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Simple Process for Buried Nanopyramid Array (BNPA) Fabrication by Means of Dopant Ion Implantation and Dual Wet Etching

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Abstract

Novel process to fabricate high density buried nanopyramid array (BNPA) on Si surface was proposed. Two phenomena, that is, the enhanced etch rate (ER) of ion-exposed SiO_2 in HF and the retarded ER of ion-exposed Si in N_2H_4, were conveniently utilized to fabricate the BNPA. Array of dots was written on SiO_2 layer grown on n-type Si substrate with 60-keV BF_2 or P ions. Then, ion-exposed SiO_2 was selectively etched away by dipping in HF. Finally, the BNPA was formed under the patterned SiO_2 layer by dipping in N_2H_4. By using this simple process, BNPA with 330 nm pitch was successfully fabricated. The electrical property of the fabricated pyramid was also explored by using scanning Maxwell-stress microscopy (SMM).

1. Introduction

Silicon field emitter array (FEA) is promising as an electron source for vacuum microelectronics device[1]. Hence, much effort has been made on developing high performance and high density Si FEA[2]. For instance, it has been reported that emission current of FEA is stabilized by fabricating n/p junction in an emitter[3]. However, the processes to fabricate high performance FEA are generally composed of many steps, such as lithography, dry etching and film deposition.

So far, we have found the ion-bombardment (IB)-retarded etching phenomenon of Si in N_2H_4[4]. It has been reported that the etch rate (ER) of SiO_2 in HF is enhanced by IB[5]. This paper describes that the combination of two phenomena enables us to easily fabricate high density Si buried nanopyramid array (BNPA) for the gated FEA.

2. Fabrication Process

High density BNPA is fabricated by the ion implantation and the subsequent dual wet etching as illustrated in Fig. 1. We used n-type Si(100) wafer with 11-nm thick SiO_2. 60-keV BF_2 or P ions were implanted through the patterned resist mask at a dose of $7x10^{14}$ cm^{-2} (Fig. 1(a)). After the resist stripping, the ion-exposed SiO_2 was selectively etched away by 1% HF dipping for 65 s (Fig. 1(b)). Finally the BNPA was fabricated under the patterned SiO_2 mask by dipping in N_2H_4 anisotropic etchant for 10 s at 115°C (Fig. 1(c)). The ERs of (100)-, (111)-oriented Si and SiO_2 in the N_2H_4 at 115°C are 3.3, 0.19 μm/min and 0.2 nm/min, respectively. Annealing for activation was performed at 850°C for 20 min.

3. Results and Discussion

The dependence of the ER of SiO_2 in 1% HF on the ion dose was investigated as shown in Fig. 2. As the ion dose increases, the ER of SiO_2 is enhanced by more than a factor of three. It has so far been reported that the enhanced etching of SiO_2 originates in structural damage and the formation of nonstoichiometric layers introduced by IB[5]. Contrastingly, the ER of Si in N_2H_4 is markedly decreased as the ion dose increases, as shown in Fig. 3. This phenomenon arises from the suppression of electrochemical reaction between Si substrate and the N_2H_4 due to the increase in the resistivity of Si as a result of IB[4]. We also confirmed that both results are independent of the ion species. This is very important for the control of the electrical property of the apex of the pyramid.

High density BNPA fabricated by utilizing the combination of two phenomena is shown in Fig. 4(a). Under the SiO_2 windows formed with selective etching in HF, the ion-exposed regions serve as etch masks against N_2H_4 and BNPA is fabricated successfully. Unexposed Si substrate is not etched by N_2H_4 at all, because unexposed SiO_2 layer acts as a mask against N_2H_4. Since the size of the pyramid apex is determined by that of the damaged region, the apex size is still large as shown in Fig. 4(b). Sharpening the apex will be performed by means of oxidation and oxide stripping after the BNPA formation. For reference, normal NPA fabricated with N_2H_4 dipping after complete stripping of SiO_2 layer[4] is shown in Fig. 4(c). In this case, nanopyramids appear outside because unexposed Si substrate is etched away in N_2H_4[4].

The conduction type of the pyramid apex was determined by scanning Maxwell-stress microscopy (SMM) as shown in Fig. 5. In this case, BF_2 ions were implanted into n-type Si. The SMM makes it possible to image both topography and surface potential of a conductive sample with nanometer spatial resolution at the same time[6]. By comparing the SMM topographical image (Fig. 5(b)) with surface potential image (Fig. 5(c)), it can be understood that the surface potential of the apex is lower than that of the periphery. This means that negatively charged acceptor ions exist just in the apex, that is, the conduction type of the apex becomes p-type. Thus, the electrical property of the apex can be easily controlled by utilizing this process.

4. Summary

Novel fabrication process of high density BNPA for the FEA was presented. By using SMM, it was confirmed that this process enables us to control the conduction type of the pyramid apex.

Acknowledgements

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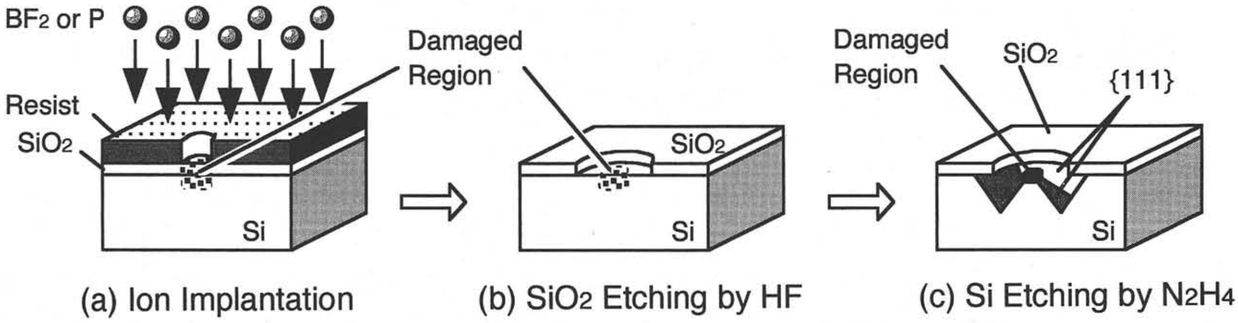

Fig. 1 Buried nanopyramid array fabrication process flow.

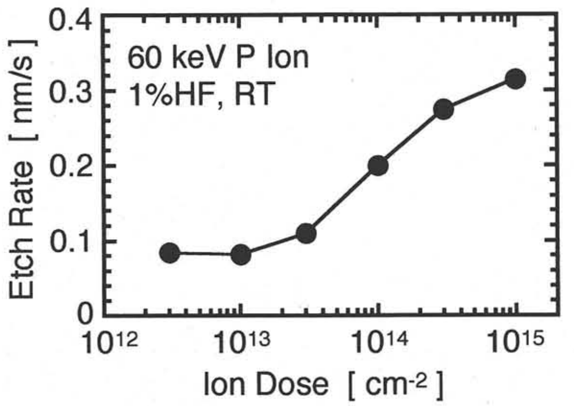

Fig. 2 Dependence of etch rate of SiO_2 in 1% HF on P ion dose.

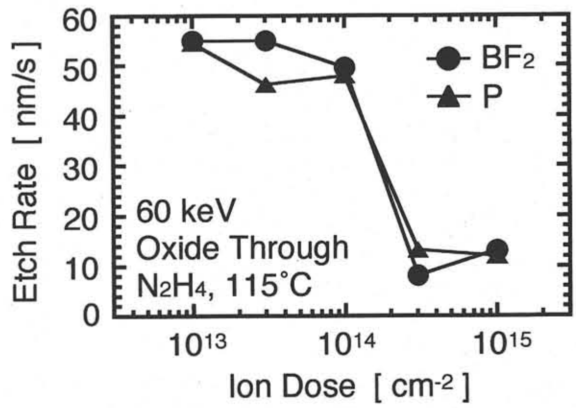

Fig. 3 Dependence of etch rate of Si in N_2H_4 on BF_2 or P ion dose.

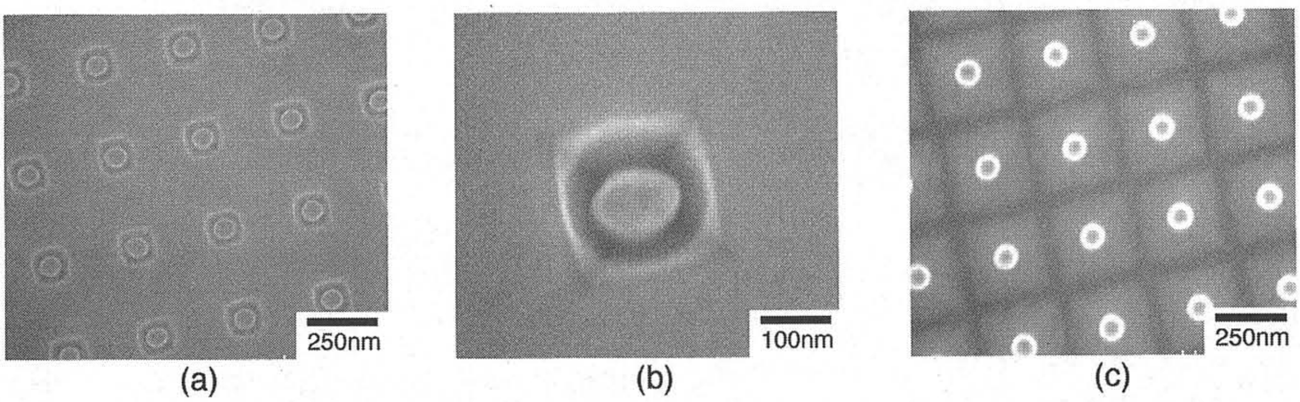

Fig. 4 SEM image of (a) BNPA with 330 nm pitch, (b) buried nanopyramid at higher magnification and (c) normal convex NPA with 330 nm pitch. All were fabricated with BF_2 ion implantation into n-type Si substrate.

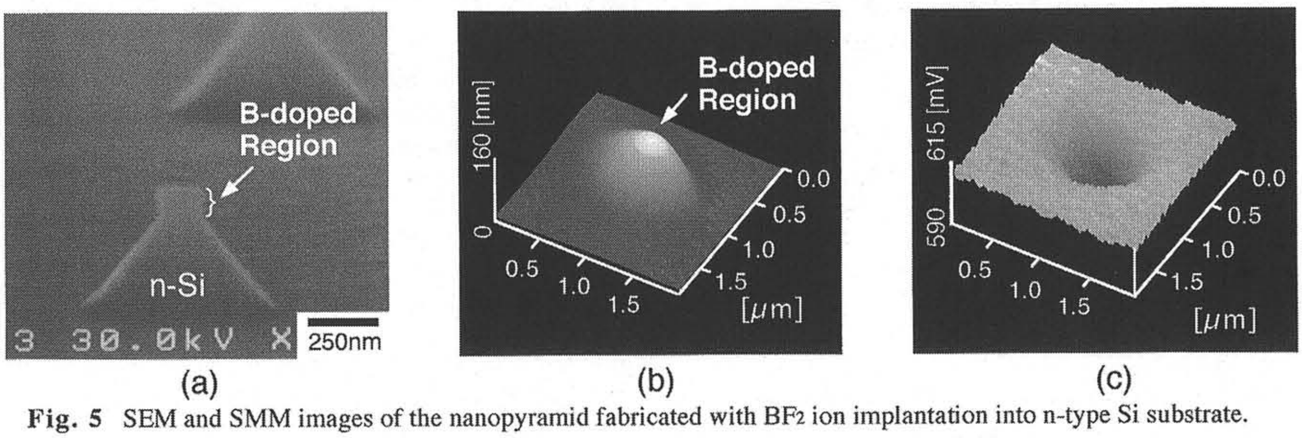

Fig. 5 SEM and SMM images of the nanopyramid fabricated with BF_2 ion implantation into n-type Si substrate. (a) is SEM image, (b) SMM topographical image and (c) SMM surface potential image.