BCB etching Process using High Density Plasma

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Abstract

BCB (Bisbenzocyclotene) material is widely used throughout semiconductors industry as interconnect structure filler or chip capsulate, mainly because it is a low-K dielectric material which causes low tangent loss at high frequency. This work presents systematic research based on the design of experiment (DoE) approach for BCB etching and integration in to the process flow in order to decrease the number of process steps and time. DoE parameters were ICP power, RIE power and two different gas mixtures CF_4+8.5%O_2/O_2/Ar and CHF_3/O_2/Ar. Empirical models constructed from the DoE results permit to evaluate the impact of the process parameter on the etching rate of the BCB. Etching rate as high as ~1 um/min BCB on 3” GaAs was achieved.

Cleaning process after etching step is important for chip assemble bonding and reliability. Deferent chemical strippers EKC 830,505 and NMP were tested to achieve optimized cleaning process, the success criteria for this step was no side wall residue and clean surface.

The improved process decreased wafer etching cycle time by 75%, reduced total process steps and left clean open areas. The new process did not change the device performances.

1. INTRODUCTION

BCB (Bisbenzocyclotene) material is widely used throughout semiconductors industry as interconnect structure filler or chip capsulate, mainly because of its low tangent loss at high frequency [2]. Typical thickness of BCB is in the range of 5-12 um and it is usually applied to the wafer using photolithography techniques including material spraying, spinning, and thermal curing. BCB via opening can be done by reactive ion etch (RIE) diode or inductive coupled plasma (ICP) system using different gas mixtures.

The basic structure of BCB is organic material containing about 4% Si atoms. Consequently the basic mixture used to etch BCB includes: oxygen to etch the basic organic structure and small quantities of Fluor is added to etch the Si atoms and prevent the formation of SiO_2 layer which acts as stop layer when formed.

The common gas mixtures involve CF_4/O_2, SF_6/O_2 [1, 3, 5] but other combination like C_2F_6/O_2 could be found [4]. In addition Ar or N_2 can be added for mixture dilution or plasma stabilization.

In this study, we investigate the impact of ICP power, DC bias, and two different gas mixtures CF_4+8.5%O_2/O_2/Ar and CHF_3/O_2/Ar in order to obtain higher etch rate using ICP system. Furthermore we show better cleaning process and flow optimization to reduce module cycle time.

2. EXPERIMENTAL DETAILS

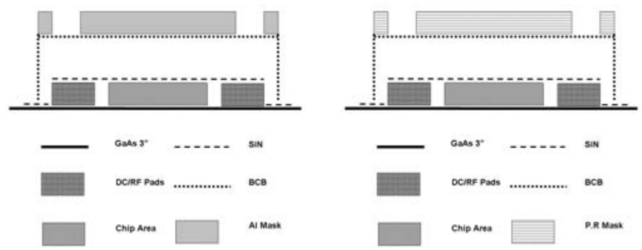


Fig.1. a) BCB etching process using Al mask (left) vs.
b) Photoresist (PR) mask (right).

After fabricating of all front side elements on top of 3” GaAs substrates, SiN were deposited on the surface to achieve better adhesion between gold (Au) top layer and BCB. CYCLOTENE 3022-57 was used as BCB layer, the layer was applied by spin coating to obtain 8.5 +/- 1 um Followed by curing process that was obtained at 250°C for 1h in N_2 ambiance. Fig. 1. (a) describes former etching process using Al hard mask, SF_6 / O_2 gas mixture, ICP Power – 700W and DC bias – 110 V. The results were: BCB etch rate of ~0.2 um/min and process time of ~ 70 min per wafer. Beyond the long cycle time of the process, wafers were often scarped because of several reasons: BCB delaminating after Back-End processes, and electrical failure mainly because of organic-metal residue that can not be removed. Those phenomena were reported previously [2], suggesting the source of metal residues is the mask being used. Fig. 1. (b) describes the new flow using ~15 um P.R (AZ 4620) as mask, to avoid metal-organic residues, and to reduce process cycle time.

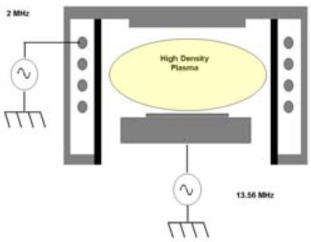


Fig.2. Orlikon ICP SLR 770

Etching experiments were carried out on Orlikon ICP SLR 770 (Fig.2.), equipped with upper 2 MHz power generator for plasma generation and bottom 13.56 MHz power generator to control dc bias voltage.

2.1 ETCHING PROCESS

In order to obtain high etch rate process ; DoE Screening Design technique was applied testing ICP Power, DC bias and CF_4/O_2 , CHF_3/O_2 ratio (table 1) in order to determine main factors and their influence on BCB etch rate. ~ 5% Ar was added to all processes. This amount is the recommended value [1]. O_2 flow rate and pressure were kept const.

Table 1: DoE Process parameters for CF_4/O_2 vs. CHF_3/O_2

ICP [W]	DC Bias[V]	CF_4/O_2	ICP [W]	DC Bias[V]	CHF_3/O_2
600	160	1.19	700	175	0.80
600	205	0.27	800	200	1.30
800	163	0.27	600	200	0.30
800	205	1.19	800	150	0.30
750	155	0.46	600	150	1.30

2.2 CLEANING TECHNIQUE

After increasing the etch rate the PR was dramatically cured because of the high DC bias. Thus, a substantial cleaning step to remove it has become essential. We examined three different stripping solutions: NMP, EKC 830, and EKC 505.

3. RESULTS AND DISCUSSION

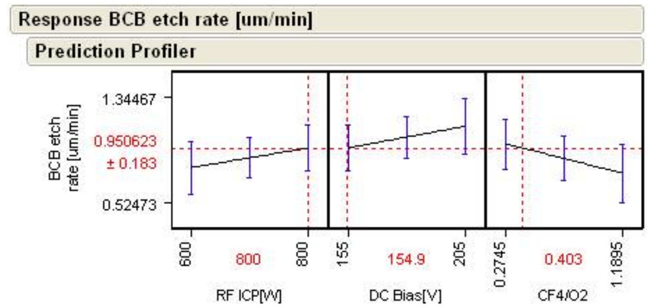


Fig.3. BCB Etch rate as function of CF_4 / O_2 , ICP Power, DC Bias.

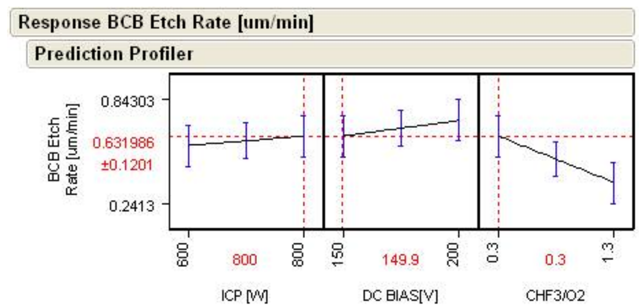
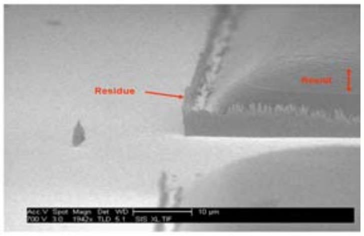
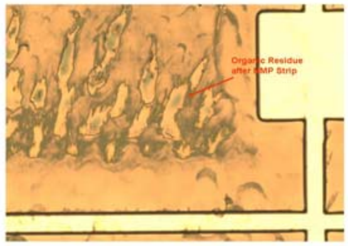


Fig.4. BCB Etch rate as function of CHF_3 / O_2 ,ICP Power, DC Bias.

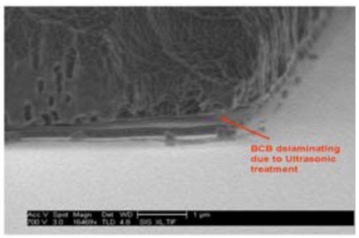
The DoE process parameters were ICP Power, DC Bias, and F/O ratio with two gas mixtures: CF_4/O_2 , and CHF_3/O_2 in order to increase BCB Etch rate. Empirical model was constructed to each gas. The models reveals the influence of each parameter on the BCB etch rate, furthermore the model can give prediction of etch rate for combination of the parameters and guiding for increasing etch rate in following experiments. Fig. 3 and 4 Show higher etch rate using CF_4 mixture ~1 um/min than using CHF_3 mixture ~0.6 um/min. In both cases it was found that main contribution to the etching rate depends on F/O ratio. All experiments have shown PR / BCB selectivity between 1-1.5. One of the major problem evolved while increasing DC bias is PR curing, meaning cleaning procedure becomes almost impossible. The above results initiated an optimization of the cleaning process.



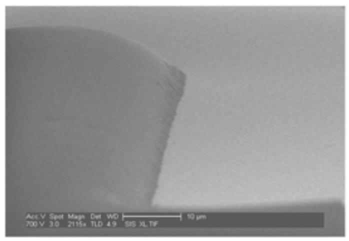
a)



b)



c)



d)

Fig.5. a) BCB Pattern after etching b) NMP – stripper could not remove cured P.R c) any stripper mix with Ultrasonic cleaning revealed BCB interface delaminating d) EKC 830 90C.

Fig. 5. (a) Shows the residues on the surface of the wafer after etching process. (b) All cleaning combinations using NMP (with different temperature and soaking) failed due to the fact that cured PR remains on wafer surface. (c) All stripers with any ultrasonic treatment caused the appearance of BCB delamination in the interface between SiN and BCB. (d) Cleaning optimization was achieved using EKC 830 soaking at 90C for 15 min.

5. CONCLUSION

In this study, we achieved BCB etching rate as high as ~1 um/min, which is 4 times higher compared to previous process. CF_4/O_2 mixture with ~0.4 F/O ratio combined with new cleaning procedures (EKC 830 striper) yielded faster, cleaner and controllable production process. By changing metal mask to the resist mask we reduced BCB etch module time by ~75%. Furthermore, no BCB delamination after Back-End process was observed.

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ACRONYMS

DoE: Design of Experiment
P.R : Photoresis
BCB: Bisbenzocyclotene