Proceedings IRF2018: 6th International Conference Integrity-Reliability-Failure
Lisbon/Portugal 22-26 July 2018. Editors J.F. Silva Gomes and S.A. Meguid
Publ. INEGI/FEUP (2018); ISBN: 978-989-20-8313-1

PAPER REF: 7109

NANOINDENTATION INDUCED PLASTIC DEFORMATION IN NANOCRYSTALLINE ZrN COATING

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ABSTRACT

Microstructure evolution of nano-indented zone of nanocrystalline ZrN coating has been investigated by transmission electron microscopy. Dislocation glides together with microcrack initiation and propagation contribute to the plastic deformation of the ZrN coating. The microcracks preferentially initiate just underneath the contact surface and then propagate along the columnar yet weak bonded grain boundaries. The microcrack propagation is found to be the probable factor deteriorating the coating hardness. Strategy to improve the coating hardness via strengthening the grain boundaries has been discussed.

Keywords: plastic deformation, dislocations, microstructure, ZrN coating.

INTRODUCTION

Nanocrystallization is one of the most important methods for strengthening materials. However, nanocrystalline materials often reveal a limited ductility owing to the occurrence of unstable plastic deformation. Investigations into the plastic deformation of the nanocrystalline materials have revealed that the inside of each nanograin has a low density of dislocations. Balance has been established between generation of dislocations and absorption of dislocations at grain boundaries (GBs). Thus, GBs dominated deformation mechanisms (such as GBs sliding, emission of full and partial dislocations from the GBs, twinning, grain rotations, etc.) have been suggested to be responsible for the plastic deformation. However, these reported investigations mainly focused on metals or alloys. Only scant information about the deformation mechanisms of nanocrystalline transition-metal nitride coatings has been recorded.

Recent advancements in focused ion beam (FIB) machining have enabled the investigation of nanoscale deformationof the hard coatings. Initiation and propagation of microcracks underneath indentation have been observed in TiN, TiAlN, nanocomposite Ti-Si-N and multilayered TiN/CrN coatings, etc. However, initiation site and propagation path of the microcracks, lattice defects (such as dislocations) produced by the deformation are still relatively unclear. Therefore, the objective of this work is to make a better understanding of the plastic deformation behavior of the nanocrystalline nitride coatings.

RESULTS AND CONCLUSIONS

The ZrN coating was deposited on silicon (1 0 0) wafers by reactive DC magnetron sputtering from a metallic Zr target. The nanoscale deformation zone of the ZrN coating was produced by nanoindentation test. The plastic work provided the necessary energy for the formation and growth of defects (microcracks and dislocations) in the deformed zone. As such, an analytical TEM study was performed to obtain a structural insight into these defects.

Figure 1 shows bright field TEM images of the deformed zone underneath the indentation of the ZrN. In Figure 1(a), a dense and columnar microstructure can be observed in the fcc-type ZrN coating (revealed by the inserted SAED pattern). A V-shaped indentation exhibits a residual depth of 130~140 nm, agreeing well with the result of the loading-displacement curve. In Figure 1(b), microcracks (marked by arrows) and dislocation tanglings (marked by circles) can be found underneath the nanoindentation. This is substantially different from the dislocation-dominated plastic deformation behavior, which usually has a severe plastically deformed region with few or no cracks. The microcrack length is found to be several hundred nanometers. The number of the microcracks reachs the maximum just underneath the contact surface and decreases towards the inner parts of the coating. Additionally, the microcracks reveal a contrary propagation direction against the grain growth. These TEM observations reveal that both the microcracks and the dislocations play crucial roles in the plastic deformation of the ZrN coating. In Figure 1(c), the top view of the columnar ZrN grain exhibits a width of ~70 nm. It can be clearly seen that the microcrack initiates at the GBs and then propagates along the GBs. No microcrack deflection can be found in the ZrN coating. Figure 1(d) reveals that the microcrack initiated just underneath the indenter tip propagates along the GBs as well. The microcrack propagation along the GBs indicates that the GBs possess a poor bonding strength than that of the ZrN grains. Consequently, in the case of suffering from a heavy loading such as the scratch test, the fracture of the ZrN coating preferentially occurs by the microcrack propagation along the columnar GBs.

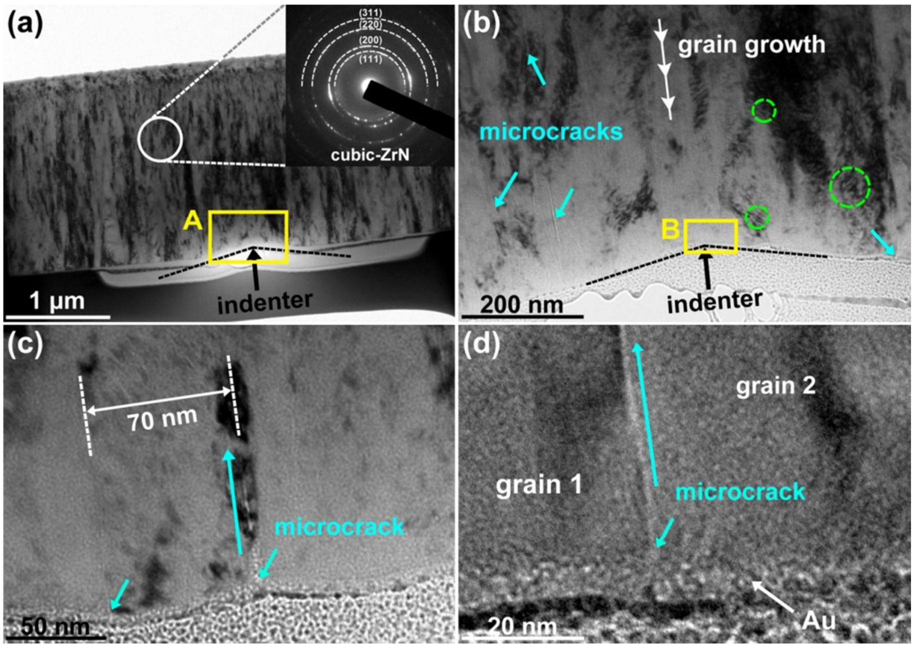

Fig. 1 - TEM images of the deformed zone underneath the indentation. (a) An overview of the indentation; (b) higher magnification image of framed region A; (c) microcrack initiation and propagation; (d) higher magnification image of framed region B in (b).

In summary, the microstructure evolution of the deformed zone underneath the nanoindentation of the ZrN coating was investigated. The plastic deformation of the coating occurs by the formation of glide dislocations, the initiation and propagation of microcracks. The microcracks preferentially propagate along the columnar grain boundaries of the ZrN coating.