[III-2]
Digital Etching of GaAs

T. Meguro
The Institute of Physical and Chemical Research (RIKEN)
2–1 Hirosawa, Wako, Saitama 351–01, Japan
Tel: +81-484-62-1111, Fax: +81-484-62-4682, E-mail: meguro@rkna50.riken.go.jp

Atomic layer manipulation techniques such as atomic layer epitaxy (ALE) [1, 2] or atomic layer etching (AL etching) is becoming a topic of increasing importance for future device production. However there has been a few reports on the AL etching with a self–limiting fashion. Though conventional dry etching technique such as reactive ion etching (RIE) or reactive ion beam etching (RIBE) has been used with great success in device production, these techniques are not based on the self–limited process and are difficult to apply the fabrication of well-defined structures with the full atomic layer controllability. We have proposed digital etching technique [3–5] to attain the ideal layer–by–layer controlled AL etching. In digital etching, the sequence is divided into several steps; i) etchant adsorption, ii) excess etchant purge, iii) etching of surface atoms (e.g., beam-induced etching), and iv) etching products purge. Here, when both the spontaneous chemical etching during etchant feed and the physical sputtering under beam irradiation are completely suppressed, the chemical sputtering (beam induced chemical etching) dominates the etching process and the preferential removal of topmost atoms bonded with etchants would be expected. Then the etch rate is independent of etching parameter and the etch depth is digitally controlled simply by number of digital etching cycles.

In the present study, digital etching employing GaAs(001)/Cl_2 system has been investigated. III–V compounds such as GaAs are complicated and sensitive materials compared with elemental semiconductors, and various etching reaction channels exist. Indeed, in the case of GaAs RIE, it is known that various species such as GaClx, AsClx (x=1–3), As_2 and As_4 are observed as etching products [6–8]. At an unreconstructed GaAs(001) surface with Ga as the top layer, steric hinderance prevents the formation of dichlorides for unreconstructed neighbors and monochlorides are formed at surface. It is easy to guess that the etch rate of digital etching is hardly reach to the ideal value of one monolayer (ML), assuming that etching products are Ga– or As–trichlorides. As shown in Table 1 that summarizes previous studies on digital etching of GaAs [3–5, 9–13], though a clear saturation of etch rate is seen and the self–limited reaction mechanism is involved, the saturated value is less than 1 ML of GaAs(001) except the result using chlorine radical (ECR)/Ar-ion system [12]. The last row in Table 1 is the result from temperature programmed desorption (TPD) study on the GaAs(001)/Cl_2 system with repetitive cycles of Cl_2 exposure and substrate heating [13], indicating the possibility of AL etching in thermal process. Lower etch rates less than 1 ML/cycle is

observed since chlorine adsorption is insufficient to completely remove a topmost layer due to formation of trichlorides. Here, if the etching product could be fixed at monochlorides instead of trichloride, the ideal AL etching would be possible.

In this talk, the digital etching technique will be reviewed and the possibility of the ideal AL etching in digital etching employing a newly developed tunable UV laser system[14] is discussed. We believe that the control of surface reactions employing a coherent monochromatic tunable light source is advantageous in selectivity of reaction column, species or channel, and also in development of low-damage or damage free etching.

References

[1] T. Suntola and J. Antson, US patent no. 4,058,430 (1977).
[2] T. Suntola and J. Hyvärinen, Ann. Rev Mater. Sci. **15** (1985) 177.
[3] T. Meguro, M. Hamagaki, S. Modarassi, T. Hara, Y. Aoyagi, M. Ishii and Y. Yamamoto, Appl. Phys. Lett. **56** (1990) 1552 .
[4] T. Meguro, M. Ishii, H. Kodama, M. Hamagaki, T. Hara, Y. Yamamoto and Y. Aoyagi, Jpn. J. Appl. Phys. **29** (1990) 2216.
[5] M. Ishii, T. Meguro, H. Kodama, Y. Yamamoto and Y. Aoyagi, Jpn. J. Appl. Phys. **31** (1992) 2212.
[6] M. S. Ameen and T. M. Mayer, J. Appl. Phys. **63** (1987) 1152.
[7] M. Balooch, D. R. Olander and W. J. Siekhaus, J. Vac. Sci. Technol. **B4** (1986) 794.
[8] S. M. Mokler, P. R. Watson, L. Ungier and J. R. Arthur, J. Vac. Sci. Technol. **B10** (1992) 2371.
[9] T. Meguro and Y. Aoyagi, Mat. Res. Soc. Symp. Proc. **222** (1991) 121.
[10] M. Ishii, T. Meguro, K. Gamo, T. Sugano and T. Aoyagi, Jpn. J. Appl. Phys. **32** (1993)6178.
[11] K. K. Ko and S. W. Pang, J. Vac. Sci. Technol. **B11** (1993) 2275.
[12] Y. Aoyagi, K. Shinmura, K. Kawasaki, T. Tanaka, K. Gamo, S. Namba and I. Nakamoto, Appl. Phys. Lett. **60** (1992) 968.
[13] A. Ludviksson, M. Xu and R. M. Martin, Surf. Sci. **277** (1992) 282.
[14] T. Meguro, T. Caughy, L. Wolf and Y. Aoyagi, Opt. Lett. **19** (1994) 102.
[15] T. Hara, M. Hamagaki, A. Sanda, Y. Aoyagi and S. Namba, J. Vac. Sci. Technol. **B5** (1987) 366.
[16] J. Z. Yu, T. Hara, M. Hamagaki, T. Yoshinaga, Y. Aoyagi and S. Namba, J. Vac. Sci. Technol. **B6** (1988) 1626.

Table 1 Comparison of systems and saturated value of etch rate of digital etching

Cl_2 feed	beam	saturation (ML /cycle)	ref.
molecule/effusive	electron	1/3	[3]
molecule/effusive	Ar-ion	1/3	[4]
radical (EBEP†)/effusive	Ar-ion	2/3	[5, 9]
radical (ECR*)/effusive	Ar-ion	1	[12]
radical (ECR*)/effusive	Ar-ion	~2	[11]
molecule/free jet	KrF excimer laser	2/3	[10]
molecule/effusive	elevating temperature[a]	1[b]	[13]

† EBEP : Electron Beam Excited Plasma [15,16].
* ECR : Electron Cyclotron Resonance.

a) Temperature Programmed Desorption (TPD) study
b) 2 MLs/2cycles