

A Thermal Pulse Model of Ion Enhanced Chemical Etching: InP/Cl₂

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I. INTRODUCTION

This talk will report the latest results from a modulated ion beam study of the etching of InP by Cl₂.¹ In the experimental work, pulses of rare gas ions ($X^+ = \text{Ar}^+, \text{Kr}^+, \text{Xe}^+$) were incident on an InP surface which also had Cl₂ continuously incident on it, and the modulated products were synchronously detected with a mass spectrometer. In order to evaluate the observed ion enhanced chemical etching in the system (InP/Cl₂/X⁺), the chemical etching (InP/Cl₂) and the physical sputtering (InP/X⁺) were also examined. The results both of these ion beam studies and of the plasma etching of InP in a Cl₂ plasma^{2,3} are analyzed in relation to a model where the ion transiently heats the surface by a small amount ($\sim 100^\circ\text{C}$), which results in the thermodynamically predicted desorption of material from the solid.⁴⁻⁷ Of particular technological interest is the fact that such a thermal pulse mechanism can result in large chemically selective enhancements over physical sputtering.

II. COMPARISON WITH CHEMICAL ETCHING

The thermodynamically predicted steady state chemical etching of InP by Cl₂ has been determined for the case of an unloaded system with negligible redeposition.⁸ These calculations indicate that for the Cl₂ pressures used in this work, the surface would be saturated with InCl₃ up to a temperature of 160°C , and that negligible chemical etching would occur. Above 160°C , the surface is predicted to change to a mixed coverage of solid InCl₂ and P, and the gas phase products InCl₂/InCl and P₄ are predicted to form. The results of this thermodynamic calculation have been confirmed in this apparatus by measuring both the chemical etch products in the mass spectrometer and the surface coverage with an Auger spectrometer as a function of both the Cl₂ pressure and the InP temperature.

The products of the ion enhanced chemical etching of room temperature InP are identical to those formed when InP is heated in the presence of Cl₂ with no ion bombardment: P₄ and InCl₂/InCl are formed in both cases. This is consistent with the thermal pulse mechanism where the role of the ion is to heat the surface and cause the chemical etching thermodynamically predicted at higher temperatures to occur. In addition, the ion enhanced chemical etching has been examined as a function of the InP sample temperature, and pronounced structure is observed in the product signals which is correlated with the thermodynamically predicted surface coverage transition temperature. The etch products have also been examined as a function of the Cl₂ pressure and all have the identical behavior characteristic of an adsorption isotherm, in contrast to the linear Cl₂ dependence observed for the chemical etching of InP at higher temperatures. These results are consistent with the thermal pulses desorbing Cl-species which were previously adsorbed on a room temperature surface.

III. COMPARISON WITH PHYSICAL SPUTTERING

The products of the physical sputtering of InP exhibited the theoretically predicted $(E_0)^{2/3}$ dependence on incident ion energy (E_0).⁹ In contrast, the ion enhanced chemical etch products appear to saturate at a relatively low ion energy ($\sim 1\text{ KeV}$). The products of the physical sputtering of InP also exhibited the linear dependence on ion flux which is predicted by the collision cascade model.¹⁰ The ion enhanced chemical etch products have a mixed behavior: P₄ is linear while InCl₂ saturates with ion flux. The ratio of the ion enhanced chemical etch products to the physically

sputtered products increases by a factor of ~ 2 as the ion mass is increased from Ar to Xe. This ion mass dependence is qualitatively consistent with the thermal pulse model, since the amount of incident ion energy which is dissipated into heating the lattice would be expected to scale with the cross section for total energy loss into nuclear motions, which increases by a similar amount with increasing ion mass.¹¹

IV. CONCLUSION

Although more work is required before these experimental results are fully understood, many aspects of the data appear consistent with a thermal pulse model for this particular ion enhanced chemical etching process.

FOOTNOTES

1. S. C. McNevin, "Rare Gas Ion Enhanced Etching of InP by Cl_2 ", J. Vac. Sci. Technol. B, (to be published).
2. V. M. Donnelly, D. L. Flamm, C. W. Tu, D. E. Ibbotson, J. Electrochem. Soc. 129, p. 2533 (1982).
3. N. DeMeo, J. P. Donnelly, F. J. O'Donnell, M. W. Geis, K. J. O'Connor, J. Nuc. Inst. and Methods, Physics Research section B: Beam Interactions with Materials and Atoms, March 1985, edited by H. H. Andersen and S. T. Picraux.
4. G. H. Vineyard, Radiation Effects 29, p. 245 (1976).
5. Roger Kelly, Radiation Effects 32, p. 91 (1977).
6. G. M. Lancaster, F. Honda, Y. Fukuda, J. W. Rabalais, J. Am. Chem. Soc. 101, p. 1951 (1979).
7. S. K. Erents, G. M. McCracken, J. Appl. Phys. 44, p. 3139 (1979).
8. S. C. McNevin, "Chemical Etching of GaAs and InP by Chlorine: The Thermodynamically Predicted Dependence on Cl_2 Pressure and Temperature", J. Vac. Sci. Technol. B (to be published).
9. S. A. Schwarz, C. R. Helms, J. Appl. Phys. 50, p. 5492 (1979).
10. P. Sigmund, in "Inelastic Ion Surface Collisions" edited by N. H. Tolk, J. C. Tully, W. Heiland, and C. W. White (Academic, NY, 1978), p. 121-152.
11. Bernard Smith, "Ion Implantation Range Data for Silicon and Germanium Device Technologies", Research Studies Press Inc. (Forest Grove, Oregon 1977).