応用物理学会学術講演会予稿のタイトル

Study of $\beta - Ga_2O_3$ Dry-Etching

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Introduction

Gallium trioxide is a promising transparent wide bandgap (from 4.6 to 4.9 eV) semiconducting oxide, with applications in several fields: power electronics, optoelectronics and sensing systems [1]. Under normal conditions of temperature and pressure, gallium trioxide is crystallized under a monoclinic lattice (that belongs to the space-group $C_{2/m}$), namely $\beta - Ga_2O_3$. The performances of $[\bar{2}01]$ oriented $\beta - Ga_2O_3$ based devices were found to be sensitive to plasma damage [2]. In this way, this work aims to develop a damage free $BCl_3/Cl_2/Kr$ based plasma etching processes in an Inductively Coupled Plasma-Reactive Ion Etching (ICP-RIE) tool, in order to obtain high etch rate and smooth surfaces (both planar and vertical ones) of $[\bar{2}01]$ oriented $\beta - Ga_2O_3$, to enable efficient power devices manufacturing. Our study particularly focuses on understanding the effects of plasma composition, density and pressure, as well as ions energy to elucidate the etching mechanisms at the origin of the observed etch rate and morphology of $[\bar{2}01]$ oriented $\beta - Ga_2O_3$ wafers.

Experiments

A 100 nm thick Ni hardmasks is patterned into an array of 10 µm width lines on top of un-intentionally n-type doped, $[\bar{2}01]$ oriented $\beta - Ga_2O_3$ wafers (from Novel crystal technology, Inc.). Each $\beta - Ga_2O_3$ sample is patched onto a 150 mm diameter Si carrier wafer to be transferred in the etching tool. Plasma are generated via an ICP-RIE tool (RIE-200iP from SAMCO) supplied with BCl_3, Cl_2 and Kr; with flow rates varied in the 10-40 sccm range. Plasma pressure is studied in the 5-30 mTorr range. The ICP-RIE source power (RF_{Source}) is varied in the 200-850 W range. Ions energy is estimated from the self-bias voltage (V_{DC}) and is varied in the 28-128 V range by tuning the ICP-RIE bias power (RF_{Bias}) in the 50-300 W range. Etch rates are measured by means of a stylus profiler, topographic analysis is carried out via Scanning Electron Microscopy (SEM) and the extreme surface composition is determined using X-ray Photoelectron Spectrometry (XPS).

Results and discussion

Plasma composition study performed at 5 mTorr and for RF_{Source} and RF_{Bias} set at 400 W and 100 W respectively, shows that the etch rate decreases with addition of Cl_2 to the BCl_3/Kr mixture from 96 ± 3 nm.min^{-1} (no Cl_2) to 79 ± 5 nm.min^{-1} in the case of 40% of Cl_2. These results indicate that addition of Cl_2 favours the recombination of BCl and Cl etchants species into BCl_3 or Cl_2. It leads to a reduction of the etchants flux towards the sample, and then a decreases the overall etch rate without significant improvement of the sidewalls morphology. For RF_{Source} varied in the 200-850 W range for BCl_3/Kr (40/10 sccm) and $BCl_3/Cl_2/Kr$ (20/20/10 sccm) plasma set at 5mTorr and 100 W RF_{Bias}, the etch rate linearly decreases with V_{DC}, this indicates that the etching is not limited by the impinging ions energy. Pressure study performed for the two plasma conditions mentioned above, reveals that at 30 mTorr, the surface is saturated with etchant species and the etch rate is controlled by the incoming ions. Fig. 1a shows the etch rate as a function of V_{DC} for the two considered plasma composition at 5mTorr and RF_{Source} set at 400W. In the case of BCl_3/Kr plasma, two regimes can be observed indicating a transition in the etching mechanism depending on the incoming ions energy. Additionally, SEM images shows the presence of a deposit on the $\beta - Ga_2O_3$ sidewalls, see Fig.1b. This compound can be removed under O_2 plasma exposure, as shown in Fig. 1c. This deposit thickness increase when no ionic bombardment is applied (RF_{Bias} set to 0 W). From XPS analysis, this deposit is identified as a $Si_XB_YCl_zO_W$ compound. The combined evolutions of etch rate as a function of V_{DC} and the deposit morphology allow us to propose the following etching mechanism depending on the ions energy. At 0 V, $Si_XB_YCl_zO_W$ growth is favoured from the reaction between BCl and Cl etchants, the Si-wafer carrier and $\beta - Ga_2O_3$, stopping the etching. For 0 V < V_{DC} < 90 V, the compound deposition rate (from radical's flux) and its removal rate (from ionic bombardment) balance each other. A steady state is established similarly to the one observed for the etching of Si by CF_4 plasma [3]. This thin layer acts as a reservoir of etchant species which are released upon ionic impact, enhancing the etch rate. At high V_{DC}, ($\leq$ 90 V) ionic bombardment becomes predominant and sputter $\beta - Ga_2O_3$.

Conclusion

We propose an in-depth etching study relying on $BCl_3/Cl_2/Kr$ plasma for $[\bar{2}01]$ oriented $\beta - Ga_2O_3$. High etch rate (about 96 ± 3 nm.min^{-1}) and smooth surfaces are obtained for BCl_3/Kr plasma followed by a O_2 plasma exposure. Finally, we provide a detailed etching mechanism for $[\bar{2}01]$ oriented $\beta - Ga_2O_3$ hinging on the formation of a $Si_XB_YCl_zO_W$ deposit, where Si originates from the carrier wafer.

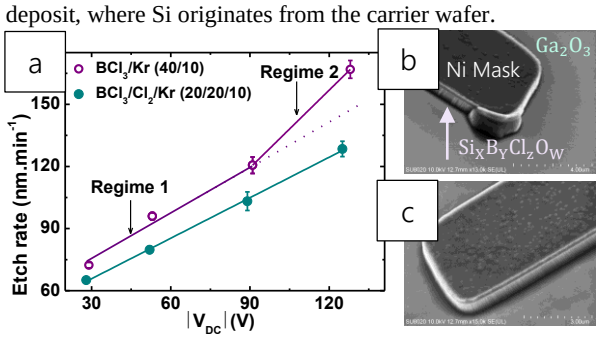

Fig. 1: Etch rate of $[\bar{2}01]$ oriented $\beta - Ga_2O_3$ as a function of V_{DC} (a). SEM images of Ni masked $[\bar{2}01]$ oriented $\beta - Ga_2O_3$ etched by BCl_3/Kr (40/10 sccm) plasma for 5 min at 5 mTorr, RF_{Source} and RF_{Bias} set at 400 W and 100 W, respectively before (b) and after (c) O_2 plasma exposure (1 min, 25 sccm, 15 mTorr, RF_{Source} at 300 W).

References

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