MICROFABRICATION OF FIELD EMITTER TIPS FOR VACUUM MICROELECTRONIC DEVICES

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ABSTRACT

Potassium hydroxide (KOH) etching was used to create four sided pyramids for potential use in vacuum microelectronic devices. Optimal structures were found to be approximately 2 microns on a side and 2.2 microns high. KOH etched the silicon at 1200 A/min in the vertical direction. A slight overetch period insured that the oxide mask was undercut completely away and the pyramids came to a sharp point, but were not attacked. Surface damage as a result of the KOH etching was minimal.

INTRODUCTION

Vacuum microelectronic devices have several advantages over traditional silicon devices. These devices exhibit a higher packing density and have faster transit times than their solid state counterparts. They are typically only several microns in diameter. Additionally, electrons in a vacuum move 10 to 100 times faster than in a semiconductor[1,2]. Such devices are radiation hard and insensitive to extreme temperature conditions [1,2,3,4]. They also have potential applications in high resolution flat panel television screen technology [1,2].

The structure of a Vacuum Field Emitting device is shown in Figure 1. The emitter is a silicon pyramid. A large potential is placed between the emitter and collector, which combined with the small emitter to collector distance and geometry of the tip, produce an extremely high electric field. The field causes electron emission. This emission current can be regulated through voltage changes at a third node, the gate. The gate is analogous to the grid in a conventional vacuum tube.

The device in Figure 1 could be fabricated with modern integrated circuit processing techniques. The tip can be created with orientation dependant etching. Oxide could be grown and patterned to provide the insulating layer. The collector and gate could be patterned with a conducting layer[1,5].

This project is designed to fabricate the field emitting tips for a such devices. Optimal tips are conic or pyramidal and form a sharp point. They are one to two microns high and have base diameters of approximately two microns. Modern micromachining techniques can be used to create four sided pyramids. KOH etches silicon at a much faster rate in the <100> direction than in the <111> [3,7,8]. Silicon nitride or silicon dioxide serve as an appropriate masking materials. Circular patterns maximize the amount of mask undercut. [1,5].

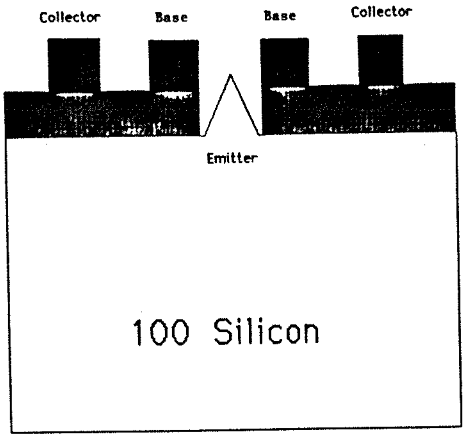

Figure 1: Vacuum Field Emission Device

EXPERIMENT

An array of circular discs was created using Chipgraph on the Appolo supercomputer. This array is shown in Figure 2. These arrays consisted of seven rows of discs of diameters 5.0, 4.0, 3.0, 2.5, 2.0, 1.5 and 1.0 microns. The circular patterns were fractured to the Mann format. This design was electronically transferred to VAX where the pattern generator was used to create a 10X reticle. Wafers were coated with positive photoresist and exposed with a Gline stepper. A total of 1000 arrays were photolithographically patterned on each wafer with the stepper program JOE1.

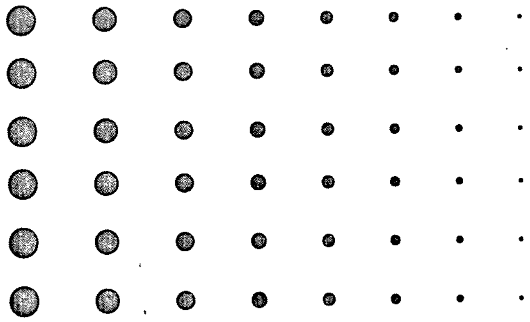

Figure 2: Circular Disc Masking Array

Both Silicon Nitride and Silicon Dioxide were investigated as masking material. 2000 A of Nitride was deposited onto 15 <100> silicon wafers. These wafers were 15 mils thick and had resistivity between 5 and 15 ohms/cm. The nitride was to be patterned with the Tiegal plasma etcher. However, several formulas were proven unsuccessful. Freon23 and low oxygen concentrations have been shown to etch nitride[6,9]. However, in this case, a thick carbon polymer apparently formed and hindered etching for a variety of Freon23/oxygen ratios. Sulfur hexaflouride, SF6, can be used to pattern nitride on oxide [9]. Several SF6 and SF6 with oxygen formulas were tried, but in all cases, a unremovable scum was found on the wafer surface. SF6 has not been sufficiently characterized for the removal of nitride directly on silicon. Nitride was abandon as a masking material. Oxide was found to be an acceptable masking material. Fifteen additional wafers (of the same specifications as the first batch) were obtained. 1600 A of oxide was grown. The oxide was successfully patterned in hydrofluoric acid, HF.

Potassium hydroxide concentration was varied between 3%, 5% and 10% by weight. Note that KOH pellets contain 15% water themselves and these conditions are uncorrected. Etch duration was varied between 10, 20 and 30 minutes. Temperature was held constant at 40 C. Agitation was supplied by a magnetic stirrer.

Each sample was examined under a 1000X optical microscope as well as a 1000X darkfeild scope. Selected samples were examined with the scanning electron microscope, SEM. Each etch condition was evaluated with respect to pyramid dimensions, amount of undercut/overetch and surface roughness.

RESULTS/DISCUSSION

Nitride deposited directly on silicon proved to be unpatternable for several plasma etching formulas with the Tiegal. Oxide, however, was found to be an acceptable mask material.

SEM evaluation for selected etch conditions are summarized in Figure 3. Figure 4 and Figure 5 contain SEM photographs of field emitters. In Figure 4, the masking oxide has not been completely undercut away. Figure 5 shows a pyramid fabricated under optimal conditions. Optimal pyramids were fabricated with 5% KOH for 30 minutes at 40 C. These four sided pyramids were generated with the 5 micron diameter masking oxide disc. They were approximately 2 microns on a side. The tip angle was measured to be 55 degrees and they were 2.2 microns high. KOH was found to etch at approximately 1200 A/min in the vertical direction under these conditions. A slight overetch was necessary to completely remove the masking material. The substrate surface did not see excessive damage.

KOH conc.	Etch time	Observations
3%	20 min	Poor pyramids: Excessive surface damage
5%	20 min	2.5 micron disc produced poorly defined pyramids and dimensions are too small. No significant surface damage.
5%	30 min	OPTIMAL CONDITIONS: 5 micron disc produced well defined four sided pyramids. Approx. 2.2 um tall 2 um on a side. cone angle of 55 degrees. No significant surface damage.
10%	10 min	Larger masking disc were not completely etched away. Smaller discs were over-etched. Smooth surface.
10%	20 min	5 um disc produced approximately 2 um base, but mask was not undercut. 4 um disc gave smaller rounded pyramids. Smaller discs were over-etched. Smooth surface.

Figure 3: Summary Table of Results

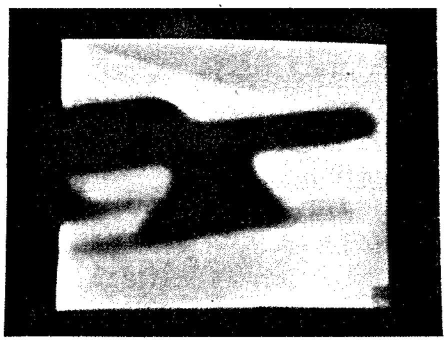

Figure 4: Field emitter with remaining masking layer

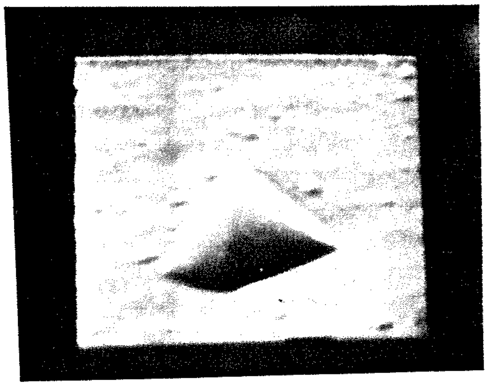

Figure 5: Field Emitter Tip fabricated under optimal conditions

CONCLUSION

Field emitter tips fabricated in this experiment were physically correct. The proper etch conditions to fabricate the desired four sided pyramids were found. Structure dimensions are appropriate for a application in vacuum microelectronic devices.

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