FAX 3526461182 MAT SCI ENG 002

SAND98-2719J Appl. Surf. Sci

INDUCTIVELY COUPLED PLASMA ETCHING OF III-V SEMICONDUCTORS IN BCl_3-BASED CHEMISTRIES : PART I : GaAs, GaN, GaP, GaSb AND AlGaAs

T. MAEDA[1]*, J. W. LEE[2], R. J. SHUL[3], J. HAN[3], J. HONG[1], E. S. LAMBERS[1], S. J. PEARTON[1], C. R. ABERNATHY[1] AND W. S. HOBSON[4]

[1] Department of Materials Science and Engineering, University of Florida, Gainesville, FL 32611

[2] Plasma-Therm, Inc., St. Petersburg, FL 33716

[3] Sandia National Laboratories, Albuquerque, NM 87185

[4] Bell Laboratories, Lucent Technologies, Murray Hill, NJ 07974

* Permanent address: Fujitsu Laboratories Ltd., Kanagawa, Japan, maeda@kahan.flab.fujitsu.co.jp

RECEIVED
DEC 10 1998
OSTI

ABSTRACT

BCl_3, with addition of N_2, Ar or H_2, is found to provide smooth anisotropic pattern transfer in GaAs, GaN, GaP, GaSb and AlGaAs under Inductively Coupled Plasma conditions. Maxima in the etch rates for these materials are observed at 33% N_2 or 87% H_2 (by flow) addition to BCl_3, whereas Ar addition does not show this behavior. Maximum etch rates are typically much higher for GaAs, GaP, GaSb and AlGaAs (~1.2 μm/min) than for GaN (~0.3 μm/min) due to the higher bond energies of the latter. The rates decrease at higher pressure, saturate with source power (ion flux) and tend to show maxima with chuck power (ion energy). The etched surfaces remain stoichiometric over a broad range of plasma conditions.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, make any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

INTRODUCTION

There are a wide variety of electronic and photonic devices fabricated from compound semiconductors that require precise pattern transfer that maintains the stoichiometry of the binary or ternary material[1-7]. The GaAs/AlGaAs system is used for high electron mobility transistors (HEMTs), heterojunction bipolar transistors (HBTs), 0.98 μm fiber pump lasers and red light-emitting diodes (LEDs), while GaP is important for high power LEDs[8]. GaN and related alloys are attracting tremendous interest for blue/green/UV laser diodes and LEDs and high temperature electronics[9]. In particular there are no simple wet etch solutions for GaN, placing emphasis on the development of dry etch processes[10].

High density plasma conditions have been reported to provide fast etch rates for GaAs/AlGaAs, GaP and GaN using Cl_2 (with additions of Ar or N_2) or BCl_3 (with additions of Ar or N_2) . Most of this work has focused on Electron Cyclotron Resonance (ECR) sources[11-17], but a few reports have appeared dealing with Inductively Coupled Plasmas (ICP)[18-20]. There are compelling reasons to focus on the latter source, because of its superior uniformity and absence of expensive electromagnets that require active cooling[13]. In particular, BCl_3-based discharges are of primary interest because of the ability of BCl_3 to remove the native oxides on compound semiconductors and hence to provide a wide process window.

In this paper we report on a parametric study of BCl_3/N_2, BCl_3/Ar and BCl_3/H_2 ICP etching of GaAs, AlGaAs, GaP, GaSb and GaN. The etch products for these materials, namely $GaCl_x$, $AlCl_x$, $AsCl_x$, PCl_x, $SbCl_x$ and NCl_x or N_2 (the nitrogen products are not yet established) are quite volatile, and thus high etch rates would be expected. In part II of this paper we report results of similar experiments on In-based compound semiconductors, where the $InCl_x$ products are much less volatile than their $GaCl_x$ counterparts. We find that BCl_3-based chemistries under ICP conditions are universal etchants for III-V semiconductors. This means that the CH_4/H_2 chemistry, popular in the past under reactive ion etching conditions, is not necessary when high density reactors are employed. The main advantage of this situation is the absence of hydrogen passivation effects, which reduce the effective doping in the near-surface of device structures.

EXPERIMENTAL

The following samples were employed in this study: semi-insulating undoped (100) GaAs and undoped (100) GaSb substrates grown by the Czochralski process; nominally undoped (p ~ 10^{16} cm^{-3}) $Al_{0.25}Ga_{0.75}As$ grown by either Metal Organic Molecular Beam Epitaxy[21] or Metal Organic Chemical Vapor Deposition (MOCVD)[22] at 550 - 650°C on semi-insulating GaAs substrates; nominally undoped GaP substrates (n ~ 10^{15} cm^{-3}) grown by the Czochralski process and nominally undoped (n ~ 10^{17} cm^{-3}) GaN grown on Al_2O_3 substrates by MOCVD at 1040°C. All samples were patterned with a Shipley 4330 photoresist.

Experiments were performed in a Plasma Therm 790 System which utilizes a He backside-cooled, rf (13.56MHz)-powered sample chuck and a 2 MHz, 1500 W ICP source[13, 18]. The total gas load was held constant at 15 standard cubic centimeters per minute (sccm). Electronic grade BCl_3, N_2, Ar or H_2 were injected directly into the ICP source. The process pressure was varied from 2 - 15 mTorr, the rf chuck power from 50 - 350 W (corresponding to dc biases of approximately -100 to -680 V) and the source power from 0 - 1000 W. Etch depths were measured by stylus profilometry of the features after removal of the photoresist, while etch anisotropy was examined by scanning electron microscopy (SEM). Surface morphology was quantified by atomic force microscopy (AFM) and near-surface stoichiometry was examined by Auger Electron Spectroscopy (AES).

RESULTS AND DISCUSSION

Figure 1 (top) shows material etch rates as a function of discharge composition in BCl_3/N_2 at fixed pressure (2 mTorr), source power (500 W) and dc self-bias (-250 V). The rates are a maximum at ~33% N_2 addition. Ren et al.[7] and Shul et al. [1, 5] reported similar results for ECR or ICP BCl_3/N_2 etching of InP, GaAs and GaP. In the former work, maximum emission intensities for atomic chlorine was found at 25% N_2 addition, which provides an explanation for the etch rate behavior through the enhanced dissociation of BCl_3 to provide reactive atomic chlorine neutrals. While the rates for GaAs, AlGaAs and GaP are relatively close, those for GaN are about a factor of 4 lower at higher BCl_3 percentages. Since the products for GaN are equally as volatile as those of the other materials, this suggests the limiting step is product formation because of the higher bond energy of GaN (8.92 eV/atom compared to 6.52 eV/atom for GaAs)[23]. Note that the rates for GaAs, AlGaAs and GaP can be controlled over a very wide range (a factor of approximately sixty) at fixed bias, pressure and source power by simply varying the BCl_3 percentage in the discharge. Etch yields are shown at the bottom of Figure 1. The calculations for etch yield will be described elsewhere[24],but in brief,we define the etch yield as the number of substrate atoms per incident ion at the energy employed in these experiments(which is about 274 eV,based on the dc self-bias of about 250 V,and the plasma potential of about 24 eV).The ion flux is determined from a semi-empirical calculation similar to that of Stewart et al.[25]

We can contrast the results with BCl_3/N_2 to those obtained with BCl_3/Ar or BCl_3/H_2 (Figure 2). In the latter case we see an initial rise in etch rate as BCl_3 is added to H_2 due to the presence of chlorine neutrals that form more volatile etch products for the group III elements compared to hydrogen, but beyond ~10% BCl_3 there is a broad range of plasma conditions where the etch rates are low. Optical emission spectroscopy and mass spectroscopy of the discharges under these conditions shows there is virtually no atomic chlorine, due to recombination to form HCl. Thus, both active etchants (Cl and H) are reduced in concentration, leading to reduced etch rates. These rates tend to rise again for pure BCl_3 plasmas due to the increase in available atomic chlorine. For BCl_3/Ar there is no parasitic scavenging of the active species; for GaAs, AlGaAs and GaP this leads to a general increase in rates as BCl_3 is added and a reduced etch rate for pure BCl_3 due to the reduced ion-assisted component of the etch mechanism. For GaN the etch rate decreases beyond relatively low BCl_3 percentages for the same reason; the difference is due to the fact that GaN has a high bond energy and requires a strong ion-assisted etch component.

The effect of process pressure at fixed dc chuck bias is shown in Figure 3. The general trend is for a drastic fall-off in etch rates above 5 mTorr as chlorine neutrals recombine with BCl_x fragments. This was confirmed by optical emission spectroscopy, which showed the chlorine atom lines between 726 - 775 nm decreasing to undetectable levels. For BCl_3/N_2 discharges the rates peak in the range 5 - 10 mTorr for materials other than GaN, where there is a good correlation with the atomic chlorine emission intensity maxima.

As ICP source power is increased, producing higher ion fluxes, there is a general tendency for etch rates to increase (Figure 4). The top two sections of this figure show results for two different BCl_3/N_2 conditions, at fixed dc chuck bias. The etch rates either saturate or start to decrease at the highest source powers, which is commonly observed in ECR etching and is usually ascribed to sputter desorption of the active species before they can react with the sample surface. At fixed rf chuck power (bottom of the figure), where dc chuck bias will decrease as source power increases (from -250 V at zero source power to -105 V at 1000 W), a similar trend is observed. This data is related to that shown in Figure 5, which displays etch rates as a function of either rf chuck power (which increases chuck bias) or chuck bias for fixed source power and several pressures. Since this bias controls the energy of ions impacting the sample surface[26], there will be a general tendency for increased etch rates until the point at which reactants are desorbed by ion-assistance before they form etch products. Note that maximum etch rates exceeding 1 μm/min for GaAs, AlGaAs, GaP and GaSb and 0.3 μm/min for GaN are obtained in BCl_3/N_2 at 2 mTorr and moderate source power and chuck bias. These are good conditions for production of through-wafer via holes in GaAs, GaP or GaSb substrates for power transistor applications.

As expected for low pressure operation with ion-assisted etch chemistries, the pattern transfer was smooth and anisotropic. Figure 6 show SEM micrographs of features etched into GaAs (top). AlGaAs (center) or GaN (bottom) using a $10BCl_3/5Ar$ discharge. The photoresist mask has been removed in all cases, using acetone. No other post etch cleaning steps were performed. Note that the etch depth on the AlGaAs sample is much larger than for the other samples,and thus the surface appears rougher.Similarly good results were obtained with $10BCl_3/5N_2$ discharges, as shown in Figure 7 for GaAs (top left), AlGaAs (bottom left) and GaN (top and bottom right). The addition of N_2 to BCl_3 chemistries typically enhances photoresist etch rates and can provide sidewall protection through redeposition, but for these Ga-based materials there does not appear to be significant undercut in any case.

AFM imaging of the etched surfaces also provided confirmation of the high quality of the pattern transfer. Figure 8 shows the root-mean-square (RMS) roughness for a fixed etch depth of one micron, measured over 5 x 5 μm^2 regions of GaAs and AlGaAs surfaces etched at fixed source power (500 W), dc bias (-250 V) and pressure (2 mTorr) in either BCl_3/N_2 or BCl_3/Ar discharges. As-grown samples typically show RMS values in the range 0.2 - 0.8 nm, and therefore the ICP etching process is not producing any significant surface roughening.

In III-V dry etching, a smooth surface essentially guarantees that it is also stoichiometric[2, 4], i.e. there has been equi-rate removal of the group III and group V etch products. Figure 9 shows AES surface scans of GaAs after etching in $5BCl_3/10Ar$ (top left), $10BCl_3/5Ar$ (bottom left),

$5BCl_3/10N_2$ (top right) or $10BCl_3/5N_2$ (bottom right). There is oxygen present from the native oxide that grows during transfer of the sample from the reactor to the AES system, and adventitious carbon from the atmospheric exposure. The residual chlorine is near the detection limit of AES (≤ 1% at %). The etched surface are therefore chemically quite clean, and remain stoichiometric, as shown in the depth profiles of Figure 10. The Ga/As ratio remains constant even at the surface, indicating that both are being removed at the same rate during the etching process.

SUMMARY AND CONCLUSIONS

Under conventional reactive ion etching conditions, BCl_3 has been found to be an attractive plasma chemistry for patterning GaAs and related compounds because of its ability to getter water vapor and readily remove the native oxides on these materials. The results from this current work on ICP etching using BCl_3-based mixtures show that it is also an attractive choice under high density conditions. The addition of N_2 at around 33% by flow produces a strong enhancement in etch rates due to dissociation of the BCl_3 and consequently higher atomic chlorine density. Under these conditions the etch rates for GaAs, AlGaAs, GaSb and GaP are 4 - 8 times higher than with BCl_3/Ar or BCl_3/H_2 discharges of the same relative BCl_3 composition. The rates are found to generally decrease with pressure and to generally increase with both ion flux and ion energy. In the latter two cases the rates may saturate or even decrease at very high fluxes or energies due to reactant desorption. The pattern transfer is smooth and anisotropic over a broad range of plasma conditions.

ACKNOWLEDGMENTS

T. M. would like to thank Drs. H. Ishikawa, H. Nishi, O. Ueda, M. Takikawa and H. Tanaka for their encouragement and support. The work at UF is partially supported by a DOD MURI administered by AFOSR (H C DeLong), Contract No F49620-96-1-0026. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed-Martin Company, for the US Dept. of Energy under contract No DE-AC04-94AL85000.

REFERENCES

1. R. J. Shul, G. B. McClellan, R. D. Briggs, D. J. Rieger, S. J. Pearton, C. R. Abernathy, J. W. Lee, C. Constantine and C. Barratt, J. Vac. Sci. Technol. **A15**, 633 (1997).
2. R. J. Shul, A. G. Baca, R. D. Briggs, G. B. McClellan, S. J. Pearton and C. Constantine, Proc. Electrochem. Soc. **96-15**, 84 (1996).
3. J. Asmussen, Jr., T. A. Grotjohn, P. Mak and M. A. Perrin, IEEE Trans. Plasma **25**, 1196 (1997).
4. S. J. Pearton and F. Ren, J. Mater. Sci. Mater. Electron. **5**, 1 (1994).
5. R. J. Shul, A. G. Baca, D. J. Rieger, H. Han, S. J. Pearton and F. Ren, Mater. Res. Soc. Symp. Proc. 421, **245** (1996).
6. S. Thomas III, K. K. Ko and S. W. Pang, J. Vac. Sci. Technol. **A13**, 894 (1995).
7. F. Ren, W. S. Hobson, J. R. Lothian, J. Lopata, J. A. Caballero, S. J. Pearton and M. W. Cole, Appl. Phys. Lett, **67**, 2497 (1995).
8. GaAs : Materials Devices and Circuits, ed M. Howes and D. V. Morgan, (Wiley and Sons, NY, 1985).
9. see for example, "The Blue Laser Diode", S. Nakamura and G. Fasol, (Springer-Verlag, Heidelberg, 1997).
10. see for example, S. J. Pearton and R. J. Shul, in GaN, vol I, ed. J. I. Pankove and T. D. Moustakas, (Academic Press, San Diego, 1998).
11. R. J. Shul, A. J. Howard, C. B. Vartuli, P. A. Barnes and S. Weng, J. Vac. Sci. Technol. **A14**, 1102 (1996).
12. V. J. Law, M. Tewordt, S. G. Ingram and G. A. C. Jones, J. Vac. Sci. Technol. **B9**, 1449 (1991).
13. C. Constantine, D. Johnson, C. Barratt, R. J. Shul, G. B. McClellan, R. D. Briggs, D. J. Rieger, R. F. Karlicek, Jr., J. W. Lee and S. J. Pearton, Mat. Res. Soc. Symp. Proc. **42**, 431 (1996).
14. H. P. Gillis, D. A. Choutov and K. P. Martin, J. Mater. **48**, 50 (1996).
15. A. T. Ping, A. C. Schmitz, I. Adesida, M. A. Khan, Q. Chen and J. W. Yang, J. Electron. Mater. **26**, 266 (1997).

16. R. J. Shul, S. D. Kilcogne, M. H. Crawford, J. E. Parmeter, C. B. Varbuli, C. R. Abernathy and S. J. Pearton, Appl. Phys. Lett. **66**, 1761 (1995).

17. M. E. Lin, Z. F. Fan, Z. Ma, L. H. Allen and H. Mortoc, Appl. Phys. Lett. **64**, 887 (1994).

18. R. J. Shul, G. B. McClellan, S. A. Casalnuovo, D. J. Rieger, S. J. Pearton, C. Constantine, C. Barratt, R. F. Karlicek, Jr., C. Tran and M. Schurmann, Appl. Phys. Lett. **69**, 1119 (1996).

19. S. A. Smith, C. A. Wolden, M. D. Bremser, A. D. Hanser, R. F. Davis and W. V. Lampert, Appl. Phys. Lett. **71** 3631 (1997).

20. H. Cho, J. Hong, T. Maeda, S. M. Donovan, J. D. MacKenzie, C. R. Abernathy, S. J. Pearton, R. J. Shul and J. Han, MRS Int. J. Nitride Semiconductor Res. 3 5 (1998).

21. C. R. Abernathy, Mat. Sci. Eng. Rep. **R14** 203 (1995).

22. W. S. Hobson, Mat. Res. Soc. Symp. Proc. **300** 75 (1993)

23. Handbook Series on Semiconductor Parameters, ed. M. Levinshtein, S. Rumyantsev and M. Shur, (World Scientific, Singapore, 1996).

24. Y. B. Hahn, et al., to be published.

25. R.J.Stewart,P.Vitello and D.B.Graves,J.Vac.Sci.Tech.B 12 478 (1994).

26. see for example, High Density Plasma Sources, ed. O. Popov, (Noyes Publications, Park Ridge, NJ, 1996)

Figure Captions

Figure 1. Etch rate (top) and etch yield (bottom) of Ga-based semiconductors as a function of BCl_3 percentage in BCl_3/N_2 ICP discharges at fixed source power (500 W), pressure (2 mTorr) and dc self-bias (-250 V).

Figure 2. Etch rates of Ga-based semiconductors as a function of BCl_3 percentage in BCl_3/Ar or BCl_3/H_2 ICP discharges at fixed source power (500 W), pressure (2 mTorr) and dc self-bias (-250 V).

Figure 3. Etch rates of Ga-based semiconductors as a function of pressure in $10BCl_3/5N_2$ or $10BCl_3$/5Ar ICP discharges at fixed source power (500 W) and dc self-bias (-250 V).

Figure 4. Etch rates of Ga-based semiconductors as a function of ICP source power in BCl_3/N_2 or BCl_3/Ar ICP discharges of different composition.

Figure 5. Etch rates of Ga-based semiconductors as a function of rf chuck power or dc chuck bias in BCl_3/Ar or BCl_3/N_2 ICP discharges at fixed source power (500 W) and pressures of 2 - 5 mTorr.

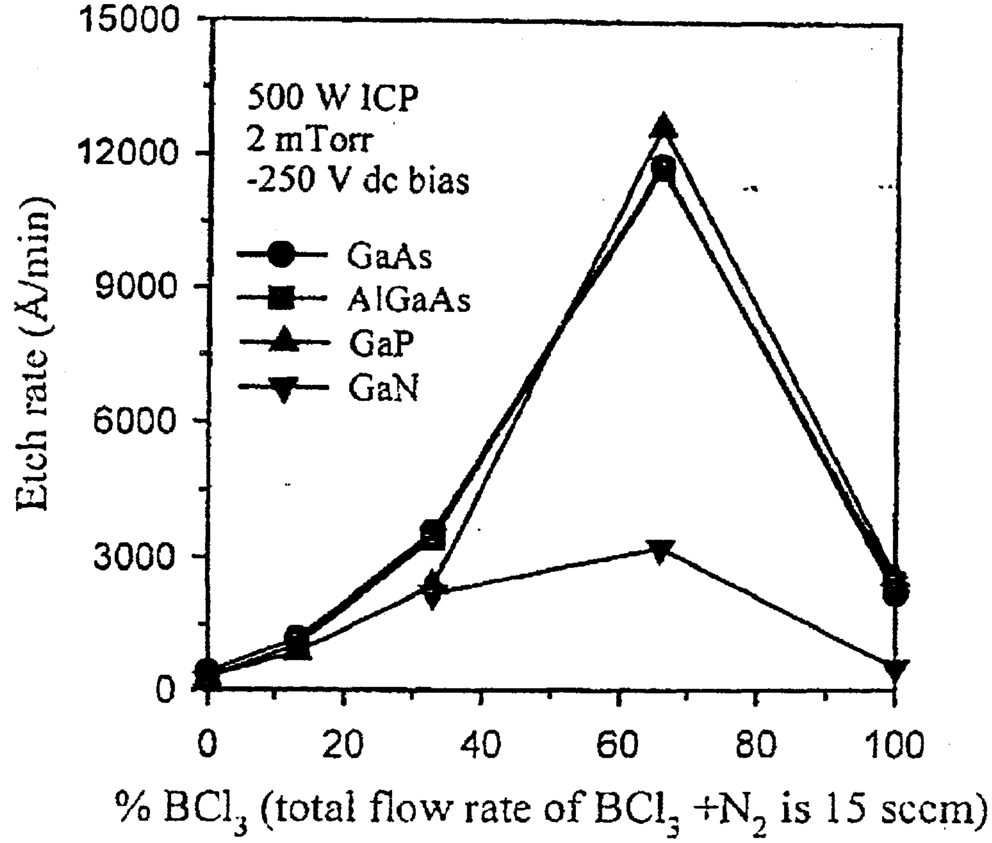
Figure 6. SEM micrographs of features etched into GaAs (top), AlGaAs (center) and GaN (bottom) with $10BCl_3$/5Ar, 2 mTorr, 500 W source power, 250 W rf chuck power discharges. The photoresist masks have been removed in all cases.

Figure 7. SEM micrographs of features etched into GaAs (top left), AlGaAs (bottom left) or GaN (top and bottom right) with $10BCl_3/5N_2$, 2 mTorr, 500 W source power, 250 W rf chuck power discharges. The photoresist masks have been removed in all cases.

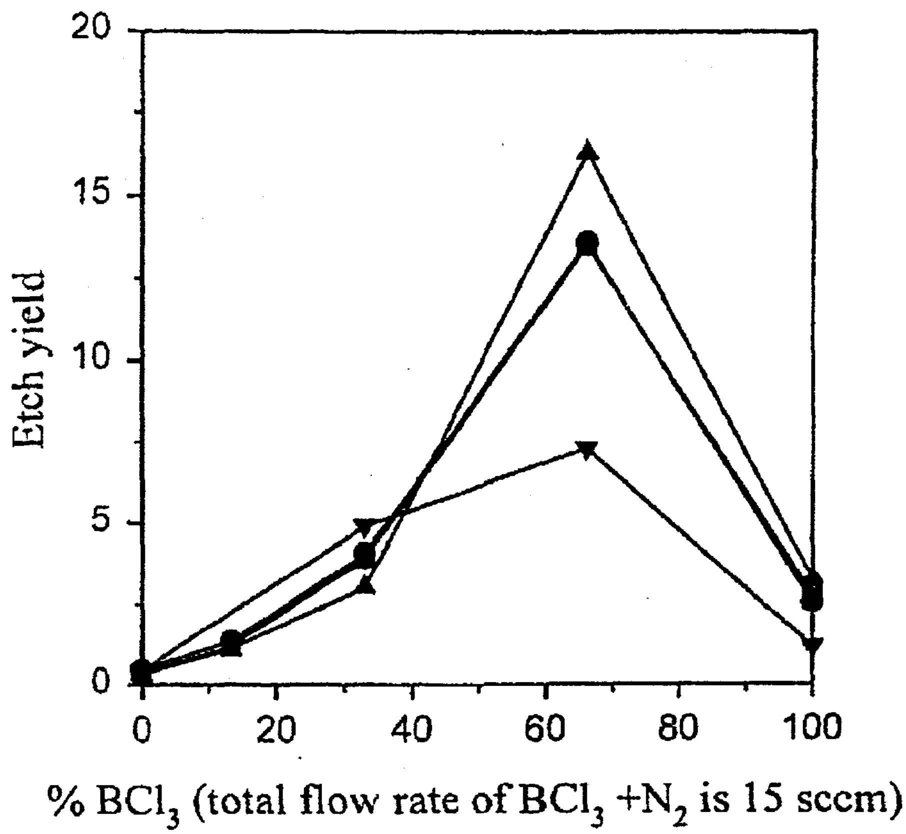
Figure 8. RMS roughness measured by AFM for GaAs and AlGaAs etched with BCl_3/N_2 or BCl_3/Ar ICP discharges as a function of discharge composition at fixed source power (500 W), pressure (2 mTorr) and dc self-bias (-250 V).

Figure 9. AES surface scans of GaAs etched in 2 mTorr, 500 W source power, -250 V dc bias discharges of $5BCl_3/10Ar$ (top left), $10BCl_3/5Ar$ (bottom left), $5BCl_3/10N_2$ (top right) or $10BCl_3/5N_2$ (bottom right).

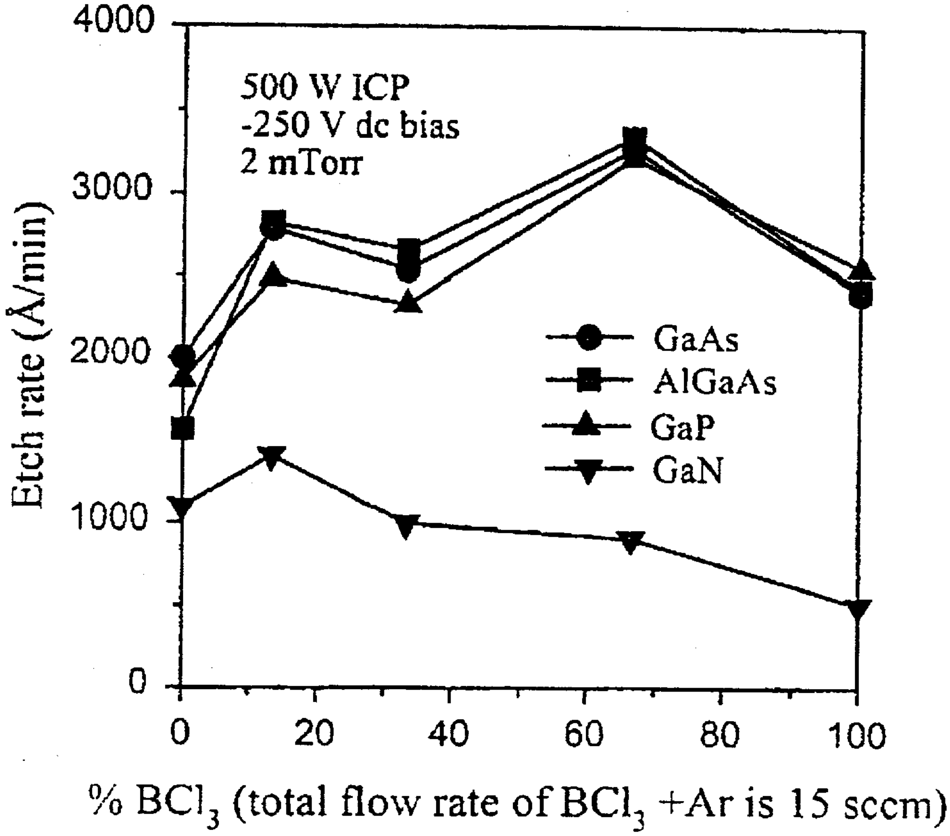
Figure 10. AES depth profiles of GaAs etched in 2 mTorr, 500 W source power, -250 V dc bias discharges of $10BCl_3/5Ar$ (top), $5BCl_3/10N_2$ (center), or $10BCl_3/5N_2$ (bottom).

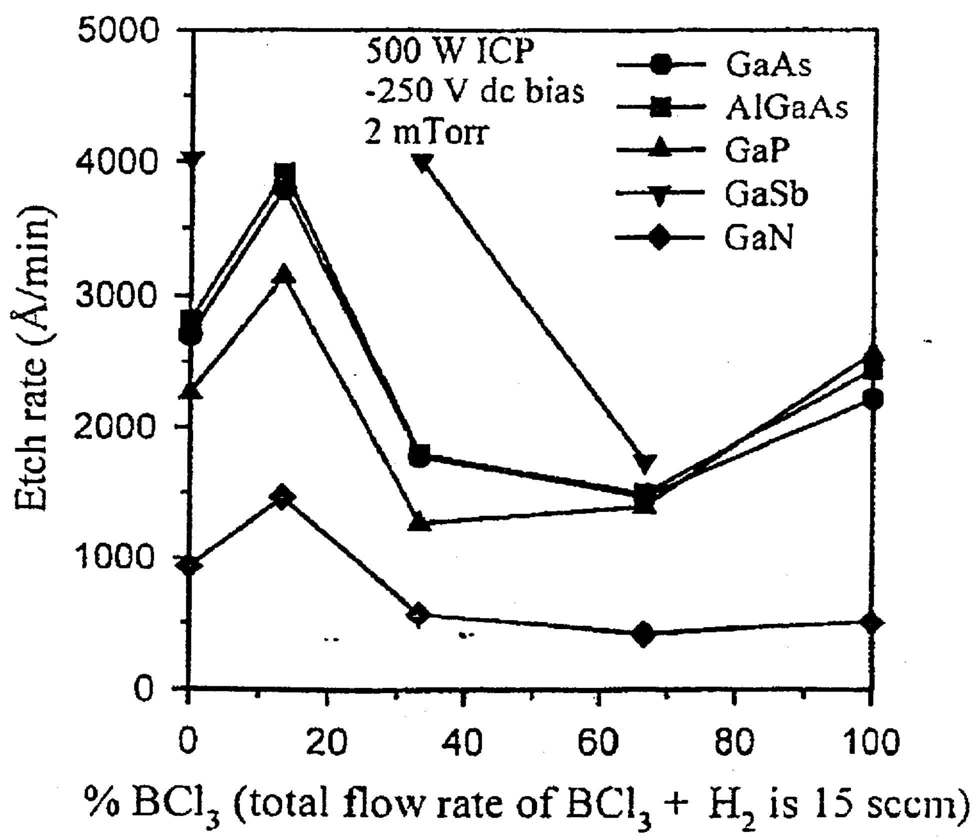


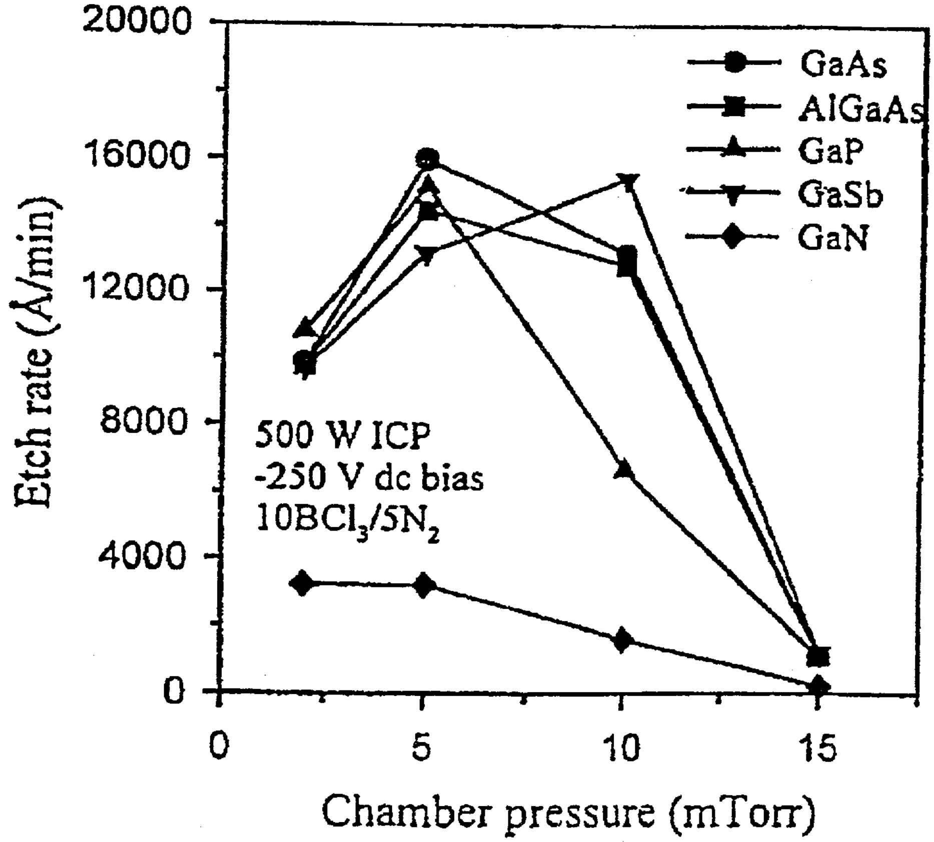
500 W ICP
2 mTorr
-250 V dc bias
GaAs
AlGaAs
GaP
GaN
Etch rate (Å/min)
15000
12000
9000
6000
3000
0
0
20
40
60
80
100
% BCl3 (total flow rate of BCl3 +N2 is 15 sccm)

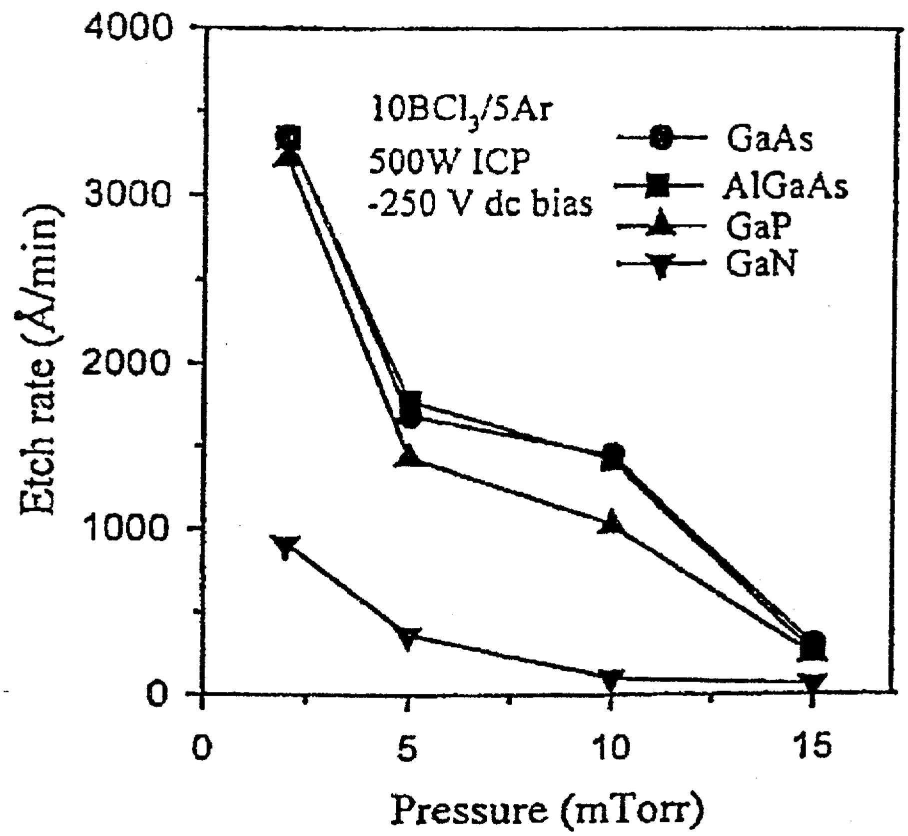


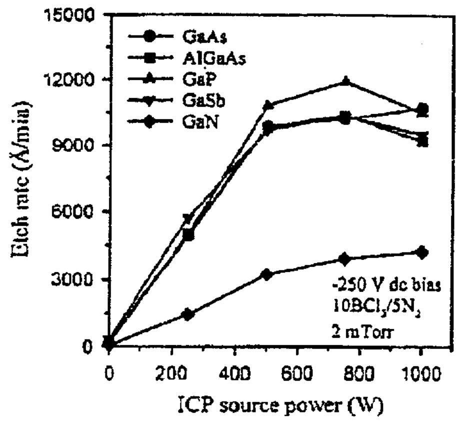
Etch yield
20
15
10
5
0
0
20
40
60
80
100
% BCl3 (total flow rate of BCl3 +N2 is 15 sccm)

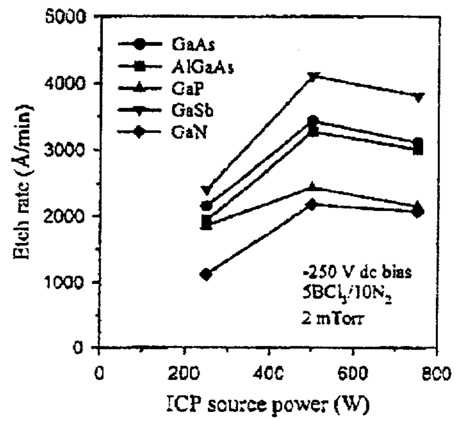

500 W ICP
-250 V dc bias
2 mTorr
GaAs
AlGaAs
GaP
GaN
Etch rate (Å/min)
% BCl3 (total flow rate of BCl3 +Ar is 15 sccm)

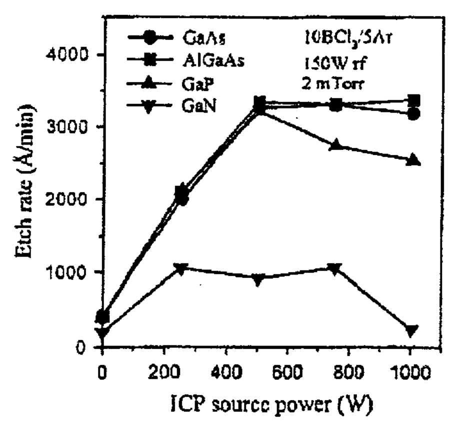

500 W ICP
-250 V dc bias
2 mTorr
GaAs
AlGaAs
GaP
GaSb
GaN
Etch rate (Å/min)
% BCl3 (total flow rate of BCl3 + H2 is 15 sccm)

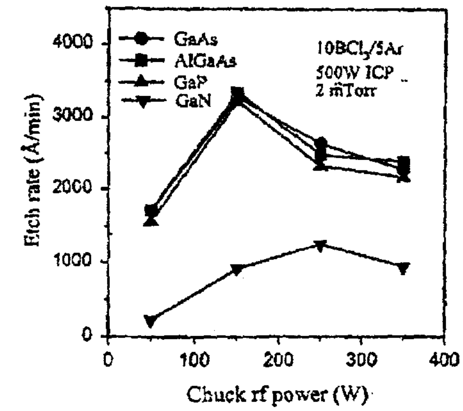

GaAs
AlGaAs
GaP
GaSb
GaN
500 W ICP
-250 V dc bias
10BCl$_3$/5N$_2$
Etch rate (Å/min)
Chamber pressure (mTorr)
20000
16000
12000
8000
4000
0
0
5
10
15

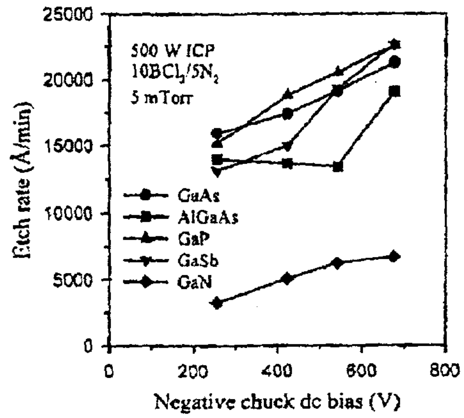

10BCl$_3$/5Ar
500W ICP
-250 V dc bias
GaAs
AlGaAs
GaP
GaN
Etch rate (Å/min)
Pressure (mTorr)
4000
3000
2000
1000
0
0
5
10
15

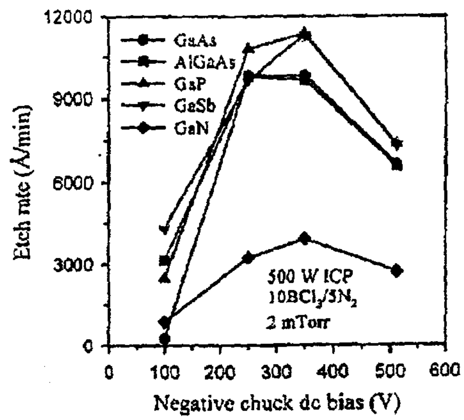

15000
12000
9000
6000
3000
0
Etch rate (Å/min)
GaAs
AlGaAs
GaP
GaSb
GaN
-250 V dc bias
$10BCl_3/5N_2$
2 mTorr
0 200 400 600 800 1000
ICP source power (W)


5000
4000
3000
2000
1000
0
Etch rate (Å/min)
GaAs
AlGaAs
GaP
GaSb
GaN
-250 V dc bias
$5BCl_3/10N_2$
2 mTorr
0 200 400 600 800
ICP source power (W)

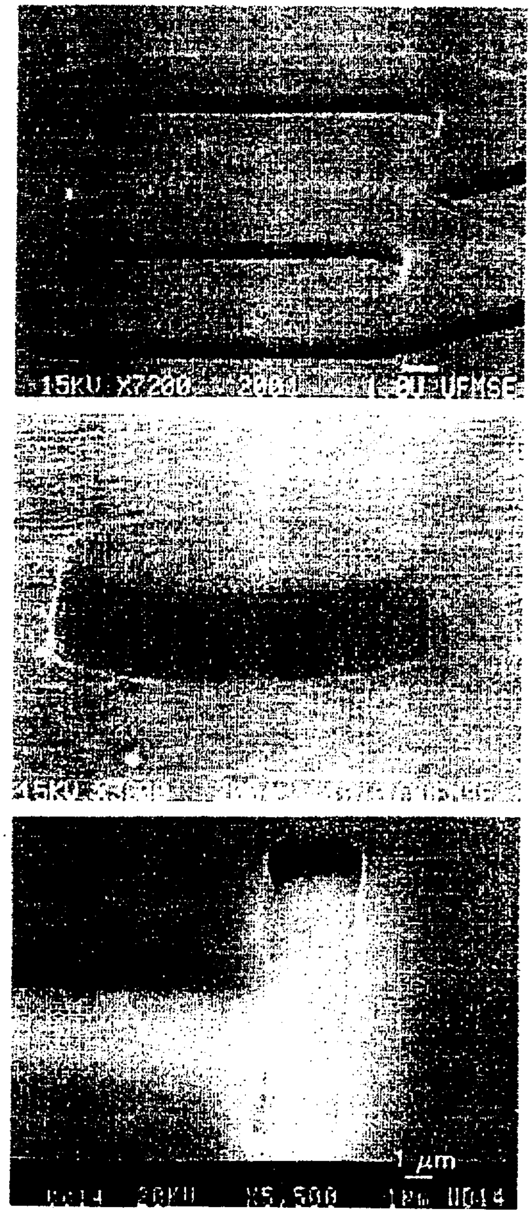

4000
3000
2000
1000
0
Etch rate (Å/min)
GaAs
AlGaAs
GaP
GaN
$10BCl_3/5Ar$
150W rf
2 mTorr
0 200 400 600 800 1000
ICP source power (W)

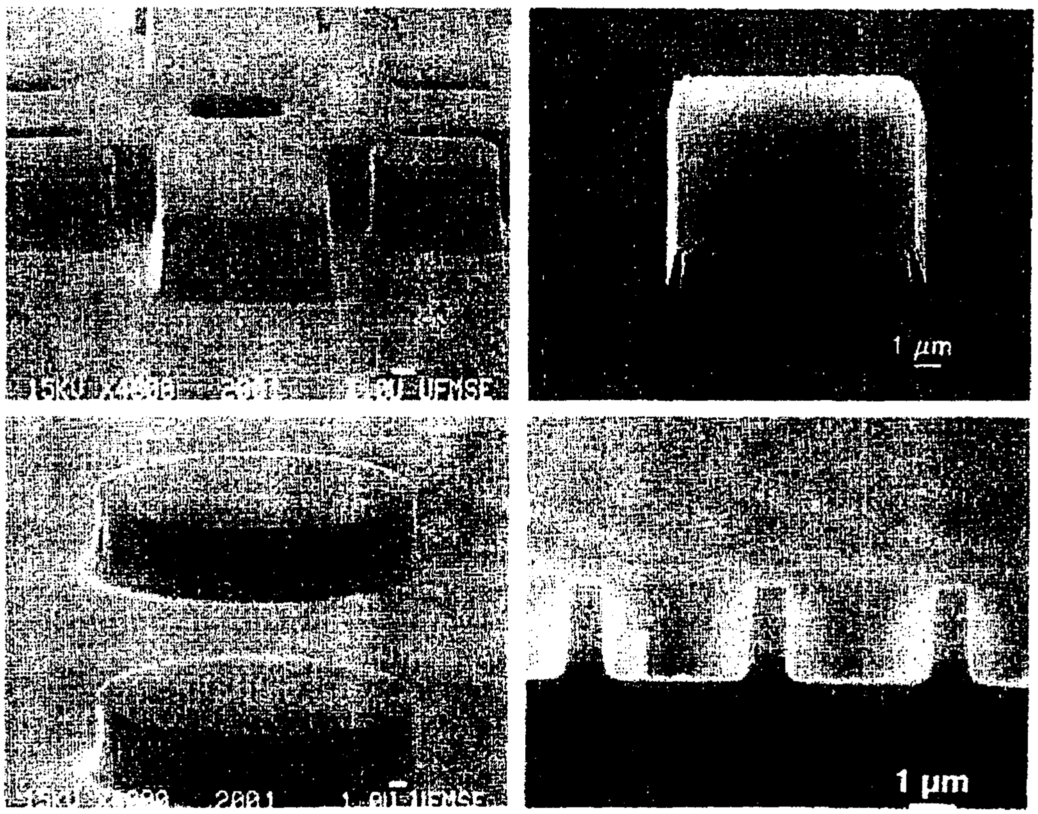

GaAs
AlGaAs
GaP
GaN
10BCl$_3$/5Ar
500W ICP
2 mTorr
Etch rate (Å/min)
0
1000
2000
3000
4000
0
100
200
300
400
Chuck rf power (W)

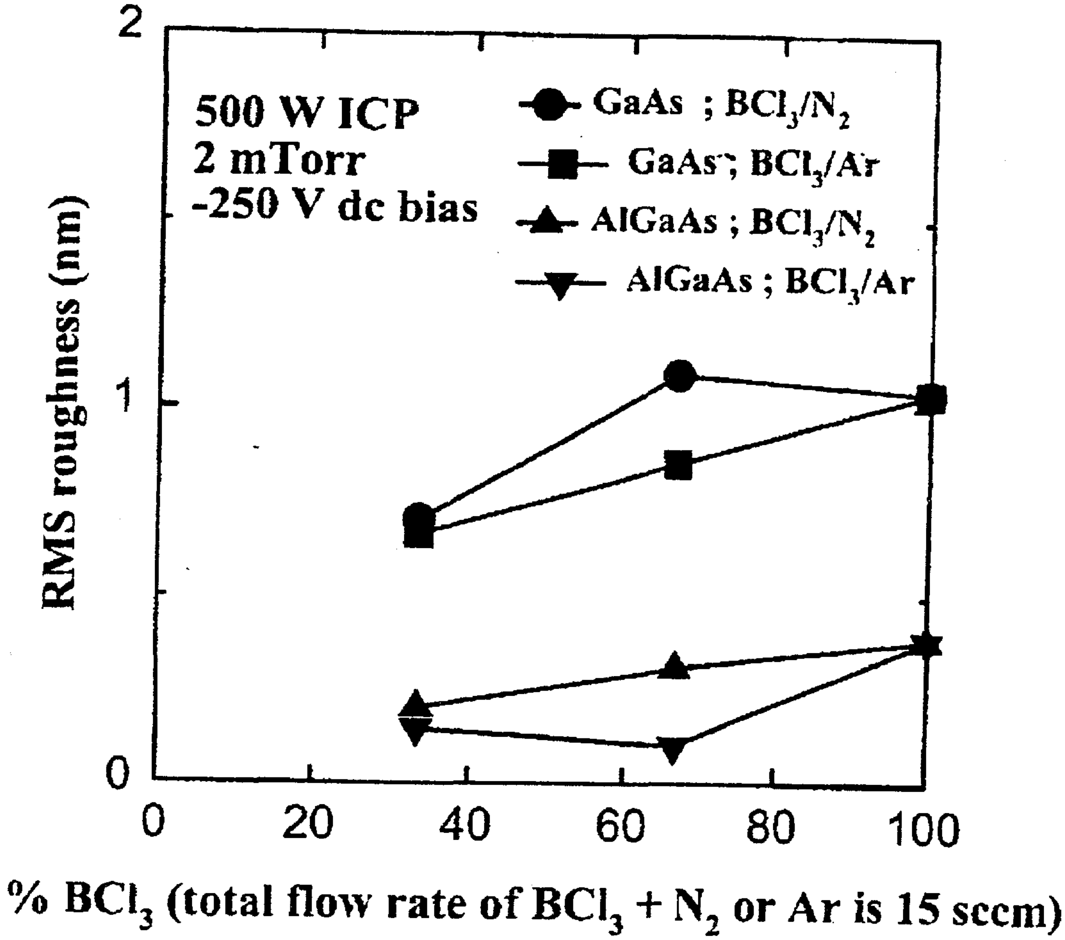

500 W ICP
10BCl$_3$/5N$_2$
5 mTorr
GaAs
AlGaAs
GaP
GaSb
GaN
Etch rate (Å/min)
0
5000
10000
15000
20000
25000
0
200
400
600
800
Negative chuck dc bias (V)

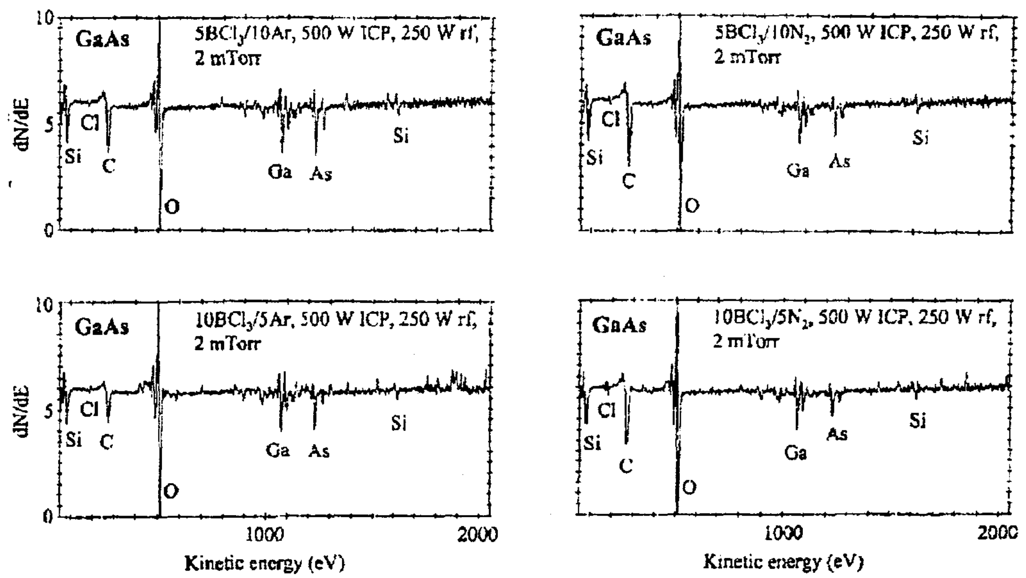

GaAs
AlGaAs
GaP
GaSb
GaN
500 W ICP
10BCl$_3$/5N$_2$
2 mTorr
Etch rate (Å/min)
0
3000
6000
9000
12000
0
100
200
300
400
500
600
Negative chuck dc bias (V)

5/10

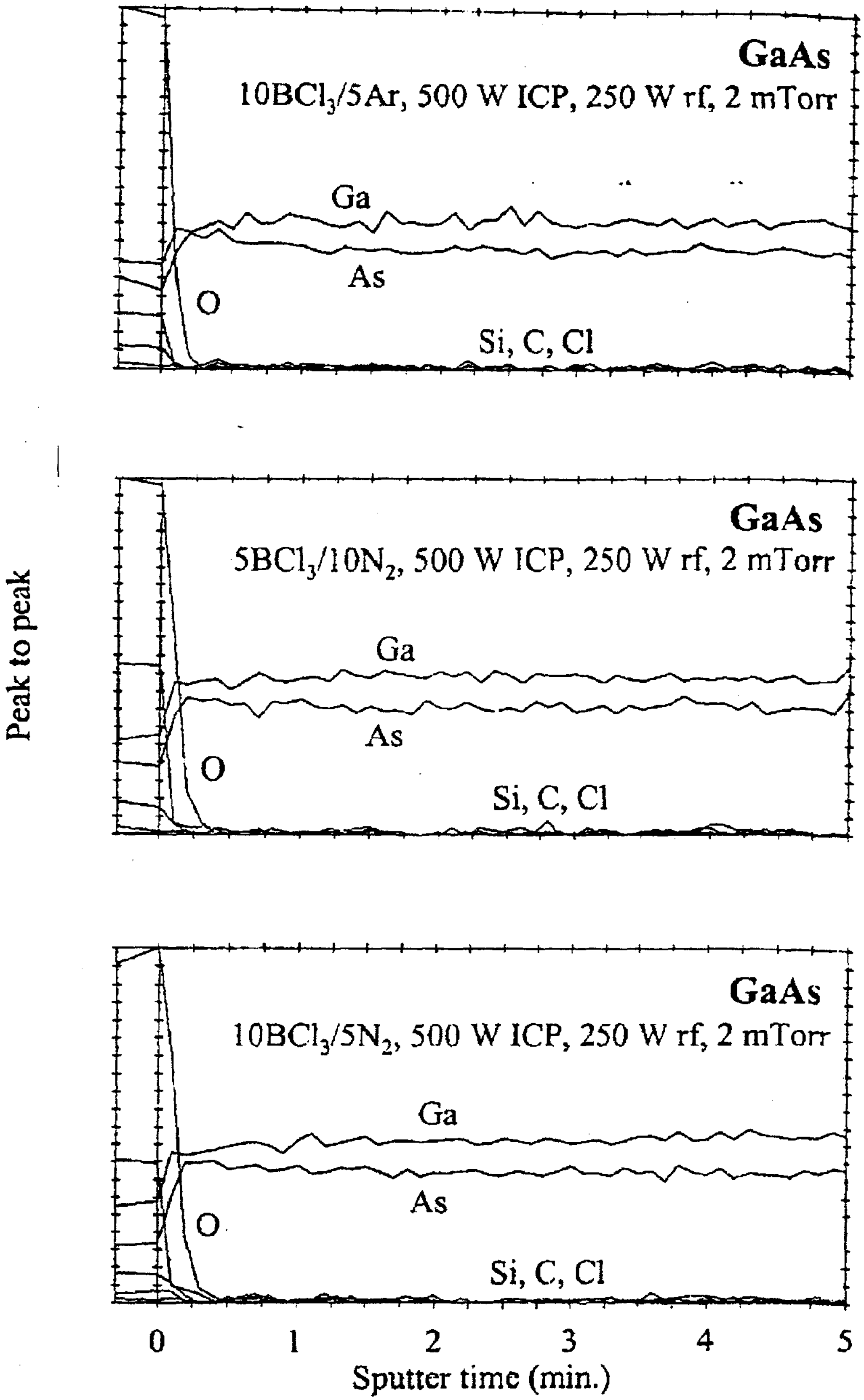

15KU X7200
1 μm


1 μm
UFMSE
1 μm


2
1
0
500 W ICP
2 mTorr
-250 V dc bias
GaAs ; BCl3/N2
GaAs ; BCl3/Ar
AlGaAs ; BCl3/N2
AlGaAs ; BCl3/Ar
RMS roughness (nm)
0
20
40
60
80
100
% BCl3 (total flow rate of BCl3 + N2 or Ar is 15 sccm)


GaAs
5BCl3/10Ar, 500 W ICP, 250 W rf, 2 mTorr
GaAs
5BCl3/10N2, 500 W ICP, 250 W rf, 2 mTorr
GaAs
10BCl3/5Ar, 500 W ICP, 250 W rf, 2 mTorr
GaAs
10BCl3/5N2, 500 W ICP, 250 W rf, 2 mTorr
Si
Cl
C
O
Ga
As
dN/dE
0
5
10
1000
2000
Kinetic energy (eV)

9/10


GaAs
10BCl3/5Ar, 500 W ICP, 250 W rf, 2 mTorr
Ga
As
O
Si, C, Cl
GaAs
5BCl3/10N2, 500 W ICP, 250 W rf, 2 mTorr
Ga
As
O
Si, C, Cl
GaAs
10BCl3/5N2, 500 W ICP, 250 W rf, 2 mTorr
Ga
As
O
Si, C, Cl
Peak to peak
0
1
2
3
4
5
Sputter time (min.)