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Modelling of the ion implantation modification of WC-Co indexable knives for wood machining

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Abstract: *Modelling of the ion implantation modification of WC-Co indexable knives for wood machining.* The paper presents the results of the modelling of nitrogen ion implantation parameters for W-C-Co material. Applications include the modification processes of WC-Co indexable knives for wood machining.

Keywords: WC-Co indexable knives, ion implantation, modelling

INTRODUCTION

Cemented tungsten carbides, which are mixtures of the hard and brittle carbides and a relatively soft and ductile metallic binder, provide an exceptional combination of attractive properties such as strength, hardness, fracture toughness, refractoriness, stiffness, resistance to compressive deformation and wear resistance at room temperature as well as at higher temperatures up to 400°C (Milman et al. 1997, Sheikh-Ahmad and Bailey 1999, Pirso et al. 2004, Bonny et al. 2010, Choi et al. 2010, Olovsjö et al. 2013). Usually, the tool lifetime is relatively short and needs an improvement. The ion implantation is one of several possible methods to improve the tool lifetime (Barlak et al. 2016, Wilkowski et al. 2019).

The results of our previous investigation (Wilkowski et al. 2018) show that the values of the peak volume dopant concentration N_{max} ranging from 1.5e22 to 7.5e22 atoms/cm^3 and the value of the projected range R_p at a level of 50 nm are needed for the best lifetime of the commercially available, WC-Co indexable knives, used for wood machining, presented in Fig. 1. The modelling of the ion implantation processes allows one to estimate the value of the main implantation parameters, i.e. the fluence and the ion energy, necessary to obtain the assumed depth profile of the implanted element.

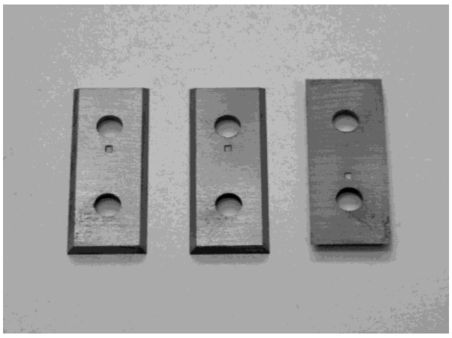

Figure 1. WC-Co indexable knives.

In this paper, the modelling of the ion implantation is presented for nitrogen – the most popular element for tribological applications/improvement.

MATERIALS AND METHODS

The W-C-Co material including in at.%: 47.4% W, 47.4% C and 5.2% Co, i.e. in wt.%: 90.86% W, 5.94% C and 3.2% Co, with the density of 15.2 g/cm^3 was adopted as the substrate material. The value of density was declared by the knives supplier.

Nitrogen was used as an implanted element. In the case of direct implantation, nitrogen is delivered as two kinds of ions, i.e. N_2^++N^+ (in ~1:1 ratio) (Wilkowski *et al.* 2019). In our case, only N^+ ions were applied (a mass separated ion implanter will be used). The following ion implantation parameters were adopted:
- energy of implanted ions: 1, 2, 5, 10, 20, 50, 100, 200, 500 and 1000 keV,
- fluences of implanted ions: 1e16, 2e16, 5e16, 1e17, 2e17, 5e17 and 1e18 cm^{-2}.

Implantation was performed at room temperature. Additionally, the implanted knives were clamped onto a water-cooled stainless steel plate to reduce the impact of heat generation.

SRIM-2013.00 (The Stopping and Range of Ions in Matter) (www.srim.org) and SUSPRE ver. 2.1.4 (www.surrey.ac.uk) freeware type codes were used for modelling of the main parameters of the depth profile of implanted nitrogen.

SRIM is a collection of software packages which calculate many features of the transport of ions in matter, using Monte Carlo method. In our case, each simulation was performed for 100 000 implanted ions. The depth profile shape, projected range R_p, range straggling ΔR_p and peak volume dopant concentrations N_{max} were modelled using this code. This modelling did not take into account the phenomenon of the substrate sputtering by the implanted ions. The theoretical values of the sputtering yield, defined as an average number of atoms sputtered (ejected) from the implanted substrate per an incident ion, were calculated with the use the quick ion implantation calculator SUSPRE, from the energy deposited in the surface region of the material using the Sigmund formula (www.surrey.ac.uk).

RESULTS AND DISCUSSION

Fig. 2. presents the depth profiles of nitrogen implanted to W-C-Co material for the ion energy from 1 to 1000 keV. The ordinate unit ((atoms/cm^3)/(atoms/cm^2)) is a special unit, used by SRIM code. Note the logarithmic scale on the abscissa.

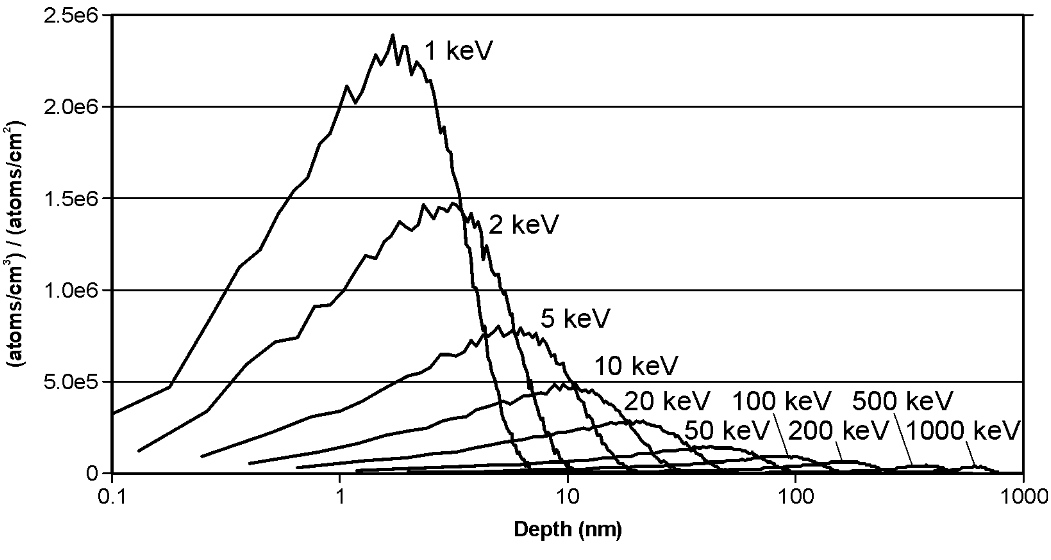

Figure 2. The depth profiles of nitrogen implanted to W-C-Co material as functions of the energy of the implanted ions.

The projected range R_p, the range straggling ΔR_p and the peak volume dopant concentrations N_{max} can be determined from these profiles. Fig. 3 shows the graphical definitions of these properties (in the insert) and the graphs for the first two as functions of the energy of implanted ions. Additionally, the graph for the sputtering yield *Y* is presented.

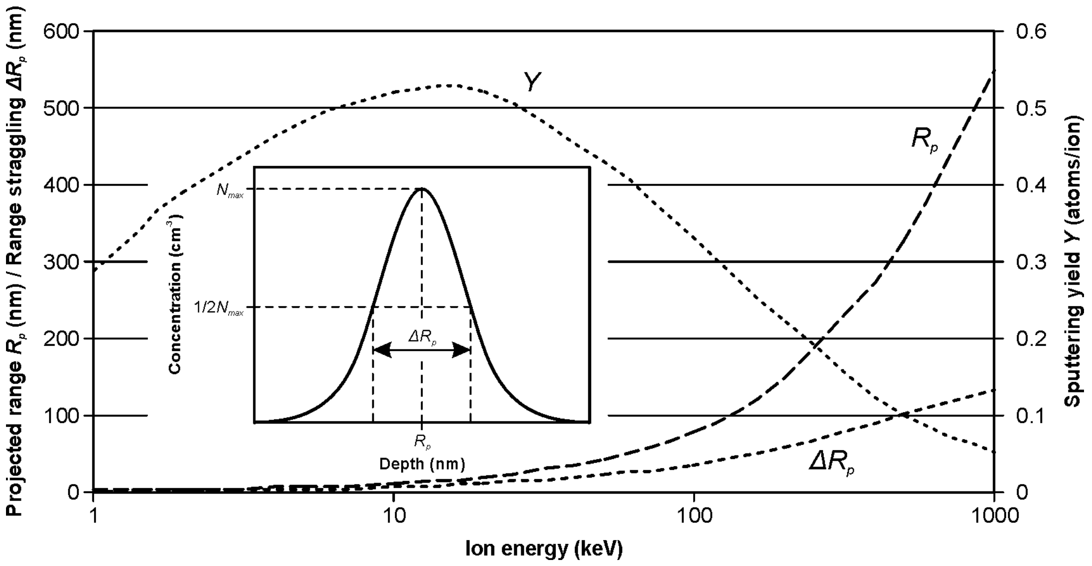

Figure 3. The graphs of the projected range, the range straggling and the sputtering yield as functions of the energy of implanted ions and the graphical definitions of the main parameters of the depth profiles.

The determined values of the projected range R_p range from 2.3 to 550.5 nm. The projected range is deeper for higher values of the ion energy.

The modelled values of the range straggling ΔR_p were from 1.3 to 133.8 nm. The implanted region is wider for higher values of the ion energy.

The calculated values of the sputtering yield *Y* were: 0.29 atoms/ion for the ion energy of 1 kV and 0.05 atoms/ion for 1000 kV. The maximum value was at the level of 0.52 atoms/ion for the range from 10 to 20 keV. One should keep in mind, that both codes used for modelling, assume the implanted substrate as a collection of separated atoms, without any chemical compounds as for example WC. It is well known, that more energy is needed for sputtering of atoms from the compound in comparison to sputtering the same atoms alone in the system. Thus, relatively low, calculated values of the sputtering yield can be lower in practice. It will be an advantageous phenomenon in the discussed processes of ion implantation.

Multiplication of depth profiles presented in Fig. 2 by the implanted fluence gives the concentration of the implanted ions (dopant) (atoms/cm^3) vs. depth. Fig. 4 presents the surface chart of the maximum peak volume dopant concentrations as functions of the energy of implanted ions and the implanted fluence, without taking into account the sputtering phenomenon. It is easy to see, that the highest values are obtained for low energy and high doses of the implanted ions.

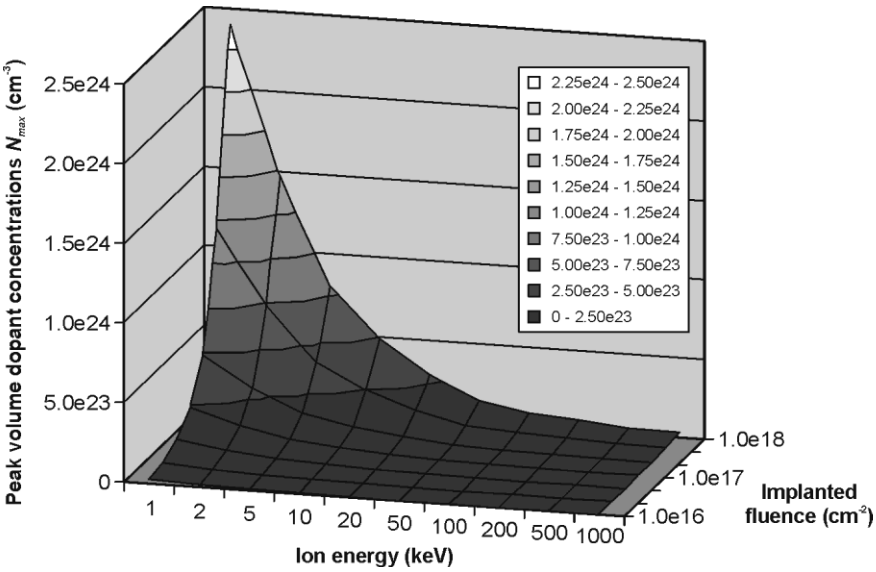

Figure 4. The peak volume dopant concentrations as functions of the energy of implanted ions and the implanted fluence.

CONCLUSIONS

The designer of tool implantation project has to reconcile many, often conflicting requirements. The ion energy must not be too low or else sputtering will prevail over implantation. On the other hand, the ion energy must not be too high, to avoid high cost associated with using high energy machines. Very often implantation profile should be located at a particular depth, to match some material parameters. Broader profiles are sometimes desired and an appropriate range straggling must be set.

The presented paper shows the ways how appropriate implantation profiles can be modelled and attained.

Taking into account all the above factors, it seems that the optimum range of the ion energy used in nitrogen implantation for W-C-Co material should be from 20-50 to 100 keV.

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Streszczenie: *Modelowanie parametrów implantacji jonów w procesach modyfikacji wymiennych noży WC-Co, stosowanych do obróbki materiałów drzewnych.* W artykule przedstawiono wyniki modelowania parametrów implantacji jonów azotu do podłoża W-C-Co. Mogą być one wykorzystane w procesach modyfikacji wymiennych noży WC-Co, stosowanych do obróbki materiałów drzewnych.

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