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Simple Fabrication of Silicon Nanopyramids for High Performance Field Emitter Array

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Abstract

A novel process to fabricate high-density convex nanopyramid array (cNPA) and buried nanopyramid array (bNPA) on Si surface is proposed. For both cNPA and bNPA fabrication, the retarded etch rate of ion-exposed Si in N_2H_4 was utilized. This process has the advantage of controlling the conduction type of the pyramid apex, which is effective in stabilizing the emission current. The feasibility of the nanopyramid array (NPA) for the field emitter array (FEA) is also discussed in terms of the electron emission characteristics.

1.Introduction

Si FEA is a possible candidate for an electron source in vacuum microelectronics device[1]. In addition, high-density nanostructure array is also attractive as a substrate for controlling the self-ordering phenomena and protein adsorption[2]. However, the processes to fabricate such two-dimensional structure arrays on Si wafer are relatively complicated because they are generally composed of many steps such as lithography, dry etching and thin film deposition.

In this paper, we propose a simple and high-throughput process to fabricate NPA, where the ion bombardment retarded etching (IBRE) phenomenon originally found by us is conveniently utilized[3]. The electron emission characteristics of various type of the NPA are also reported.

2.Fabrication Process

We fabricated two types of the NPAs, that is, the cNPA and the bNPA, as illustrated in Fig. 1. The cNPA was fabricated by the dopant ion implantation and the subsequent wet etching (Fig. 1(a)). We used both n-type and p-type Si(100) wafers. 60 KeV BF_2 or P ions were implanted through the patterned resist mask at a dose of $5x10^{14}$ cm^{-2}. After the resist removal, cNPA was fabricated by dipping in N_2H_4 anisotropic etchant for 8 s at 115℃. We have confirmed that the IBRE is independent of ion species. By the choice of ion species combined with the subsequent heat treatment for electrical activation of the implanted ions, we can easily control the conduction type of the NPA apex.

The bNPA was fabricated by the dopant ion implantation and dual wet etching (Fig. 1(b)). First, 60 KeV BF_2 or P ions were implanted onto Si with 50nm thick SiO_2 through the patterned resist mask. The SiO_2 mask was selectively etched through the resist by 1% buffered HF dipping for 600 s. Then the resist was completely removed. Finally, the bNPA was fabricated under the patterned SiO_2 mask by dipping in N_2H_4. Activation of implanted dopant ions and sharpening of the apexes were simultaneously performed at 900℃ for 20 min.

3.Results and Discussion

Table. 1 shows the comparison between conventional Si FEA fabrication process and our process. There is no need of dry etching in our process. Hence, our process can contribute to reduce process steps and cost. Although the fabrication process of the cNPA is simpler than that of bNPA, the cNPA may be influenced by the contamination of exposed Si surface over wide area. In contrast, for the bNPA, the surface is passivated by the SiO_2 film. This structure is suitable also for the gated FEA.

The cNPA and the bNPA before and after sharpening are shown in Fig. 2 and Fig. 3, respectively. The obtuse apex of the NPA represents damaged region due to the ion bombardment. We sharpened the apex of the NPA by wet oxidation at 900℃ for 20 min and the subsequent etching of the SiO_2 by HF dipping. The radius of curvature of the apex was estimated to be less than 20 nm after sharpening.

In our process, the conduction type of the NPA apex was controllable by the choice of implanted ion species. We have already confirmed the controllability of the electrical properties of the NPA apex by means of the scanning Maxwell-stress microscopy (SMM)[4]. Fig. 4(a) shows the I-V characteristics of the fabricated cNPA. The distance between the NPA cathode and anode was controlled by using a slide-glass of 130 μm as a spacer. The electrons were emitted from the cNPA at over 16 V/μm, while no electron emission was recognized without the cNPA. Fig. 4(b), fig. 4(c) and fig. 4(d) show the Fowler-Nordheim (FN) plots of three types of the cNPA. It is evident from fig. 4(b) that the n-type apex cNPA fabricated on n-type substrate exhibited typical field emission characteristics. On the other hand, the current saturation was observed in both p-type and n-type apex cNPAs fabricated on p-type substrates as shown in Fig. 4(c) and Fig. 4(d). It is considered that the current saturation is due to the depletion layer in the p-type substrate[5]. The emission current is limited by the thermal generation rate of electron-hole pairs in the depletion region. It was reported that current saturation contributes to stabilization of emission current[5]. Hence, the controllability of the pyramid conduction type by our processes is of great benefit to fabricate high performance FEA.

4.Summary

We have proposed a simple process to fabricate two types of the NPA for FEA. It was confirmed from the investigation of the field emission characteristics that the controllability of the pyramid conduction type by our process is effective for realizing high performance FEA.

Acknowledgements

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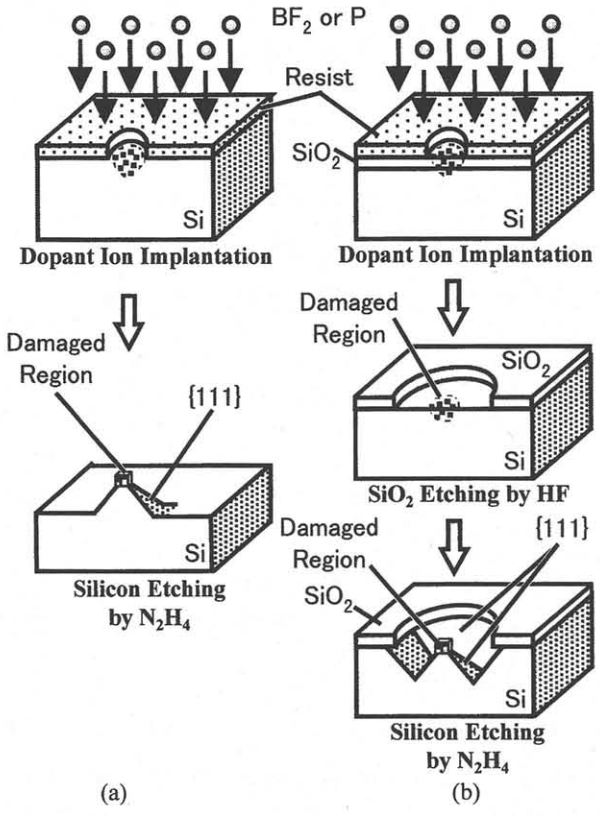

Fig. 1 Fabrication process flow of (a) the cNPA and (b) the bNPA.

Table. 1 Comparison between conventional Si FEA fabrication process and our process.

Conventional Process	New Process (This work)	
	cNPA	bNPA
SiO_2 Deposition		Oxidation
Lithography		Lithography
SiO_2 Patterning by Dry Etching		
Si Dry Etching		Dopant Ion Implantation
Tip Sharpening by Wet Oxidation		SiO_2 Patterning by Wet Etching
Dopant Ion Implantation		Si Wet Etching by N_2H_4
Anneal for Activation		Tip Sharpening by Wet Oxidation

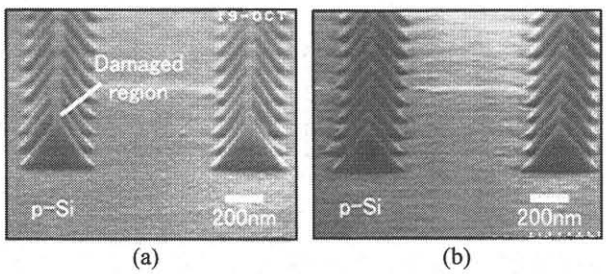

Fig. 2 SEM images of cNPA fabricated with P ion implantation into p-type Si substrate (bird's-eye view) (a) before sharpening, (b) after sharpening.

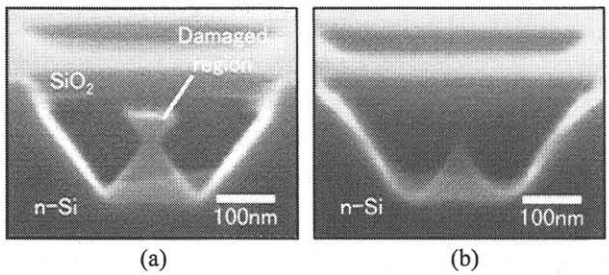

Fig. 3 SEM images of bNPA fabricated with BF_2 ion implantation into n-type Si substrate (profile) (a) before sharpening, (b) after sharpening.

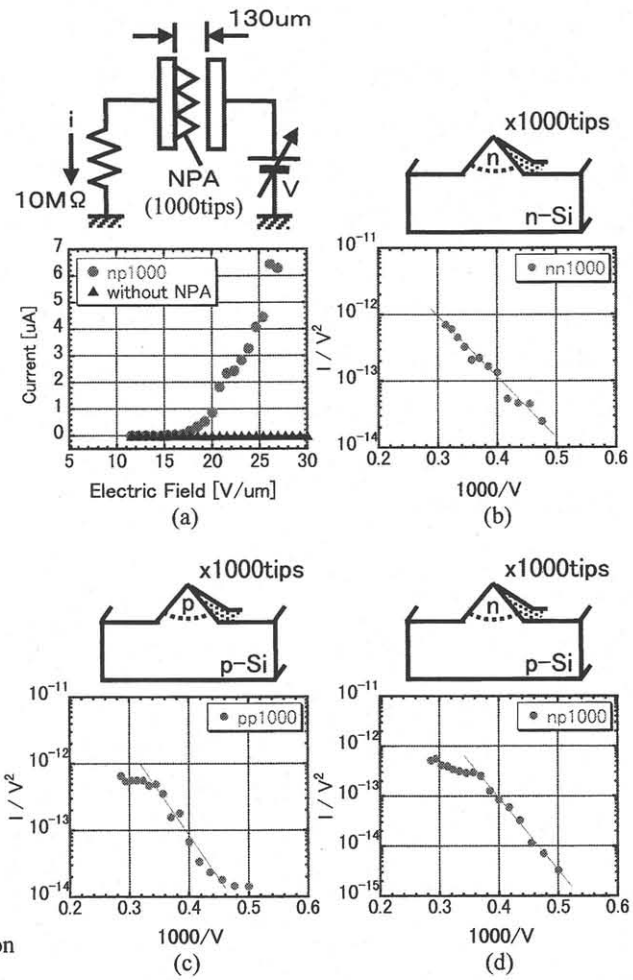

Fig. 4 Field emission characteristics of the cNPA (a) I-V plot, (b)-(d) Fowler-Nordheim plots.