is Hm470, the boundary region Hm300 and the original substrate Hm 200. The specimens of stainless steel 9Cr18 and GCr15 after quenching and low temperature anneal were implanted by similar doping conditions. The hardness enhancement were demonstrated in the examination of microhardness. For the sample of 9Cr18 the hardness is Hm653 before implantation and Hm1149 after implantation. For GCr15, the hardness is Hm824 before implantation and Hm1021 after implantation.

Fig. 5 Scanning electron micrography of the pyramid population appearing in the ferrite region of the bombarded surface

Conclusions

The preliminary results of pulsed implantation show that the utilization of MPC with proper beam energy and current density opens a new way to carry out the surface modification of materials. The following conclusions may be made based on these experiments mentioned above:

(1) Pulsed implantation of metallic and gasoeus mixing ion beams results in two stages of ion mixing and high heating and cooling rates of localized heat treatment.

(2) The hardness increase of implanted surface of the carbon steel and stainless steel substrates is experimentally proved. The enhancement of corrosion resistance and the improvment of friction and wear behaviours of the substrate materials are expected.

(3) It is interesting to note that the Ti atomic concentration in the virgin iron sample is measured to be more than 20% in spite of the effects of sputtering and vaporization. The thickness of implanted atom layer is deduced to depend on temperature during ion bombardment that is, at high temperatures, the thick implanted layer is formed.

(4) Futher study of discharge mechanism of MPC could lead this device to be a highly versatil, low cost and controllable research tool for material testing and modification.

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