# A Design of Experiment for High Throughput GaAs Via Etch by Reactive Ion Etch

Juifen Lee, Hungchun Tsai, Yee-Shyi Chang
Materials Science and Engineering, National Tsing–Hua University
Hsin-Chu, Taiwan, ROC

Rong-Ting. Huang
Global Communication Semiconductor Inc.
23155 Kashiwa Ct., Torrance, CA 90505
Email: rthuang@gcsincorp.com

## ABSTRACT

A design of experiment for high throughput GaAs via etch by reactive ion etch is reported. An effective GaAs backside via process for connecting the front side circuits to the backside ground plane reduces the ground inductance and thus improves the RF performance of fabricated circuits. We conducted a Design of Experiment (DOE) for GaAs via etch to obtain high etch rate and smooth via profile with a non-reentrant slope simultaneously on a four mils thick GaAs substrate. The DOE consisted of four major varying parameters, which were pressure, RF power, $BCl_3/Cl_2$ ratio, and Ar flow rate. Dependence of output results, such as GaAs etch rate, photoresist etch rate, etch selectivity between GaAs and photoresist, and cross-section view of via holes, on the four major parameters is discussed. A smooth via profile with non-reentrant slope was achieved for a GaAs backside process with a combination of multiple etches.

## INTRODUCTION

The GaAs backside via process has been widely used in microwave and millimeter-wave circuits for the connection of the front side circuits to the backside ground plane. This approach can reduce the ground inductance and thus can improve the RF performance of fabricated circuitry [1]. The process starts by having a front side processed and substrate thinned GaAs wafer selectively etched from the rear of the GaAs substrate so that via holes are opened up to the metal contact pads on the front side [2-6]. Subsequently deposited metal connects the front side contact pads through the side wall surface of via holes to the backside ground plane. Since the backside via process requires to etch via holes through 2 to 4 mils thick of an GaAs substrate, low etch rate of GaAs via holes becomes a bottleneck for the throughput of the backside via process. Moreover, via hole profile has a significant impact on the step coverage of the subsequent metalization process. As a result, via etch with improved throughput requires not only high GaAs etch rate but also smooth via hole profile with a non-reentrant slope.

We conducted a Design of Experiment (DOE) for GaAs via etch to obtain high etch rate and smooth via profile with a non-reentrant slope simultaneously on a four mils thick GaAs substrate. A Plasma-Therm SLR RIE reactor with four 4-inch wafers capacity was used for this experiment. The DOE consisted of four major varying parameters, which were pressure, RF power, $Cl_2/BCl_3$ ratio, and Ar flow rate.

Based on the Taguchi DOE method, it requires a minimum of 9 experiments to complete the study of dependence on those four parameters. The GaAs etch rate, photoresist etch rate, etch selectivity between GaAs and photoresist, and cross-section view of via holes were selected as the output results to be optimized in the etching process.

Dependence of output results on the four major parameters will be discussed. A smooth via profile with non-reentrant slope was achieved for a GaAs backside process with a combination of multiple etches.

## EXPERIMENT

The GaAs substrate of 25 mils thickness was initially mounted on a sapphire substrate using a wax-free process. The GaAs substrate was then thinned to 4 mils. The subsequent processes for wafer preparation were as the following:
1) Surface clean; 2) Photoresist coat and soft bake; 3) Align and develop photoresist; 4) Hard bake; 5) Descum; and 6) RIE dry etch. The dry etch was performed in a Plasma-Therm SLR 720 Shuttlelock RIE system with four 4-inch wafers capacity. The SLR substrate electrode was RF powered and its temperature was controlled by a circulating liquid medium. The RF Generator was

a 500 W solid-state 13.56 MHz generator.

The Taguchi DOE method is a simple and convenient way to explore the process window. Based on the characteristics of reactive ion etch, the Taguchi L9 method was chosen in the experiment design. The DOE consisted of four major varying parameters, which were pressure, RF power, $Cl_2/BCl_3$ ratio, and Ar flow rate. The GaAs etch rate, photoresist etch rate, etch selectivity between GaAs and photoresist, and cross-section view of via holes were selected as output results to be optimized in the etching process.

The photoresist profile also played an important role in controlling the via profile during via hole etch. Hence, photoresist etch rate and etch selectivity of GaAs against photoresist are both the critical parameters for this experiment. The AZ4620 photoresist was used for via hole patterning and the etch selectivity between GaAs and photoresist was greater than 10. Table I shows the details of process parameters used in this experiment. The RF powers were 125, 150 and 175 W, respectively. The chamber pressures were 12, 25 and 35 mtorr, respectively. The $Cl_2/BCl_3$ ratios were 20/40, 30/30 and 36/24 respectively, and the Ar gas flow rates were 0, 6, 18 sccm, respectively.

Table I: process parameters used for L9 DOE experiment

| | RF (W) | Pressure (mtorr) | $Cl_2/BCl_3$ (sccm) | Ar (sccm) |
|---|---|---|---|---|
| L1 | 125 | 12 | 20/40 | 0 |
| L2 | 125 | 25 | 30/30 | 6 |
| L3 | 125 | 35 | 36/24 | 18 |
| L4 | 150 | 12 | 30/30 | 18 |
| L5 | 150 | 25 | 36/24 | 0 |
| L6 | 150 | 35 | 20/40 | 6 |
| L7 | 175 | 12 | 36/24 | 6 |
| L8 | 175 | 25 | 20/40 | 18 |
| L9 | 175 | 35 | 30/30 | 0 |

## RESULTS AND DISCUSSION

Table II shows the details of output results as functions of RF power, pressure, $Cl_2/BCl_3$ ratio and Ar gas flow rate.

### 1) Etch Rate vs. RF Power, Pressure, $Cl_2/BCl_3$ ratio and Ar flow rate

Fig 1 shows the dependence of etch rate on RF power, pressure, $Cl_2/BCl_3$ ratio and Ar flow rate. While the RF power increased from 125 W to 175 W, the etch rate of GaAs via hole remained stable at about 0.76 μm/min. However, the etch rate increased nearly 100% as the chamber pressure increased from 15 mtorr to 35 mtorr. The via etch rate increased about 30% as $Cl_2/BCl_3$ ratio increased from 20/40 to 36/24. However by adding Ar gas into chamber, the via etch rate did not show consistent trend as we expected. These results indicate that via etch rate strongly depends on the chamber pressure and $Cl_2/BCl_3$ ratio, but less depends on RF power and Ar flow rate.

Table II: Summary of L9 DOE output results

| RF Power | Etch Rate (um/min) | Uniformity (%) | Profile Angle (degree) |
|---|---|---|---|
| 125W | 0.79 | 11.10 | 18.67 |
| 150W | 0.72 | 8.17 | 8.00 |
| 175W | 0.78 | 7.25 | 10.50 |
| **Pressure** | | | |
| 15mTorr | 0.48 | 9.75 | 12.00 |
| 25mTorr | 0.69 | 8.23 | 5.00 |
| 35mTorr | 1.01 | 9.37 | 20.67 |
| **$Cl_2/BCl_3$=** | | | |
| 20/40 | 0.66 | 7.50 | 7.00 |
| 30/30 | 0.78 | 9.40 | 13.00 |
| 36/24 | 0.88 | 10.80 | 20.50 |
| **Ar (sccm)** | | | |
| 0 | 0.77 | 6.80 | 11.00 |
| 6 | 0.91 | 8.35 | 7.50 |
| 18 | 0.65 | 11.73 | 17.67 |

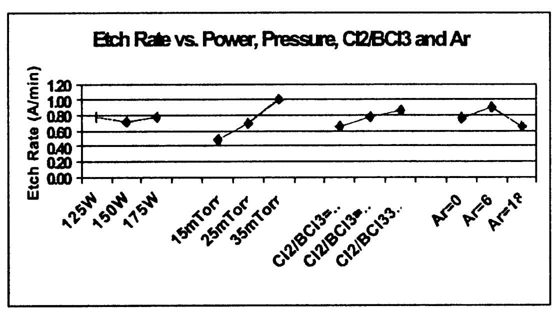


Fig 1. Dependence of via etch rate on RF power, pressure, $Cl_2/BCl_3$ ratio and Ar flow rate

### 2) Uniformity vs. RF Power, Pressure, $Cl_2/BCl_3$ ratio and Ar flow rate

Fig 2 shows the dependence of etch uniformity on RF power, pressure, $Cl_2/BCl_3$ ratio and Ar flow rate. While the RF power increased, etch uniformity of GaAs via became better. However, change of chamber pressure did not affect etch uniformity much. Etch uniformity degraded as the $Cl_2/BCl_3$ ratio increased. Adding Ar gas into chamber also degraded etch uniformity.

**3) Profile Angle vs. RF Power, Pressure, $Cl_2/BCl_3$ ratio and Ar flow rate**

The slope of via profile plays an important role on the step coverage of subsequent metalization process. As shown in Fig 3, low RF power and high chamber pressure provided better slope for via profile. The slope of via profile improved as the $Cl_2/BCl_3$ ratio increased due to the increased etch isotropy resulting from chemical reactive $Cl_2$ gas.

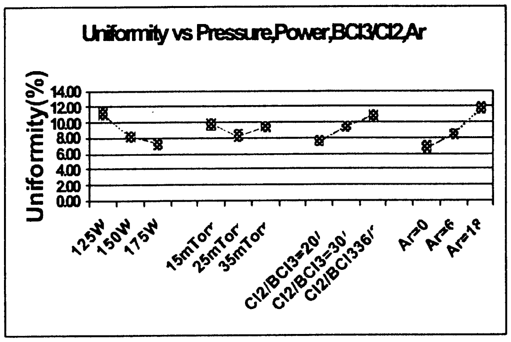


Fig 2. Dependence of etch uniformity on RF power, pressure, $Cl_2/BCl_3$ ratio and Ar flow rate

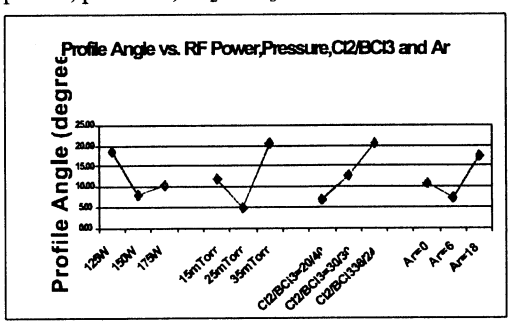


Fig 3. Dependence of slope angle on RF power, pressure, $Cl_2/BCl_3$ ratio and Ar flow rate

**4) Multiple Steps Etch**

The process window was defined after finishing the L9 DOE experiment. However, no single process step could produce an acceptable via profile for the subsequent metalization process. For instance, increasing the pressure could increase the etch rate but would degrade the slope angle. Increasing the $Cl_2/BCl_3$ ratio would increase the etch rate but would adversely affect the etch uniformity and slope angle. An etch process should have three major steps based on the widely used etch recipes in silicon industry: breakthough, main etch and overetch. Breakthough emphasizes on ion bombardment, which is used to etch the top and hard layer. It is common to use high RF power for breakthough process. However, high RF power results in high etch rate for photoresist. Thus breakthough is limited to a short time period. Main etch will etch most of the film after breakthough, with high etch rate and high etch selectivity against photoreisist. Overetch will then follow to etch the residue. In order to achieve a smooth via profile, we chose three recipes from the nine experiments and combined these three different etch recipes into one main etch step. The breakthough step still served to provide high etch rate and vertical profile for the surface layer. With the combination of multiple etches, the main etch step provided high etch rate, proper isotropic etch and good etch selectivity between GaAs and photoresist. The final overetch step provided low etch rate for smoothing the via profile. A smooth via profile with non-reentrant slop was achieved with such a combination of multiple etches. Figs.4, 5, 6 and 7 show the SEM cross section views of the via profile with nominal via size of 30, 40, 50 and 60 μm, respectively.

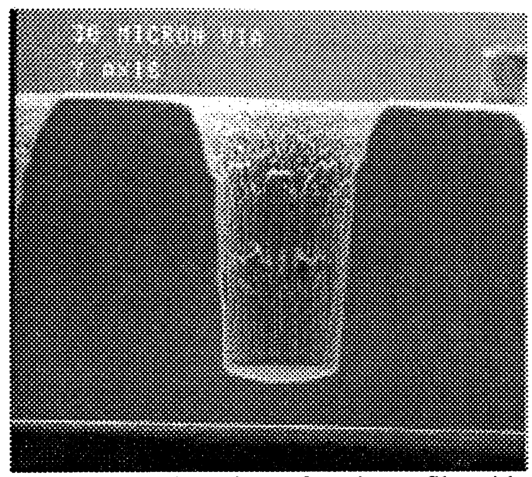

Fig.4: Cross-section view of a via profile with a nominal via size of 30 μm

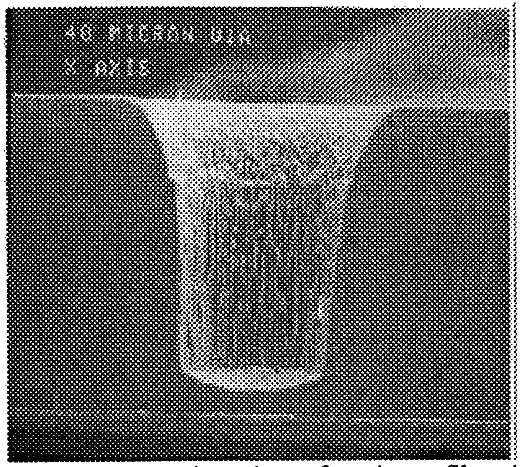


Fig.5: Cross-section view of a via profile with a nominal via size of 40 µm

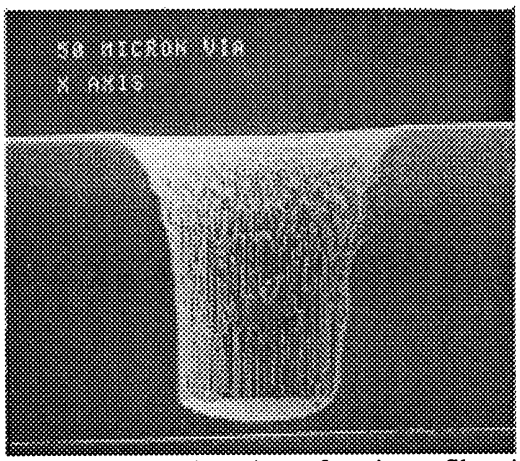


Fig.6: Cross-section view of a via profile with a nominal via size of 50 µm

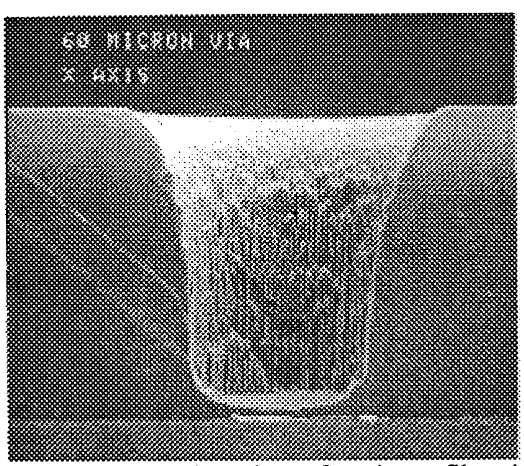


Fig.7: Cross-section view of a via profile with a nominal via size of 60 µm

## CONCLUSIONS

We designed an L9 DOE experiment based on Taguchi method to investigate the GaAs via characteristics. The via etch rate was found strongly dependent on the pressure and $Cl_2/BCl_3$ ratio, but less dependent on the RF power and Ar flow rate. The etch uniformity was found strongly dependent on RF power, $BCl_3/Cl_2$ ratio and Ar flow rate, but less dependent on the pressure. The via slope angle strongly depended on the $BCl_3/Cl_2$ ratio due to increased etch isotropy from reactive $Cl_2$ gas. A smooth via profile was achieved with a combination of multiple etch steps.

## ACKNOWLEDGEMENTS

We wish to thank Dr. Diana Tsou for reviewing the manuscript and Tom Quach for wafer preparation at GCS.

## REFERENCES

1. L. A. D'Asaro, A. D. Butherus, J. B. Dilorenzo, D. E. Inglesias, and S. H. Wemple, *Proceedings of GaAs and Related Compound,* AIP Conf. Proc. No. 56 ( AIP, New York, 1981 ), p. 267.
2. A. E. Geissberger and P. R. Clayton, J. Vac. Sci. Technol. A 3, 863 (1985).
3. T. E. Kazior, B. I. Patel, and B. J. Guerin, *Proceedings of the 13$^{th}$ State-of-the-Art Program on Compound Semiconductors,* edited by H. Lee, O. Ueda, P. Clechet, and J. M. Woodall (Electrochemical Society, Pennington, NJ, 1991), Vol.91-1, p. 299.
4. L. G. Hipwood and P. N. Wood, "Dry etching of though substrate via holes for GaAs MMICs," *J. Vac. Sci. Technol*.,vol. B3, pp. 395-397, 1985
5. P. Daga, K Frickle, and H. L. Hartnagel," Improved via hole etching for source grounding of microwave MESFET, " *J. Electrochem. Soc.*, vol. 133, pp. 2660-2661, 1987
6. Edward Y. Chang, Rao M. Nagarajan, Charles J. Kryzak, and Krishna P. Pande, " Hybrid dry-wet chemical etching process for via hole for Gallium Arsenide MMIC manufacturing," *IEEE Transactions on Semiconductor Manufacturing*, vol 1. No. 4, Nov. 1988