Thin Solid Films 518 (2010) 6488–6491

Contents lists available at ScienceDirect

Thin Solid Films

journal homepage: www.elsevier.com/locate/tsf

Dry etching process of GaAs in capacitively coupled BCl_3-based plasmas

J.W. Lee [a,*], H.S. Noh [a], S.H. Lee [a], J.H. Park [a], K.H. Choi [a], S.J. Pearton [b]

[a] School of Nano Eng., Inje University, Gimhae, GN 621-749, Republic of Korea
[b] Dept. of Materials Sci. and Eng., University of Florida, Gainesville, FL 32611, USA

ARTICLE INFO

Available online 10 February 2010

Keywords:
Plasma etching
RIE
GaAs
BCl_3
BCl_3/N_2
BCl_3/Ar

ABSTRACT

Dry etching of GaAs was investigated in BCl_3, BCl_3/N_2 and BCl_3/Ar discharges with a mechanical pump-based capacitively coupled plasma system. Etched GaAs samples were characterized using scanning electron microscopy and surface profilometry. Optical emission spectroscopy was used to monitor the BCl_3-based plasma during etching. Pure BCl_3 plasma was found to be suitable for GaAs etching at >100 mTorr while producing a clean and smooth surface and vertical sidewall. Adding N_2 or Ar to the BCl_3 helped increase the etch rates of GaAs. For example, the GaAs etch rate was doubled with 20% N_2 composition in the BCl_3/N_2 plasma compared to the pure BCl_3 discharge at 150 W CCP power and 150 mTorr chamber pressure. The GaAs etch rate was ~0.21 µm/min in the 20 sccm BCl_3 plasma. The BCl_3/Ar plasma also increased etch rates of GaAs with 20% of Ar in the discharge. However, the surface morphology of GaAs was strongly roughened with high percentage (>30%) of N_2 and Ar in the BCl_3/N_2 and BCl_3/Ar plasma, respectively. Optical emission spectra showed that there was a broad BCl_3-related molecular peak at 450–700 nm wavelength in the pure BCl_3 plasma. When more than 50% N_2 was added to the BCl_3 plasma, an atomic N peak (367.05 nm) and molecular N_2 peaks (550–800 nm) were detected. Etch selectivity of GaAs to photoresist decreased with the increase of % N_2 and Ar in the BCl_3-based plasma.

1. Introduction

Dry etching is a complex process with many factors that must be considered for optimization of the process. Capacitively coupled plasma (CCP) etching, so called reactive ion etching (RIE), is one of popular patterning techniques for semiconductor processing [1–5]. CCP has advantages for plasma etching of GaAs in terms of low cost of ownership and easy maintenance. However, there have been issues such as ion-induced damage due to its relatively high ion energy, and low etch rates (typically ≤0.2 µm/min) [6–10]. There has also been great interest in developing advanced etch processes with a capacitively coupled plasma system for GaAs [11–16]. At a fixed ion energy (or at fixed RIE chuck power and self-bias), if the etch rate of GaAs is relatively high, then the etch damage near the etched GaAs surface will be low since damage generation typically occurs due to ion bombardment with slow removal rate of defected GaAs atoms, i.e. a high etch rate process at the same ion energy (or self-bias) can alleviate ion-induced damage with a fast removal rate. Plasma etching of a material can be enhanced by synergistic assistance of reactive neutral plasma species and bombarding ions on the surface [16]. Achieving high etch rate with a low ion damage process is a key goal for GaAs etch process development.

The maintenance of surface smoothness after etching is another important factor for plasma processing. For etching of binary or ternary semiconductors, such as GaAs and AlGaAs, the volatilities of group III and group V etch by-products are different [16]. Typically group V etch by-products have higher volatility than those of the group III. Unbalanced removal rate of etch by-products can cause rough etched surfaces, and these can be sources for degradation of device performance by providing defect centers for recombination [17]. The prerequisites for advanced etch process include high etch rate, low damage and smooth surfaces. In addition, vertical sidewall passivation, etch selectivity and reproducibility are some other important parameters. In this paper, we report an investigation of an optimized etch process for GaAs in capacitively coupled BCl_3, BCl_3/N_2 and BCl_3/Ar plasma at >100 mTorr.

2. Experimental

A custom-built capacitively coupled plasma (CCP) system was used for the experiment. The diameter and the height of the reactor chamber were 400 mm and 350 mm, respectively. In this experiment, 150 W RF power of 13.56 MHz frequency was used in order to supply electromagnetic energy for generation of a plasma discharge in the chamber. Chamber evacuation and processing pressure were maintained with a single mechanical pumping (Woosung Automa, 600 l/min) module. The process pressure was changed in the range of 150–300 mTorr. Gas flow rates of BCl_3, N_2 and Ar were controlled with electronic mass flow controllers. Each flow rate of the gases was varied from 0 to 20 sccm

* Corresponding author.
E-mail address: jwlee@inje.ac.kr (J.W. Lee).

0040-6090/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.tsf.2010.02.003

(standard cubic centimeter per minute) with the fixed total flow rate of 20 sccm.

Photoresist (AZ 4620) patterned (100) GaAs wafers were cut into 1×1 cm^2 samples, which were placed on the center of the 150 mm electrode. The GaAs substrates were semi-insulated and double side-polished. The RF electrode was made of stainless steel. The GaAs samples were placed on the electrode manually. All the process was done at room temperature.

The peak intensities of the plasma discharges were characterized with optical emission spectroscopy (OES) during dry etching. The OES analysis was carried using SD 2000 model, Ocean Optics, Inc. Its hardware consists of an optical fiber, 2048 element linear silicon CCD array and A/D converter. The monitoring frequency range was 400–900 nm. OES resolution was ~1 nm and integration time was 100 ms.

Etch time was fixed to 5 min. Etch depth and surface roughness was measured with a surface profilometry (Tencor alpha-step IQ). Etched surface morphology and sidewall passivation were analyzed using scanning electron microscopy (SEM).

3. Results and discussion

Fig. 1 shows the etch rate of GaAs and induced self-bias as a function of % N_2 in the BCl_3/N_2 plasma. RIE chuck power (i.e., CCP power) and chamber pressure were fixed at 150 W and 150 mTorr, respectively. Notice that the highest etch rate of GaAs was found at 20% N_2 composition in the BCl_3/N_2 (i.e. 16 sccm BCl_3/4 sccm N_2) plasma. The etch rate of GaAs was 0.40 µm/min after etching in the condition, while that at 20 sccm BCl_3 (100% BCl_3) was 0.21 µm/min. 20 sccm N_2 (i.e. 100% N_2) plasma did not etch the GaAs at all. Therefore, there was a synergetic effect of N_2 in the BCl_3/N_2 plasma. The etch rates of GaAs in the BCl_3/N_2 plasmas were higher than pure BCl_3 until % N_2 became 80% (i.e. 4 sccm BCl_3/16 sccm N_2). The maximum etch rate could be found in the range of $0 < x \leq 20\%$, $x = \%\ N_2$ in BCl_3/N_2, where a favorable chemical equilibrium might exist. The synergetic effect of N_2 in BCl_3/N_2 was reported earlier with high density plasma etching sources. Ren et al. [19], Shul et al. [18,20,21] and Maeda et al. [22] reported similar results in BCl_3/N_2 with an electron cyclotron resonance (ECR) etching or inductively coupled plasma (ICP) etching.

In this CCP etching of GaAs, attention was paid to development of high rate etching process with a simple and cost effective etching tool. A simple mechanical pumping system was used without assistance of high vacuum components, such as turbomolecular pumps, which are assumed to be prerequisite for generation of high density plasmas. Here, a relatively high etch rate of GaAs (0.40 µm/min) was obtained, which was comparable to that in a moderate power ICP tool. It was also found that there was a broad range of % N_2 composition (20–80%) for fast etch rates of GaAs by the synergetic role of N_2. In the fast etch regime, the maximum etch rate of GaAs was found at 20% of N_2 composition in the BCl_3/N_2 plasma. The gas composition range was similar to the solution ratio in wet etching of GaAs-related materials in HCl and HNO_3 mixtures in order to get the highest etch rate, where about 25% composition of HNO_3 in the total solution of HCl and HNO_3 provided the highest etch rate of AlInP [23], InGaP [24] and AlGaP [25].

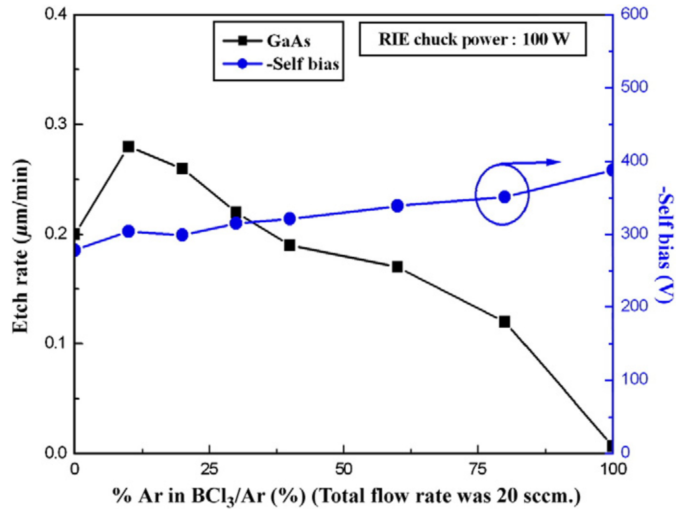

Fig. 2. Etch rate of GaAs and self-bias on the chuck as a function of % Ar in the BCl_3/Ar plasma.

Fig. 2 shows etch rates of GaAs in BCl_3/Ar plasma at 100 W CCP power and 150 mTorr. Total gas flow rate was 20 sccm. BCl_3/Ar also provided a similar trend for generating a synergistic effect of high etch rate when % Ar was <30%. However, it was also noted that the GaAs etch rate was continuously decreased with Ar gas fraction after 10% Ar in the BCl_3/Ar even though self-bias was continuously increased with % Ar.

Fig. 3 shows etch selectivity of GaAs over the photoresist as a function of % N_2 in the BCl_3/N_2 plasma. Notice that the selectivity gradually decreased with increase of % N_2 from 4.6:1 at the 20 sccm

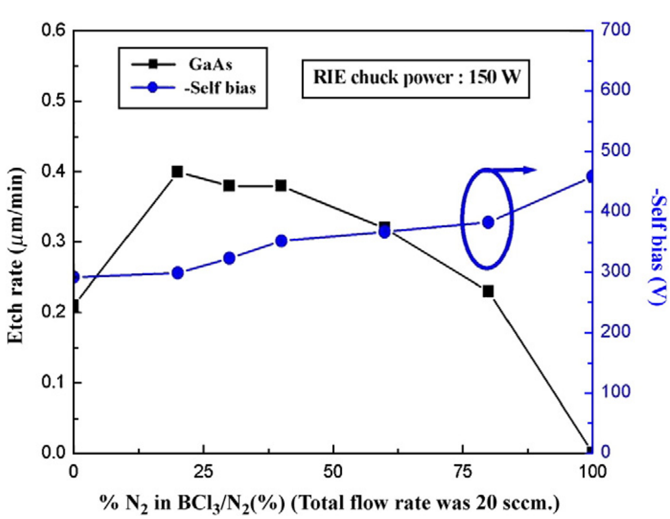

Fig. 1. Etch rate of GaAs and self-bias on the chuck as a function of % N_2 in the BCl_3/N_2 plasma.

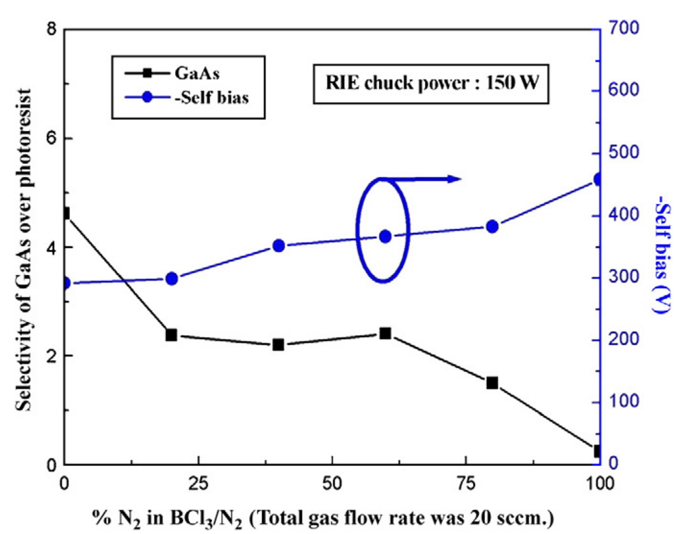

Fig. 3. Etch selectivity of GaAs over the photoresist as a function of % N_2 in the BCl_3/N_2 plasma.