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Characterization of Germanium Dry Etching Using Inductively Coupled BCl_3 Plasma

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This study investigates the etch rates and the etched surface for Ge as a function of variations in the BCl_3 flow rate, inductively coupled plasma (ICP) power and work pressure. It was found that the peak etch rate is at 40 sccm of a BCl_3 flow rate. The etch rate of Ge decreases from 2370 to 1780 Å/min as the BCl_3 flow rate increases from 40 to 80 sccm. The etch rate of Ge decreases from 2835 to 2094 Å/min as ICP power increases from 200 to 500 W, whereas the etching rate of Ge increases from 2370 to 2900 Å/min as work pressure increases from 10 to 50 mTorr. The etched surface has a very smooth surface appearance at parameters of a BCl_3 flow rate of 40 sccm, 400 W of ICP power, and 10 of mTorr work pressure.

Keywords: etching, plasma, ICP, Ge, BCl_3

1. INTRODUCTION

Applying a dry etching technique to Ge and related compounds is one of the key processing steps in fabricating integrated photonic devices and circuits.[1-4] Dry etching is capable of reproducing anisotropic walls, and one characteristic of this process is its highly reproducibility. For such systems, Ge devices are designed in the micrometer and submicrometer ranges; where chemical etchings would have undesirable effects in terms of etch controllability and the nature of the sidewall profiles. Thus, plasma-based dry etching is essential as the only practical means of deep Ge etching for device fabrication. In most dry etching techniques applied thus far, inductively coupled plasma (ICP) has been shown to be a very promising technique owing to its high flux with lower-ion energy, which enables the achievement of excellent anisotropy etching at a high-etch rate for Ge. This is true even at relatively low-bias voltages. Traditionally, chlorine-based plasmas have been used for the dry etching of semiconductor materials.[4-12] Typical gases employed include Cl_2, $SiCl_2$, BCl_3 or CCl_2F_2 with additions of argon, helium or oxygen to provide easier ignition of the plasma, more stable operation or dilution to control the etch rate. Pure chlorine tends to have extremely fast etching rates and leaves a rough surface because the native oxides on the semiconductor surface are not removed in a uniform fashion. Boron trichloride is a particularly attractive discharge gas because it getters water vapor and is therefore quite forgiving of residual amounts of water in the vacuum chamber. It also readily attacks the native oxide on semiconductor materials and provides smooth and controlled etching. The gases of Cl_2, $SiCl_2$ and BCl_3 are all toxic and corrosive and require cautious handling.

This article reports the etching results of Ge using ICP in BCl_3 gas under varied processing parameters. The etch rate and etched surface were investigated as a function of the BCl_3 flow rate, ICP power and work pressure.

2. EXPERIMENTAL PROCEDURE

Samples used for etching experiments were typically 1 × 1 cm in size and were cut from two-inch n-type (100) oriented Ge substrates. They were cleaned in a Class 100 clean room using acetone and methanol in an ultrasonic bath for a period of 5 min for each solvent. Thereafter, samples were rinsed under DI water, blow dried with N_2 gas and pre-baked in an oven at 90°C for 10 min. After heating, samples were spin-coated using a spin-coater with a photo-resist at 5000 rpm for 30 s and were then placed in an oven for soft baking at 90°C for 30 min. Photo-lithography was performed using an I-line mask aligner under ultraviolet light (365 nm) with an intensity of approximately 5 mW. Four-inch mask plates with line features were used for patterning.

Samples were etched in a load-locked high-density plasma etch system consisting of an ICP chamber (operating at 2 MHz) and an additional RF bias (13.56 MHz) for the sample chuck. Helium back-side cooling was incorporated to allow the temperature of the substrate to be controlled more effectively. Samples were mounted on a six-inch Si carrier wafer

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with vacuum grease before they were introduced into the etching chamber. BCl_3 gas with a purity of 99.999% was introduced for etching with varying process parameters. After etching, the etch depths in Ge were determined using an α-step surface profiler. The etched surface of Ge samples exposed to ICP has been analyzed by SEM. The SEM image provides a qualitative measure of the etching anisotropy and surface morphology.

3. RESULT AND DISCUSSION

The effects of Ge etching by varying the processing parameters of the BCl_3 flow rate, ICP source power and work pressure are discussed in this section. First, etch rates were determined as a function of the BCl_3 flow rate. Samples were etched for 1 min at constant parameters of 400 W of ICP power, 100 W of bias power, 10 mTorr of work pressure, and a temperature of 20°C. Figure 1 shows the results of the etch rates for Ge samples as a function of the BCl_3 flow rate. It was found that the peak etch rate is at a BCl_3 flow rate of 40 sccm. This shows that the etch rate of Ge decreases from 2370 to 1780 Å/min as the BCl_3 flow rate increases from 40 to 80 sccm. As the BCl_3 flow rate increases, a higher Ge etching rate is observed due to the higher concentrations of reactive species. This increases the chemical component of the etch mechanism. The etching rate also decreased under high-BCl_3-flux conditions owing to the saturation of the reactive species at the surface. Second, the etch rates and sidewall profiles were determined as a function of the ICP power. Samples were etched for 1 min at constant parameters of a bias power of 100 W, a BCl_3 flow rate of 40 sccm, a pressure of 10 mTorr and a temperature of 20°C. Figure 2 shows the etch rate results for Ge as a function of the ICP power. As shown in the figure, the etch rate of Ge decreases from 2835 to 2094 Å/min as the ICP power increases from 200 to 500 W. Generally, the etch rates increased as the ICP source power increased due to higher neutral and ion flux. However, in the experimental results, the etch rates decreased at powers in excess of 200 W. The observed decrease in the etch rates at a high source power was due to either saturation of the reactive neutrals at the sample surface or to sputter desorption of the Cl radicals before they had time to react with the surface.[13] Ion energies can influence the physical component of the etch mechanism by changing the sputter desorption and bond breaking efficiencies of the etch process. Last, etch rates and sidewall profiles were determined as a function of the work pressure. Samples were etched for 1 min at constant parameters of an ICP power of 400 W, 100 W of bias power, a BCl_3 flow rate of 40 sccm and a temperature of 20°C. The results of the etch rates of Ge as a function of the work pressure are shown in Fig. 3. The figure shows that the etch rate of Ge increases from 2370 to 2900 Å/min as the work pressure increases from 10 to 50 mTorr. This is due to the higher concentration of reactive species, which increases the chemical component

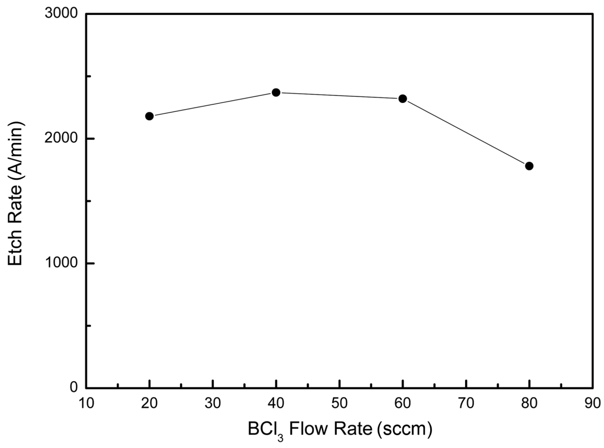

Fig. 1. Etch rate of Ge as a function of the BCl_3 flow rates.

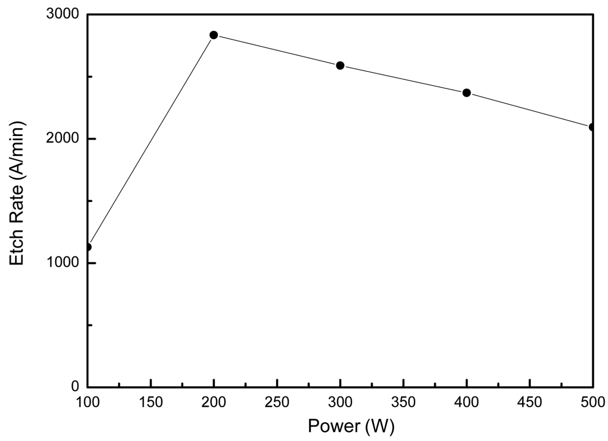

Fig. 2. Etch rate of Ge as a function of variations in the ICP power. (BCl3 flow rate of 40 sccm, bias power = 100 W, work pressure = 10 mTorr, temperature = 20°C)

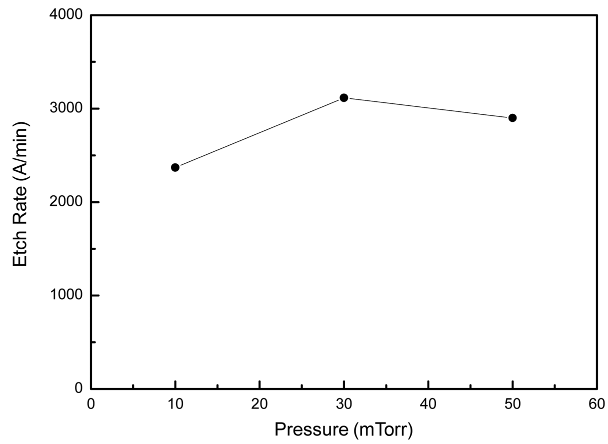

Fig. 3. Etch rate of Ge as a function of variations in the work pressure. (BCl3 flow rate of 40 sccm, ICP power = 400 W, bias power = 100 W, temperature = 20°C)

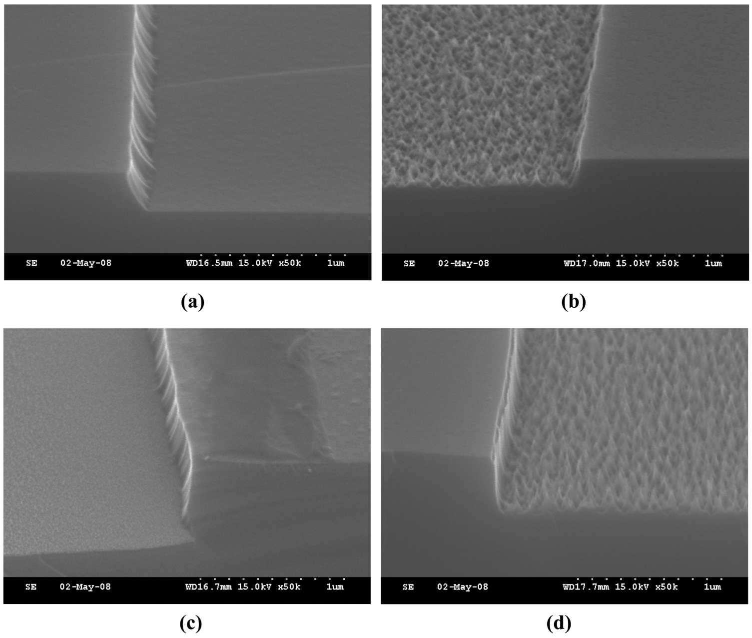

Fig. 4. SEM images of a Ge sample etched at BCl_3 Plasma: (a) BCl_3 flow rate of 40 sccm, ICP power = 400 W, work pressure = 10 mTorr. (b) BCl_3 flow rate of 80 sccm, ICP power = 400 W, work pressure = 10 mTorr. (c) BCl_3 flow rate of 40 sccm, ICP power = 500 W, work pressure = 10 mTorr. (d) BCl_3 flow rate of 40 sccm, ICP power = 400 W, work pressure = 30 mTorr.

in the etching mechanism. As a result of a higher ion flux, an increase in the bond breaking and sputter adsorption of the etching mechanism will occur.[14] Increasing the pressure increases the density of the reactive species that are present in the chamber. However, it also decreases the mean free path, thereby affecting the energy with which the ions impinge on the substrate as well as the average lifetime of the ions before they recombine. This occurs because the mean free path of the ions can be reduced until they are much shorter than the length of the sheath in the plasma at high pressures. This effect can reduce the directionality of the ions impinging on the Ge samples, thereby reducing the etch rates at higher-work pressures, as shown in Fig. 3.[15,16] SEM images of an etched Ge sample are shown in Fig. 4. The etched surface (a) has a very smooth appearance with the parameters of a BCl_3 flow rate of 40 sccm, an ICP power of 400 W, and a work pressure of 10 mTorr. The etched surface shown in (b), (c) and (d) becomes very rough at a flow rate of 80 sccm, an ICP power of 500 W and a work pressure of 30 mTorr due to the deposition of the chlorine-related materials. As these etching products are involatile, it is highly possible that their self-masking effect directly caused the rough surfaces. Chlorine may therefore have a constituent of these particles after ICP etching.[9] The observed roughness in the etched surface at a high source power was due to either saturation of the reactive neutrals at the sample surface or to sputter desorption of the Cl radicals before they had time to react with the surface.[13] Increasing the pressure increases the density of the reactive species that are present in the chamber.[16]

4. CONCLUSION

This study presents a systematic study of ICP etching on Ge with BCl_3 chemistry with varied processing parameters. It was found that the peak etch rate occurs at a BCl_3 flow rate of 40 sccm. The etch rate of Ge decreases from 2370 to 1780 Å/min as the BCl_3 flow rate increases from 40 to 80 sccm. The etch rate of Ge decreases from 2835 to 2094 Å/min as the ICP power increases from 200 to 500 W, whereas the etching rate of Ge increases from 2370 to 2900 Å/min as the work pressure increases from 10 to 50 mTorr. The etched surface has a very smooth appearance at parameters of a BCl_3 flow rate of 40 sccm, an ICP power of 400 W, and a work pressure of 10 mTorr.

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