Low energy ion beam fabrication of ultra smooth and sharp AFM nano-tips from single crystal diamond rods

S. F. Mahmud[1,2], Y. Sato, S. A. Pahlovy, and I. Miyamoto
[1]Applied Electronics Department, Tokyo University of Science, 2641 Yamazaki, Japan
[2] Bangabandhu Fellowship on ICT project, Bangladesh
sf.mahmud19@yahoo.com

1. INTRODUCTION

Monolithic silicon AFM tip, an integral part of a cantilever, can be mass-produced using a semiconductor manufacturing process. However, the life time of such Si tip is short due to lower hardness and poor wear resistance. But, AFM probes made from diamond exhibits a long life time due to ultrahigh hardness, ultra high tensile strength and high thermal conductivity. Conventionally, diamond nano- tip for AFM probes are fabricated using a combination of CVD – diamond film, standard lithography and dry etching process. But it is difficult to control the shape of the tip by the above processes. FIB (focused ion beam) machining is found to be more effective for ultra-fine machining of diamond tip but the process is very slow, and ripples are formed on the processed surface. Moreover the machining cost is high. We therefore proposed a technique of low energy broad ion beam machining where multiple numbers (more than 100 pcs) of ultra smooth and sharp diamond nano tips can be fabricated at a time from single crystal diamond rods. Result shows that ultra smooth and sharp AFM tips with the diameter of 20-25 nm and apex angle of 45º-50º can be fabricated by 3 keV oxygen ion beam in 2 hours.

2. EXPERIMENTS AND RESULTS

The experiments were conducted in two types of ion beam apparatus to generate 1-3 keV Ar^+ or He or Xe^+ or O^+/O_2^+ ion beam. One type of apparatus was an electron cyclotron resonance (ECR) and another is high voltage discharge type. First, several natural single crystal diamond rods of 100 µm length and 2 µm diameter was fabricated by a metallographic etching technique using a Ni film. Then, sharpening of the diamond rods were performed by 1-10 keV Ar^+, He^+, Xe^+ and O^+/O_2^+ ion beam sputtering process separately. The un-processed and processed surfaces were observed by SEM.

Fig.1 shows the SEM images of fabricated diamond rods by the above mentioned method. Fig. 2 and Fig. 3 show the SEM images of fabricated diamond tips by 1-10 keV Ar^+, He^+, Xe^+ and O^+/O_2^+ beam sputtering process. As shown in the Fig. 2 and 3, two types of ripples were formed on the heads and side walls of the tips when the diamond rods were processed by Ar^+ or Xe^+ beam. The origin and orientations of the ripples can be explained by the Bradley and Harper (BH) theory [1]. However, ripples were not formed on the processed tips when the processing was done by He^+ or O^+/O_2^+ beam. In case of 1keV O^+/O_2^+ beam, the processed tips were not uniform and ultra sharp. While processing with 3 keV O^+/O_2^+ beam, ultra smooth and sharp uniform nano-tips were obtained. The reason of ripple elimination from side wall and head of rod in oxygen ion beam processing can be discussed by two smoothening mechanisms-(1) enhanced erosion of surface protrusions on the side walls [2] and (2) surface confined viscous flow near the head of the tips [2-3]. The relaxation rate of surface confined viscous flow is higher for higher ion range. We calculated the ion range by SRIM simulation software and found that the order of ion range is $He^+ > O^+ > Ar^+ > Xe^+$. Therefore, ultra smooth diamond nano tips were obtained by the He^+ or O^+ beam processing. Among the 4 types of ion beam machining process, O^+/O_2^+ beam processing is the fastest and exhibits least amount of damage on the diamond crystal structure.

The assemble of processed nano tip on a cantilever was carried out in several steps. First, the tip was broken from the machined diamond rod manually by a manipulator, then it was inserted on Si cantilever and finally was fixed on Si cantilever by epoxide – based adhesive.

3. CONCLUSION

We successfully fabricated an ultra smooth and sharp AFM tip with the diameter of 20 nm and apex angle of 50º by 3 keV oxygen ion beam.

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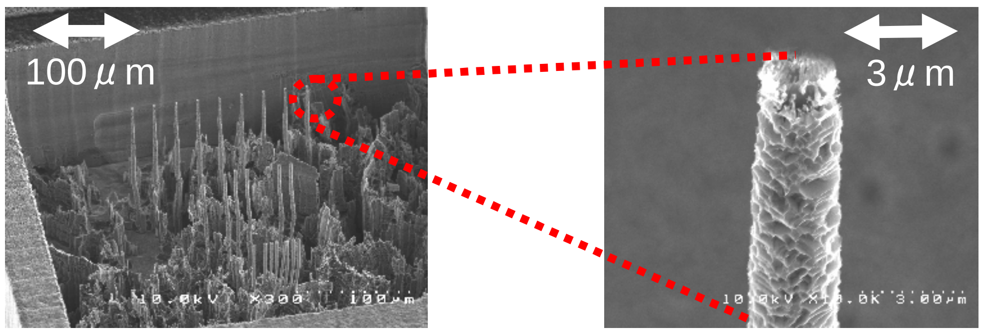
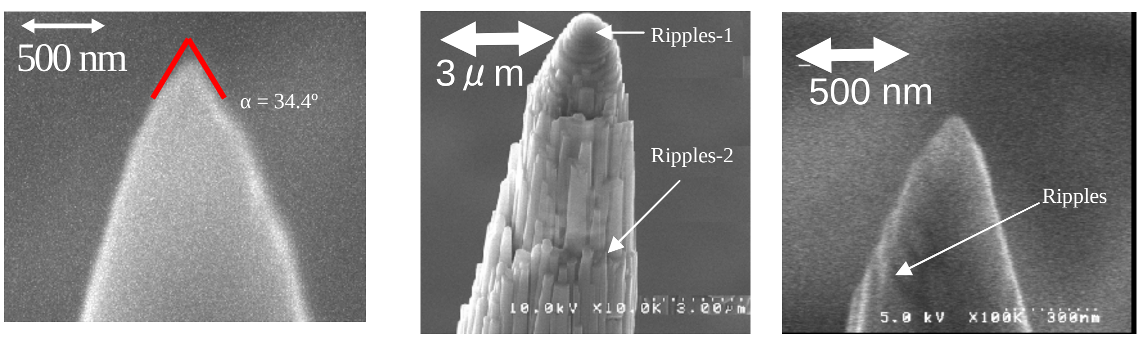
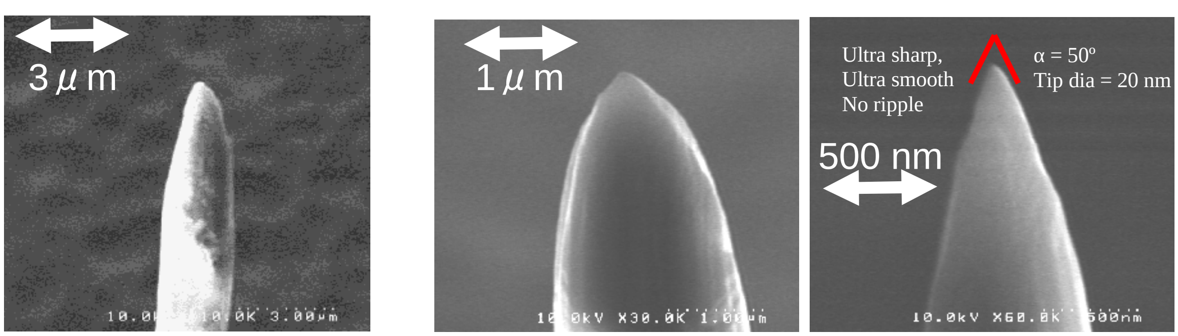


Fig.1. SEM image of fabricated diamond rods



(a) 3 keV He, 4 hours (b) 3keV Xe, 6 hours (c) 10keV Ar, 4 hours

Fig.2. SEM images of fabricated diamond nano-tips with ripples



(a) 1keV Oxygen, 2 hours (b) 3keV Oxygen,1 hour (c) 3keV Oxygen, 2 hours

Fig.3. SEM images of fabricated ultra sharp and smooth diamond nano-tips