STUDY OF THE FOCUSED ION BEAM AND ITS APPLICATION TO METAL IMPLANTATION MODIFICATION*

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ABSTRACT

The properties and designment of the strong focusing lens system and the application to metal modification of gear cutting tools are described. The focused ion beam produced by a special three asymmetric voltage lens has the unique features of short midfocal length, strong focusing and omitted focusing electric power. These properties of strong focusing lens system are due to the application of the high energy ratio of 20 to 50 onto the lens.

Keywords: Strong focussing lens Focussed ion beam Metal modification

1 INTRODUCTION

The three element asymmetric voltage lens has been used for many different focusing conditions[1].

In this paper the focusing properties obtained by an special three element asymmetric voltage lens with the shortest midfocal lengthes were described here for metal implantation modification use. This lens system has shown the unique features and the functions of extracting the ion from P. I. G Source, focusing and transporting the ion beam to the target in implantation chamber and omitted a especial focusing electric power. The focused N ion beam (at a 1 mA, 23 mm dia. 50 keV) applied in modification of gear cutting tools is described here as well.

2 THE CONSTRUCTION OF THE LENSES

This lens system is matched with P. I. G Source. The construction and parametres of the asymmetric triple cylinder lens and beam envelope are shown as Fig.1.

The difference and function of the lens system were as follows. V_1 was at P. I. G

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Source body of high potential of 50 kV. The three cylinder electrodes were at potential V_2, V_3 and V_4.

Electrode V_4 was held at a negative value of 500 V which was connected and equal to the negative restrained electrode in the target of chamber, so as to provide an electrical barrier to prevent the backstreaming of electrons from the chamber region back into the lens and source body, and omitted the obtained ion energy of 0.5 keV when the ion was in electrode V_4 (V_{res}) position.

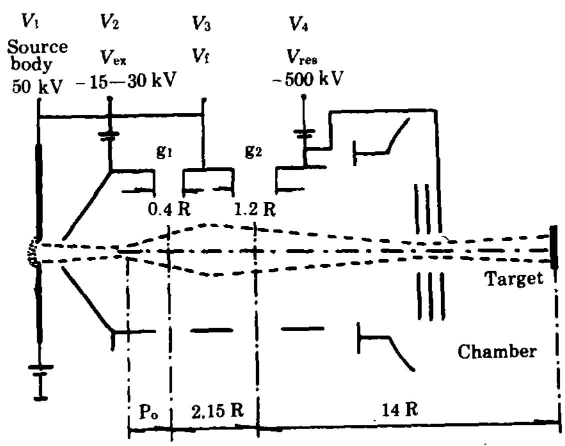

Fig.1 Construction and beam envelope of the three element asymmetric lenses

The focusing electrode V_3 was connected with the source body and were at the same high potential of 50 kV, in which the ion has only the initial energy which was equal to the arc potential of P. I. G Source. And the extracting electrode V_2 formed a electric field only for extracting the ion beam from P. I. G Source and formed a beam waist in a position behind the hole of the extracted electrode V_2[2]. And neglected the lens function between the electrode V_4 and the ground electrode.

In this case, this lens system could be simplified as a special three element asymmetric voltage lens which was combined by a decelerating lens g_1 (gap length of 0.4 R) and an accelerating lens g_2 (gap length of 1.2 R), and the length between the midpoints of two gaps was 2.15 R. The selection of the geometry parametres of the lens system was for forming an image at a position of the restrained grid of 7 R before the target at a lower ion energy of 20 kV, then the focused ion beam was diverged toward onto the target, and all the main parametres of objects (P), images (Q), beam radius (r), the divergence angle r′ of the centre particle and magnifications (M) for this lens system can be calculated one by one used by using the optical method of Newton formula $Q_i = X_i + F_i$, $X_i = Mf_i$, (X_i, the distance along the axis from corresponding F_i focus to image point) $M = f_o / (P_o - F_o)$, and Lagrange relation $r' = r_o' \cdot N^{-1/2} \cdot M^{-1}$ [$N = (V_3 / V_2$, or $V_4 / V_3)$ energy ratio of lens], for the measured initial ion beam parametres of r_o, r_o' and P_o[2] and the double cylinder lens parametres[3] in the selected geometry conditions of lens system of Fig.1.

Noted especially that the lens parametres for decelerating lens g_1 was the same, but the provided subscripts 0 and *i* should be interchanged on f_o and f_i, F_o and F_i, and the value of V_3 / V_2 was replaced by the value of V_2 / V_3 for lens g_1. All the values of lens cardinal ponts f_o, f_i, F_o and F_i were nermalized with respect to R, the radius of the cylinder electrodes.

3 THE RESULTS OF CALCULATION AND MEASUREMENT

For the two kinds of N^+ ion current of 0.5 mA and 1 mA at an arc potential 1 kV, the main parametres of image Q, ion beam radiur, divergence angle r′ at the image position and target position of 14 R were described as follows.

3.1 For ion current of 0.5 mA N^+, arc potential of 1 kV

The initial parametres at object position were measured P_o was −0.35 R, r_o was 1.2 mm, r_o' was 5.5 °[2] for the decelerating lens g_1. The V_{ex} (V_2) voltage was 15 kV, then the ion energy in V_2 position was 16 keV, the ion energy in V_3 position was 1 keV, then the energy ratio was $N_1 = V_3 / V_2 = 1/16$ for the given lens g_1 parametres in Newton formala and Lagrange relation. We can calculate Q_{i1} to be −1.31 R, r_{i1} was 4.43 mm, r_{i1}' was 5.96 °. For the accelerating lens g_2, the above parametres were just as the parametres of the object P_{o2}. Then P_{o2} was −3.46 R, r_{o2} was 4.43 mm, r_{o2}' was 5.96 °. When V_3 electrode was varied at a potential 20, 25, 30, 40, 50 kV, then the energy ratio $N_2 = V_4 / V_3$ was 21, 26, 41, 51 (by the lens parametres of 50 instead of 51). The Q_{i2} can be calculated respectively to be 5.35, 4.56, 3.48, 2.56 and 2.11 R. The beam radius was respectively 4.22, 3.59, 2.92, 2.22 and 1.91 mm in image position. The diverging angle r_{i2}' of centre particle was 1.37, 1.44, 1.62, 1.86 and 1.94 respectively. Based on the free motion of centre particle with a diverging angle r_{i2}', extended to the target position of 14 R we can obtain the beam dia was respectively 12.37, 14.27, 17.86, 22.32 and 24.12 mm. The measurement values of ion beam in target position of 14 R was respectively 7, 8, 12.5, 14 and 16 mm measured by the spots of ion bombardment at Ti sheet of 0.01 mm thickness.

3.2 For ion current of 1 mA N^+, arc potential of 1 kV

The initial parametres at the object position were measured: P_o was −0.25 R, r_o was 1.6 mm, r_o' was 6.5° [2] for the decelerating lens g_1. When the V_{ex} (V_2) voltage was 21 kV, then the ion energy in V_2 position was 22 keV, the ion energy in the focusing electrode V_3 was 1 keV, so the energy ratio was $N_1 = V_3 / V_2 = 1/22$ for the given lens g_1 parametres[3] in Newton formula and Lagrange relation, we can calculate Q_{i1} was −1.51 R, r_{i1} was 7.28 mm, r_{i1}' was 6.7°. The above parametres were just as the parametres of the object P_{o2} for the accelerating lens g_2, so P_{o2} was −3.66 R, r_{o2} was 7.28 mm, r_{o2}' was 6.7 °. During V_3 electrode was varied in potential of 20, 25, 30, 40, 50 kV, the ion energy in V_3 position was only at a 1 keV and the ion energy in V_4 electrode position was respectively 21, 26, 31, 41, 51 keV and the energy ratio $N_2 = V_4 / V_3$ was respectively 21, 26, 31, 41, 51, (by the lens parametres of 50 instead of 51). So we can calculate the Q_{i2} to be 5.06, 3.80, 3.07, 2.28 and 1.22 R, the beam radius was respectively 6.33, 4.95, 4.08, 3.13 and 2.72 mm in image position. The diverging angle r_{i2}' of the centre particle was respectively 1.68, 1.93, 2.15, 2.43, 2.52. Based on the free motion of the centre particle with a diverging angle r_{i2}', extended to the target position of 14 R, we can obtain the ion beam dia was respectively 15.75, 20.64, 26.94, 29.90 and 33.7 mm. The measurement values of ion beam dia in target position of 14 R was respectively 10, 12, 14, 19 and 23 mm measured at the spots of Ti sheet of 0.01 mm thickness in ion bombardment.

4 DISCUSSION OF THE CALCULATION AND MEASUREMENT VALUES

Based on the above values from the calculation and the measurement values, the following properties of this focused ion beam system can be observed:

a. The focusing ability of this lens system was increased with the increment of the ion energy changing from 20 keV to 50 keV, because the midfocal length F_0 of the lens g_2 decreased. The image position Q_i changed from 5.35 R to 2.11 R for 0.5 mA N^+ ion current, and the image position Q_i changed from 5.06 R to 1.22 R for 1 mA N^+ ion current.

b. The varied tendency of the beam diametre values of the calculation and measurement at a target position of 14 R were the same, the values of the calculation were more than the values of measurement. The values of measurement was better approched to the value of the calculation during the ion energy was in higher ion energy owing to the decrement of space-charge effect, and the reason of difference between the calculation and measurement values comes from the affect between the electric fields of the two lenses, and had a stronger focussed ability because the two lenses of the lens system were not separated well by a field-free space.

c. The higher energy ratios of 25 to 50 applied in lens g_2 are the nature reason of obtained this strong focused ion beam, because the ion energy in focusing electrode V_3 was equal to the arc potential of about 1 keV of P. I. G Source.

d. The ion beam diameter at target position of 14 R was increased with the ion current and ion energy, and the ion current density would be decreased with the increment of the ion current and ion energy, for omitting a special focusing power. It is just expected results and feature of designment of the strong focused ion beams for us, and in the meanwhile, the gear-cutting tools at target position when ion implantation was in rotary and up-down mechanical scanning. It is very available to substain a proper heating effect of implantation ions.

5 APPLICATION OF THE FOCUSED N^+ ION BEAM IN CUTTING TOOLS

The focused N^+ ion beam (at a proper 1 mA, dia 23 mm, 50 keV) has been applied in metal surface modification treatment of the gear cutting tools which were in rotary and up-down mechanical scanning during N^+ ion implantation.

An enriched nitrogen layer on the surface of the high speed steel $W_{18}Cr_4V$ sample was formed by nitrogen ion implantation which created the condition of forming nitride. The dose of N^- was 3.39×10^{17} N^- / cm^2 measured by $^{14}N(d,\alpha)^{12}C$ reaction, during the proper dose of N^- ion implantation sample was 4×10^{17} N^- / cm^2.

In the X-ray photoelectron spectroscopy of the implantation layer on the $W_{18}Cr_4V$ sample. The Fe_2N and Fe_4N phases with high hardness were found. It was the main reason that the microhardness and the wear resistance of the high speed $W_{18}Cr_4V$ were increased.

In the industrial production for the cylindrical-like gear M_3-cutter tools of implantation nitrogen, the wear resistance and durability of the N^- ion implantation were over doubled from 1 raised to 3 times, and after the cutting tools were ground for 30 times, the improvement in durability of a cutting tools remained the same and can last for its whole working life. Buι for some alloy-tools the durability of N ion implantation can be raised up to 7 times.

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