Selective and Anisotropic Dry Etching of Ge over Si

Marcelo S. B. Castro1, Sebastien Barnola2 and Barbara Glück3

1 Laboratório de Optronica e Sensores, Centro Tecnológico do Exército, Rio de Janeiro, Brazil
2,3 CEA, LETI, MINATEC, Grenoble, France
e-mail: marcelobortolini@uol.com.br

I. INTRODUCTION

Germanium (Ge) and Silicon (Si) are basic materials in the fabrication of microelectronic devices such as infrared photodetectors [1, 2], sacrificial layers for structures like silicon on nothing (SON) [3], and bipolar heterojunction transistors [4]. In this work a process has been developed to selectively etch thick Ge layers (500 nm) on Si with anisotropic profile of the etched features to realize PIN photodetector structures.

For a long time dry etching processes of Si and Ge are well known and widely studied [5 - 8]. Because etching mechanisms of both materials are similar, halogen based chemistries including chlorine (Cl2), fluorine (CF4, SF6) and bromine (HBr) reactive gases are generally used for both materials. Germanium is usually more rapidly etched than silicon in conventional halogen plasmas at low bombardment conditions but it is possible to reverse this result by using a gas mixture SF6/H2/CF4 [9].

It is not easy to realize selective etching of one material to the other and control the profile of the etched features at the same time. Several authors have studied the ion etching mechanism of SiGe alloys [10-12] and high selectivity has ever been associated to isotropic etching. As it will be presented in this work, high selective etching of Ge to Si can be achieved under low ion bombardment conditions, but it is always associated to isotropic etching profiles.

The challenge of this work was to study the etching of Ge and Si using Cl2, CF4, SF6, and HBr feed gases by varying pressure and bias power so as to get a selective ICP etch process for Ge with stop on Si and with anisotropic profile of the etched structures.

II. EXPERIMENTAL PROCEDURES

The etching was performed in an ICP reactor model Centura AP1, manufactured by Applied Materials, using 13.56 MHz as power supplies for both, source and bias power. The inductively coupled source power was initially fixed at 350 W and after changed to 600 W. The bias power was varied from 0 to 50 W. CF4, HBr, SF6, and Cl2 were used as main gases. The pressure was varied from 4 to 50 mTorr. All experiments were done on 200 mm silicon wafers kept at 60 °C.

A preliminary study of Ge/Si etch selectivity used full 2.5 μm Ge layers epitaxially grown on Si wafers by reduced pressure chemical vapor deposition (RP-CVD) as described by J. M. Hartmann et al. in their work [13]. Silicon samples were virgin polished 200 mm Si wafers. Ge and Si etching rates were determined by a weighing comparative process using a pre-

ABSTRACT

Inductively coupled plasma (ICP) etching of Ge with high selectivity over Si and anisotropic etched profiles using CF4, HBr, SF6, and Cl2 reactive gases has been studied. Because pressure and biased power should be the most important parameters to drive selectivity and etch profile, they were varied from 4 to 50 mTorr and from 0 to 50 W, respectively, so as to investigate their influence on process. Total gas flow (100 sccm) and source power (350 W) were initially held constant. Selectivity greater than 100:1 of Ge over Si was achieved using 100% Cl2 etch gas at 50 mTorr and zero bias power but the profile of the etched features was isotropic. With the addition of N2 to the feed gas (Cl2) the profile became more anisotropic. A three steps ICP etch process was developed with a final Ge/Si etch selectivity of 5:1 and anisotropic profiles.

Index Terms: plasma etching, germanium, silicon, selectivity, etch profile.
Selective and Anisotropic Dry Etching of Ge over Si
Castro, Barnola & Glück

105

power was kept constant at 350 W for all preliminary experiments. CF₄, HBr, SF₆ and Cl₂ reactive gases were separately used and the gas flow were always kept constant at 100 sccm, except for SF₆. Here it was limited by the equipment at 50 sccm.

Fig. 1 shows the Ge/Si etch selectivity for the different etch conditions (a, b, c, and d). Except the point of low pressure and low bias (“b” condition), Cl₂ was the gas, that promoted the highest Ge to Si selectivity. The peak value of 116 was found at 50 mTorr and a 0 W bias power (Fig. 1.d). With SF₆ no Ge/Si etch selectivity was found under all pressure and bias power conditions. Using CF₄ the highest Ge/Si etch selectivity was 6 at the point of low pressure and low bias power. For all other conditions the Ge/Si etch selectivity was approximately 2, independent of the etch gas. It is worth mentioning that with the Cl₂ etch gas at 50 mTorr and 0 W bias power (condition “d”), the etch rate of Si was nearly zero. This result can be explained by the fact that chlorine etching of undoped Si follows an ion-assisted mechanism and Si etching is only made possible by disruptive effect of ions bombarding the Si surface [6].

The average error on Ge and Si etch rate were lower than 0.5 % and 2.7 % respectively. The highest values of error on Ge and Si etch rate were found under 0 (zero) W bias power and high pressure conditions, independently of the reactive gas. The greatest error on the etch rate was 6.98 %, corresponding to silicon etched by Cl₂ gas at 0 W bias power and 50 mTorr. Under these conditions, the Si etch rate was quite null and the processing time was increased 2.5 times to increase the consumption of silicon and minimize the final error.

B. Initial process parameters optimization

Based on preliminary results, Cl₂ was chosen as principal reactive gas and a more detailed analysis of the pressure and bias power parameters influence was...
done. Source power (350 W) and the Cl$_2$ gas flow (100 sccm) were kept constant. Ge and Si etching rate were measured at the pressure of 4, 35, 50 and 70 mTorr and at 0, 10, 25 and 50 W bias power. The results are shown in Fig. 2 in detail.

As expected, the higher the pressure and/or the lower the bias power the lower the etching rate of both, Ge and Si. Even though the decreasing the Ge etching rate is more pronounced than that of Si the difference between them becomes more significant. Consequently the higher the pressure and/or the lower the bias power the higher the Ge/Si etch selectivity. Those results are presented in a cartographic perspective in Fig. 3.

Table 1. Initial parameters used to etch 500 nm epitaxial Ge layers patterned with a 790 nm thick M78Y photoresist mask.

<table>
<thead>
<tr>
<th>Step</th>
<th>Time (s)</th>
<th>Source (W)</th>
<th>Bias (W)</th>
<th>Pressure (mTorr)</th>
<th>Flow (sccm)</th>
<th>CF$_4$</th>
<th>Cl$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>BT</td>
<td>5</td>
<td>350</td>
<td>50</td>
<td>4</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>ME</td>
<td>120</td>
<td>600</td>
<td>25</td>
<td>70</td>
<td>0</td>
<td>100</td>
<td>0</td>
</tr>
</tbody>
</table>

The ME’s parameters were found during the initial process optimization and presented a high Ge/Si etch selectivity (7.5:1). However, it can be seen in Fig. 5a) that the resulting profile showed isotropic characteristics which were not desired.

It is known that the addition of nitrogen can help to improve the profile by a passivation process in which a protective polymer layer is formed on the flanks during the etching [8]. This is the reason why in the next set of experiments N$_2$ was added to Cl$_2$ etch gas. N$_2$/Cl$_2$ ratio flows were varied from 0 to 3.33. The N$_2$ addition was held constant at 50 sccm (limited by equipment) whereas the Cl$_2$ gas flow was lowered to 50 sccm, 25 sccm, and 15 sccm respectively. Source power, bias power and total chamber pressure were kept constant at respectively 600 W, 25 W and 70 mTorr. The profiles developed under these conditions can be compared in figures 5b, c, and d.

The best profile was obtained with a gas flow of 15 sccm Cl$_2$ and 50 sccm N$_2$ (Fig. 5.d). At this condi-
Selective and Anisotropic Dry Etching of Ge over Si
Castro, Barnola & Glück


After the first etch step, the Ge etching rate was 300 nm/min and the Ge/Si etch selectivity was 5:1. Although this process generated an anisotropic profile with a reasonable selectivity, the result was not perfect. At the bottom of the structure, a kind of “foot”, with a lateral tilt of about 54° remains.

D. Final etch development

In order to optimize the etched profile another anisotropic step was inserted into the process which was redefined as a three steps sequence. The first one was the same BT, so as to remove the native oxide layer. The second one, called “main etch 1” (ME1), represents a mostly anisotropic process developed during preliminary studies (350 W source power, 50 W bias power, 4 mTorr total pressure and 100 sccm Cl2). Fig. 6 shows the straight profile obtained at these conditions.

Because this step is less selective (approximately 2:1), it was used for a partial etching of the main part of the Ge layer and has been stopped after a defined period of time, depending on the etching rate and the Ge thickness. Between 5 to 10% of Ge layer thickness should remain to be etched by a following higher selective step.

For this last step, called “main etch 2”, in a first trial the process with a Ge/Si etch selectivity higher than 100 (Fig. 1.d) was chosen. However after the full 3 steps etching process, the profile is partially isotropic and presented a sort of lateral indentation in the structure of Ge (Fig. 7).

A second attempt was realized with the same process parameters which were used to achieve an anisotropic profile and a Ge/Si etch selectivity of 5:1 (Fig. 5.d). The parameters of the successfully selective and anisotropic final etching process are shown in Table 2 and the profile analysis is presented in Fig. 8. None trenching or any other surface irregularities were observed.

Table 2. Final etch process parameters.

<table>
<thead>
<tr>
<th>Step</th>
<th>Time (s)</th>
<th>Source (W)</th>
<th>Bias (W)</th>
<th>Pressure (mTorr)</th>
<th>Flow (sccm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BT</td>
<td></td>
<td>350</td>
<td>50</td>
<td>4</td>
<td>100 CF4 0 0</td>
</tr>
<tr>
<td>ME1</td>
<td>50</td>
<td>350</td>
<td>50</td>
<td>4</td>
<td>0 100 0</td>
</tr>
<tr>
<td>ME2</td>
<td>40</td>
<td>600</td>
<td>25</td>
<td>70</td>
<td>0 15 50</td>
</tr>
</tbody>
</table>

E. Validation tests

Ending the process, the remaining photoresist was stripped by a two steps sequence. First the photoresist was burned in a downstream reactor by O2/N2/H2/CF4 plasma. The use of a N2/H2 flow promotes
Selective and Anisotropic Dry Etching of Ge over Si
Castro, Barnola & Glück

nitridation and protection of Ge surface and avoids Ge oxidation. During the second step contaminants were removed by a wet cleaning process performed in 0.1% HF bath and rinsed by deionized water.

The full process (etching + stripping) was successfully used to realize PIN structures. For this a 220 nm poly-Si film and a 500 nm thick Ge layer have to be etched consecutively with stop on bulk silicon using a patterned 790 nm resist mask. Because of the similar etch characteristic of Ge and Poly-Si, these two materials were both etched during ME1 with the same process parameters (see table 2). Only the etch time of this step was adapted to the actual thickness of the poly-Si plus Ge layers.

As to see in Fig. 9, with the developed 3 step process PIN structures with dimensions less than 1μm and anisotropic profile was realized. The Si substrate consumption was less than 15 nm. It remains a little “foot” at the bottom of the structures, more pronounced for the dense structures, that was negligible for the given application.

IV. CONCLUSIONS

Cl₂ gas, at 50 mTorr and a 0 W bias power conditions, promoted a Ge to Si selectivity of 116, the highest value among all reactive gases tested. With SF₆ no Ge/Si etch selectivity was found under all pressure and bias power conditions. The higher the total pressure and / or the lower the applied bias power the greater the Ge / Si selectivity but the lower the grade of anisotropy. A 3-step ICP anisotropic etching process was developed, using Cl₂/N₂ gas mix at 70mTorr and 25 W bias power conditions during the last step. This process was applied to realize 500 nm - PIN structures with anisotropic etch profile and minimum etch attack of the silicon stop layer on 200 mm wafers.

REFERENCES


