# Mesa etching process for InAs/GaSb SLs grown by MBE

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Abstract: Dry etching and wet etching were usually used in the mesa etching process of InAs/GaSb SLs. Three kinds of etch atmosphere ($Cl_2$ based, Ar based and $CH_4$ based)were studied in inductively coupled plasma (ICP) dry etching. The results show that the $CH_4$ based atmosphere give much more smooth surface and less etch pits according to the SEM measurement. Then wet etching was introduced to eliminate the etching damage of ICP dry etching, tartaric acid based etchant and phosphoric acid based etchant, were studied. It was found that the phosphoric acid based etchant gave better result to remove etching damage, and provide a more stable etching rate. InAs/GaSb SLs photodiodes by standard photolithographic procedures were fabricated using this etching recipe. The diodes exhibits a high breakdown voltage and low leakage current, the measurement result reveals a dynamic impedance values of $R_0A$ =1.98×$10^4$ Ωcm$^2$ at 77 K.

Key words: InAs/GaSb super lattice; dry etching; wet etching; mesa
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# InAs/GaSb 超晶格探测器台面工艺研究

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**摘 要**: InAs/GaSb SLs 探测器台面刻蚀常用的工艺有干法刻蚀和湿法刻蚀。研究了三种等离子刻蚀气体($Cl_2$ 基, Ar 基和 $CH_4$ 基)对超晶格的刻蚀效果,SEM 结果表明,$CH_4$ 基组分能够得到更加平整的表面形貌和更少的腐蚀坑;之后采用湿法腐蚀工艺,用于消除干法刻蚀带来的刻蚀损伤,分别研究了酒石酸系和磷酸系两种腐蚀溶液的去损伤效果,结果表明,磷酸系腐蚀液的去损伤效果更好,且腐蚀速率更加稳定。采用优化的台面工艺制备了 InAs/GaSb SLs 探测器,其 **I-V** 特性曲线表明二极管具有较低的暗电流,其 77 K 时动态阻抗 $R_0A$ =1.98×$10^4$ Ωcm$^2$。

**关键词**: InAs/GaSb 超晶格; 干法刻蚀; 湿法腐蚀; 台面

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## 0 Introduction

InAs/GaSb SLs is recognized as one of the ideal system for the fabrication of the 3rd generation IR detectors [1-3]. The investigation of production process of InAs/GaSb SLs infrared detector is very important to the fabrication of novel double color, large focal plane array detector [4-6]. Fabrication of these devices requires etching to form mesa, it is one of the vital procedures which affects the performance of the device. Etching can be broken down into two different approaches: wet and dry etching. Wet etching is an attractive approach to mesa definition because it is a very straightforward process to carry out and can be done inexpensively with a few readily available chemicals[7]. But the disadvantages[8-9] to this approach include the undercutting of the photomask which results in reduced fill factor and it has ragged sidewall because of the different etching rates of InAs and GaSb. To increase device yield or for smaller dimensions, dry etching is preferable to wet etching [10]. Dry etching can provide much more vertical and smooth sidewall profiles, and has no undercutting of the mask. However, dry etching tends to produce damage[11] in the devices, which results in higher leakage current and poor device performance.

In this paper, dry etching was used to fabricate the mesa of InAs/GaSb SLs, three kinds of etch atmosphere including $Cl_2$ based, Ar based and $SiH_4$ based were studied. And then wet etching was introduced after ICP dry etching to eliminate the etching damage, two kinds of etchant, tartaric acid based and citric acid based were studied, the appropriate etchant was selected. The I-V characteristics of the diode, which was fabricated with this mesa etching recipe, were tested.

## 1 Experiment

The system used for the ICP processes is the SENTECH SI500 inductive coupled plasma system. A schematic of the system is given in Fig.1.

The InAs (8 ml)/GaSb (8 ml)SLs samples used for this study were grown on undoped GaSb (001)substrates via VG80H MKII MBE system. The structure of superlattices sample is shown in Tab.1.

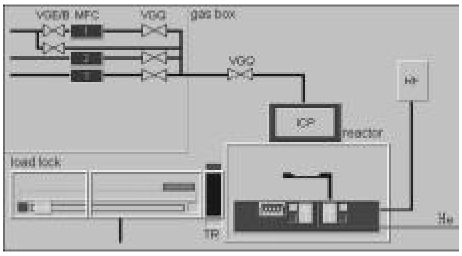



Fig.1 Schematic diagram of ICP system

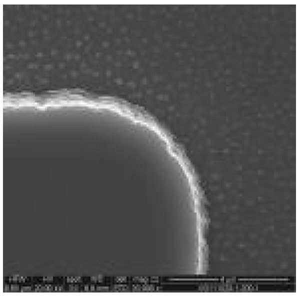
Tab.1 InAs/GaSb superlattices structure schematic

| Layer | Thickness/nm | Doping/cm$^{-3}$ | Description | |
|---|---|---|---|---|
| Cap layer(N-type) | 20 | $5\times10^{18}$ | InAs:Si | |
| N-type SLs | 285 | $5\times10^{18}$ | GaSb undped<br>InAs:Si | 60 |
| Undoped SLs | 950 | — | GaSb undped<br>InAs undped | 200 |
| P-type SLs | 285 | $5\times10^{18}$ | GaSb:Be<br>InAs undped | 60 |
| Buffer SLs (P-type) | 600 | $5\times10^{18}$ | GaSb:Be | |
| GaSb substrate(undoped) | | | | |

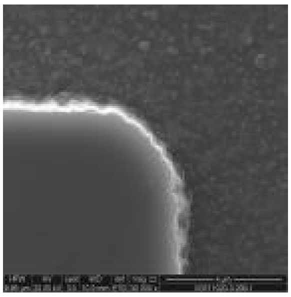
After the samples were cleaned with boiling freon, acetone, and ethyl alcohol, a layer of $SiO_2$ was deposited by PCVD. Patterns were defined on the $SiO_2$ layer by standard photolithographic procedures and etched in buffered hydrofluoric acid (BHF). To optimize the ICP etching process, the wafer was cut into several parts etching in three kinds of etch atmosphere, which is $Cl_2$ based, Ar based and $CH_4$ based, the temperature of the ICP etching process is 20 ℃. Then we researched the effect of removing damage in wet etching, two kinds of solutions were studied, which is tartaric acid based (tartaric acid: $H_2O_2$:BHF:$H_2O$=3.5 g:4 ml:1ml:100 ml), and phosphoric acid based ($H_3PO_4$:citric acid monohydrate:$H_2O_2$:$H_2O$ = 10 ml:10 ml:20 ml:200 ml), the temperature of the solutions is 30 ℃. The etching profiles and surface morphology were evaluated by FEI Quanta 650 SEM system. The diode was fabricated by standard photolithographic procedures with this optimized etching recipe. I-V measurement was carried out using I-V measurement system.

## 2 Results and discussion

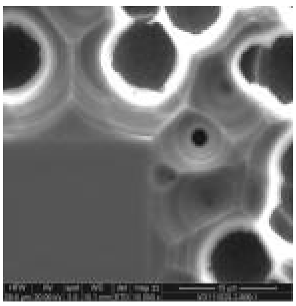
Figure 2 shows the SEM image of etched mesa of InAs/GaSb SLs after dry etching in different kinds of etch atmosphere respectively. It can be seen that the surface of Fig.2 (c), which reference to Ar based atmosphere, is much more worse than that of Fig.2(a)and Fig.2(b), the reason for it is the etching process of Ar based atmosphere is physical etch completely, the surface is damaged seriously. In Fig.2(a) and Fig.2(b), the surfaces can be accept, have no undercutting of the mask, but both of them have etch pits which will affect the preference of the devices. It is because the different rates of chemical etch and physical etch, during the period of chemical etch, the generated product deposits on the surface of the wafer, when it comes to physical etch, the accumulated deposit can be removed by desorption, when the rate of the former is faster than that of the later, the rates in different regions are different, which results in the emergence of etch pits. The etch pits in Fig.2(a) is smaller than that in Fig.2(b), and the sidewall is more vertical, so $Cl_2$ based atmosphere was chosen for dry etching of InAs/GaSb SLs.



(a) $Cl_2$ based atmosphere



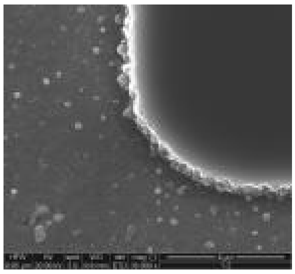
(b) $CH_4$ based atmosphere



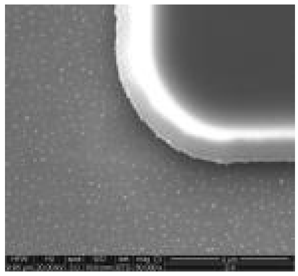
(c) Ar based atmosphere

Fig.2 SEM micrograph of InAs/GaSb SLs after dry etched at different atmosphere

Figure 3 shows the SEM image of wet etching mesa of InAs/GaSb SLs in different kinds of etchant respectively after dry etching. It can be seen that the phosphoric acid based etchant gives better result to remove etching damage. In phosphoric acid based solution [12], the phosphoric and citric acids act to remove the oxides of the constituent superlattice materials which are created by the strong oxidation properties of hydrogen peroxide. Additionally, the phosphoric acid based etchant offers a etch rate of 200-400 nm/min, which allowed for a very controllable etches that could be readily terminated in the desired location. So the phosphoric acid based etchant was chosen to remove damage produced by ICP dry etching.



(a) Tartaric acid based



(b) Phosphoric acid based

Fig.3 SEM micrograph of InAs/GaSb SLs after removing damage in different kinds of etchant

A wider field-of-view SEM image, showing the topographical nature of the etched mesas after removing damage by phosphoric acid based etchant, is shown in Fig.4. It can be observed that the mesas etched using our recipe consisting of dry etching and wet etching to remove damage gives clean etch profile, has no undercutting and the surface appears smooth.

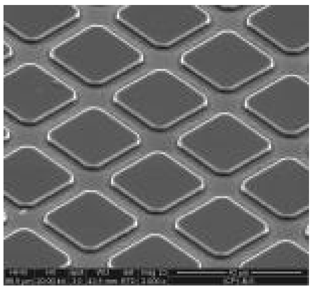


Fig.4 SEM micrograph of a field of etched mesas after removing damage

The **I-V** characteristic of the diode was shown in Fig.5,

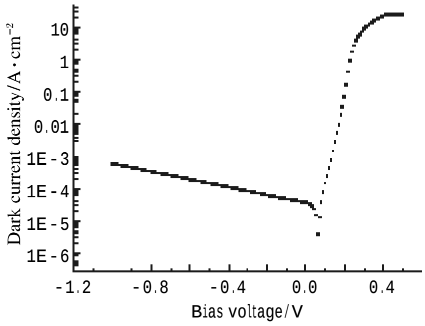



Fig.5 Dark current density vs voltage bias for InAs/GaSb SLs detectors at 77 K

the size of the diode was 200 μm ×200 μm, and it exhibits high breakdown voltage and low leakage current. The dark current density of the diode was equal to $6.1\times10^{-5}$ A/$cm^2$ at a reverse bias of -200 mV. The $R_0$ of this device was $4.95\times10^4$ kΩ, so the measurement reveals dynamic impedance value of $R_0A=1.98\times10^4\ \Omega cm^2$ at 77K.

## 3 Conclusion

Mesa etching process for InAs/GaSb SLs grown by MBE was studied in this paper. Three kinds of etch atmosphere were used in ICP dry etching, the $Cl_2$ based gave much more smooth surface and less etch pits compared with the Ar and $CH_4$ based atmosphere. Then two kinds of etchant were introduced to remove the etching damage, the phosphoric acid based etchant gives better result than the tartaric acid based, and it offers a more stable etching rate of 200-400 nm/min. The mesas using this etching recipe show very good surface morphology. Then InAs/GaSb SLs photodiodes by standard photolithographic procedures were fabricated, the dynamic impedance value of $R_0A=1.98\times10^4\ \Omega cm^2$ at 77 K.

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