

APPLICATION OF PLASMA ETCHING FOR CdHgTe TWO DIMENSIONAL INFRARED DETECTORS

J.Pilkington, L.Hipwood, R.Catchpole and M.Ordish

BAE SYSTEMS Infrared Limited.

ABSTRACT

Inductively coupled plasma (ICP) reactive ion etching (RIE) has been applied to CdHgTe (CMT). Using a CH₄/H₂/Ar chemistry the CMT etch rate was studied as a function of the main processing parameters: Gas ratio, ICP power, RIE power and total pressure. Etch depths were measured using a Wyko optical profiler, the surface morphology qualitatively assessed with a scanning electron microscope (SEM). CH₄ was observed to be the dominant etch species. A ratio of between 5% and 25% CH₄/H₂ produced the best CMT morphology. Etching with H₂/Ar was demonstrated but resulted in severe surface roughing.

Keywords: CdHgTe, dry etching, Inductively coupled plasma, CH₄/H₂/Ar

INTRODUCTION

The compound semiconductor Cd_xHg_(1-x)Te has long been the first choice of detector material used in the fabrication of high performance Infrared (IR) detectors. The current development of high performance cooled detectors revolves around two-dimensional (2D) focal plane arrays (FPA's) formed from CMT heterojunctions. FPA's are based on a matrix of photodiodes that are connected to a silicon integrated circuit. Each photodiode individually reacts to IR radiation from the environment, with the radiation being converted into an electrical response. The response is collected by the silicon chip, integrated and transformed into a useable image.

CMT IR detectors at affordable prices need to be developed for a number of defence applications. One of the main areas for development is increasing the resolution of a detector while constraining its physical size in order to achieve a cost-effective package. The latest generation of Medium Wave (MW) FPA's contain a 640x512 matrix of photodiodes on a 24 µm pitch giving an overall physical array size of 18x15 mm. Individual photodiodes are

formed by etching through the as-grown CMT junction. The current technology used to define the diodes is a chemical wet etch. The isotropic profile associated with wet etching is the limiting factor in reducing current pitch dimensions. This work presents an initial investigation of plasma dry etch technology. Dry etch technology offers the ability to produce anisotropic etch profiles, resulting in more photodiodes per unit area. Dry etching is being investigated in order to reduce pitch dimensions down to 16 µm on large matrix (1024x768), 18x15 mm formats. This work will present the initial investigations into the etch rate characteristics of CMT through dry etching.

BACKGROUND

There has been a growing interest and an increasing demand to introduce plasma etch processing into CMT IR detector technology. Plasma processing introduces significant benefits over wet chemical etching, which include anisotropic profiles, etch depth control and greater uniformity. Dry etching is an advanced technology in semiconductor processing, however CMT with its weaker crystal strengths and greater defect density can suffer from extensive

electrical and physical damage from ion bombardment [6]. The system described in this report is an ICP RIE. The ICP system consists of an inductor coil wrapped around the top of a dielectric process chamber, see Figure 1. The desired process gas is injected into the top of the chamber. A plasma is created by applying RF power to the coil, the plasma breaks the injected gases into reactive etch species which diffuse down to the sample. The sample to be etched is placed at the bottom of the chamber on an electrode. An independent bias can be applied to the electrode, referred to as the RIE power; this bias will attract ions from the plasma to the sample. With a small RIE power the ion attraction will be low and the corresponding etch

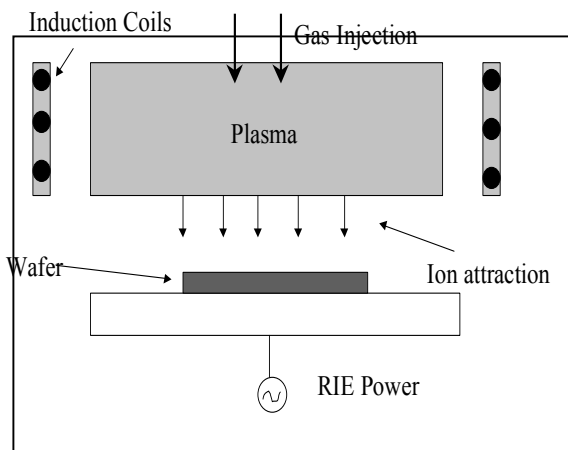


Fig.1. Schematic diagram of an ICP RIE system

isotropic in nature. With a high RIE power ions will be strongly attracted to the sample, arriving with a large amount of energy, promoting a more physical, anisotropic etch. The ability to decouple the plasma generation and ion energy through the RIE power, enabling precise control of the ion energy impacting on the sample surface, is key in achieving an anisotropic etch, while minimising electrical damage to the CMT.

The first stage of the work was to carry out

a literature review. From the review the most commonly used etchant gases for CMT were $\text{CH}_4/\text{H}_2/\text{Ar}$ [1-7], although H_2/Ar have also been proposed. In a CH_4/H_2 plasma discharge atomic hydrogen, organic radicals and ions are produced [1]. The key step proposed for etching CMT is the generation of the CH_3 radical from CH_4 [7]. The proposed primary etch products are elemental Hg, TeH_2 , $\text{Te}(\text{CH}_3)_2$ and $\text{Cd}(\text{CH}_3)_2$ [1] If these etch products are true the role of the CH_3 radical is critical in promoting the etch process. The role of polymer formation, created from the breakdown of CH_4 , was seen to have a detrimental effect on surface morphology. The initial phase of the DTC work was aimed at assessing and understanding CMT etch rates.

EXPERIMENTAL DETAILS

The experimental studies carried out were mechanical in nature, with the aim of assessing CMT etch rates in an ICP RIE system. The samples used were Metal-organic vapour phase epitaxy (MOVPE) grown CMT of varying composition and thickness. Doping and Cd fraction were assumed to have negligible effects on bulk etch rate. All the samples were patterned with AZ photoresist, on a $30\ \mu\text{m}$ pitch, $4\ \mu\text{m}$ line-width, and 320×256 matrix. The samples were mounted on a 4" silicon carrier, held in the machine with an electrostatic chuck. Backside cooling was used to help maintain the sample temperature through processing. Four etch depth measurements were carried out, centre to edge, per sample on a Wyko optical profile system, and an SEM picture taken to qualitatively assess surface morphology. A wide range of parameters were investigated, these included Pressure, Gas ratio, ICP power, and RIE power. The Pressure was varied from 0.06-0.18 mbar ($45\text{-}135\ \text{mTorr}$) controlled with a variable throttle valve. The upper limit of the system is 0.2 mbar. The gas flows for CH_4 ,

H₂, and Ar were controlled by independent mass flow controllers, and injected directly into the top of the chamber. The ICP and RIE powers are independently controlled. Parameters were kept constant during processing except the one being investigated. The considerations for a viable, practical, dry etch process in CMT include anisotropic profile, low physical/electrical damage and smooth surface finish. These place a limit on the range to which the parameters are varied, for example the RIE bias needs to be kept as low as possible to avoid any possible type conversion within the CMT.

RESULTS AND DISCUSSION

The etch dependence with CH₄/H₂ ratio is shown in Figure 2. The graph can be split into three distinct regions. Between 5% and 40% there is a linear increase of etch depth with CH₄/H₂ ratio, which is consistent with previous reports who also describe a linear increase of etch rate with increasing

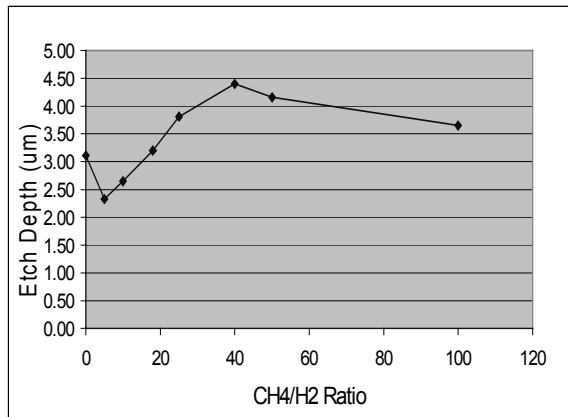


Fig.2. Etch Depth Vs CH₄/H₂ ratio. H₂/Ar (30/7) sccm, ICP=480 W, RIE=20 W, Pressure = 0.18 mbar.

CH₄/H₂ ratio [2,3,4]. It is proposed that the etch radical CH₃ is the vital etch species in CH₄/H₂ chemistries. An increase of CH₄ will therefore lead to an increase in etch rate. The behaviour here agrees with those

findings. At ratios above 40% a decrease in etch depth is observed. At these higher ratios substantial polymer deposition was observed on the etched samples and chamber walls. At zero CH₄ the results show CMT being etched in a H₂/Ar chemistry. The etch rate observed is greater than that expected through physical ion etching alone. The surface condition of the CMT after the H₂/Ar etch was considerably rougher than that seen with the addition of CH₄. The surface roughness may be indicative of preferential etching of Hg and Te. The degree of surface roughness observed would indicate that a H₂/Ar chemistry would be unsuitable for a viable process.

Figure 3 shows the etch rate dependence with pressure for three RIE powers. Pressure is expected to affect the ion bombardment that the sample receives and the total number of radical (CH₃) etch species available for etching. As the chamber pressure is decreased the number of gas molecules available for ionisation decreases resulting in the

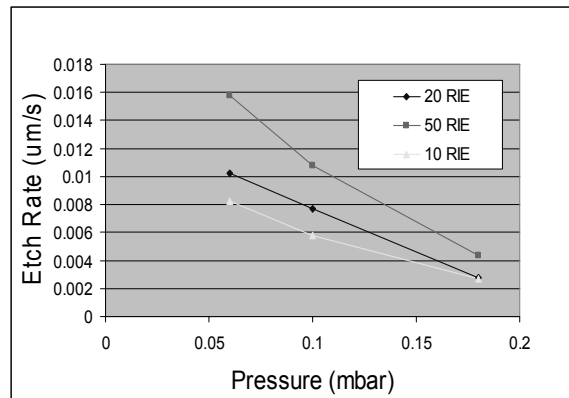


Fig.3. Etch Rate Vs Pressure. CH₄/H₂/Ar (5/27/30) sccm, ICP = 480 W

number of etch species decreasing. With fewer etch species we would expect a reduction in the etch rate. However the trends for all three RIE powers is for an increase in etch rate for a decrease in pressure. The reduction in etch rate with

increasing pressure may be explained by relating the etch rate with polymer formation. The generation of the etch radical CH_3 from CH_4 also leads to CH_2 and CH radicals [7]. CH_2 and CH are known to be precursors of hydrocarbon polymers, which leads to the formation of polymer films. Polymer films will deposit on the surface and sidewalls of the sample and, being impervious to the etch chemistry, inhibit further etching. As the pressure increases, more CH_4 is available for ionisation, more polymer will be produced and etching will be inhibited. As the pressure increases the energy of the incoming ions decreases due to more collisions occurring in the denser plasma. So at high pressures more polymer is formed, but physical sputtering is reduced, leading to a reduced etch rate. At low pressures, less polymer is formed, and more physical sputtering occurs. To promote etching the polymer needs to be physically sputtered by the incoming ions. At the highest pressure the three RIE powers are tending towards a similar etch rate, indicating that the polymer formation is the dominant factor at

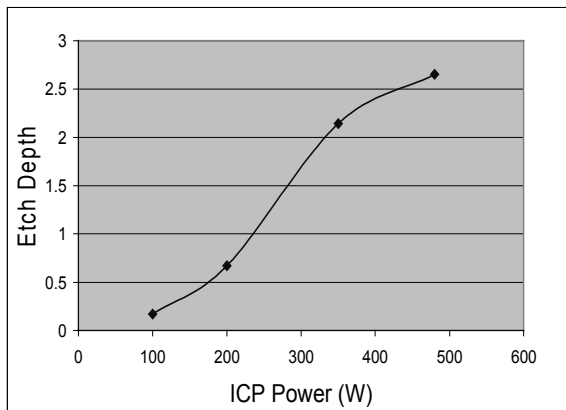


Fig.4. Etch Depth V_s
ICP Power. $\text{CH}_4/\text{H}_2/\text{Ar}(5/27/30)$ sccm,
Pressure 0.18 mbar, RIE=20 W
higher pressures. The results do not seem indicative of an ion assisted etch process. Figure 4 shows the etch dependence with varying ICP power. The generation of the radical CH_3 is the key step for CH_4/H_2

etching [3]. The number of ionised species in the plasma is a function of ICP power, the higher the ICP power the greater the number of ionised radicals. The graph shows an increase in etch rate as ICP power is increased. This indicates that it is the ionised radicals that dominate the etch process, and the proposed radical is CH_3 . A slight decrease in the rate of etch rate at higher ICP powers may be explained by the formation of polymers on the sample which would inhibit the etch rate. A change of surface condition was noted with the increasing ICP power, with the surface becoming increasingly rougher.

SUMMARY AND CONCLUSION

The application of ICP dry etching to CMT has been investigated. The studies were mechanical in nature, investigating etch characteristics with a $\text{CH}_4/\text{H}_2/\text{Ar}$ etch chemistry. Results indicate the importance of CH_4 to the etch chemistry. The etch rate is strongly dependant on the methane concentration and from increasing etch rate with increasing ICP power it is a radical created from CH_4 that is dominant. Etching with H_2/Ar was demonstrated, but the roughness of the CMT surface excludes this etch chemistry from becoming a viable process. The decrease of etch rates for higher CH_4/H_2 ratio's and high pressures indicate the interplay between polymer deposition and ion bombardment. The optimisation of polymer removal through ion bombardment will determine the etch characteristics in terms of etch rate, physical damage and structure profile. The best surface morphology was produced with a ratio of between 5% and 25% CH_4/H_2 . Higher ratios exhibited severe surface roughening on the samples, and polymer deposition on the chamber.

The work has demonstrated etching CMT is viable with an ICP system using a $\text{CH}_4/\text{H}_2/\text{Ar}$ etch chemistry. Etch rates were

achieved with desirable surface finishes and low ion energies, see Figure 5.

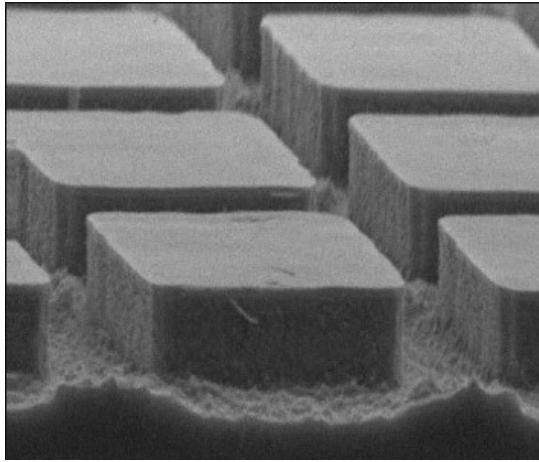


Fig.5. SEM image showing dry etched photodiode on a 30 μm pitch. Etch depth is approximately 5 μm . Note anisotropic profile.

FUTURE WORK

Mechanical assessments for dry etching CMT have proved encouraging. The work carried out over a broad range of parameters has shown trends and relationships that can be utilised in a viable etch process. In order for a viable process to be achieved continued investigation into two main areas will be required.

1) *Electrical Damage*: CMT has a weak crystal lattice, and ion bombardment over certain energy will cause type conversion. The extent of any ion damage occurring through the plasma process needs to be investigated with electrical device assessments. If electrical damage is found, investigations into reducing the ion energy in the process or removal of the damaged regions will have to be explored. Electrical assessments are currently proceeding.

2) *Sidewall Mesa Profile*: A critical step in manufacturing 2D FPAs is the passivation of the sidewalls where the junction comes to the surface. Poor passivation leads to substantially reduced electrical characteristics. With current passivation deposition technology a 70-80 degree mesa slope is required to ensure a uniform unbroken passivation layer. This means that the dry etch process must be capable of etching structures with the desired sidewall angle. There are two techniques for achieving a sloped profile with a dry etch process. The first is to use the polymer created within the etch process to coat the sidewalls of the CMT which inhibits lateral etching, the second is to use a two step process. The two step process involves an alternate sequences of etching, and resist erosion, creating a stepped, tapered structure. Work is ongoing in finding the best method for achieving the desired slope.

REFERENCES

- [1] E.P.G Smith, C.A.Musca, D.A Redfern, J.M Dell and L.Faraone: 'Reactive ion etching for mesa structuring in HgCdTe',
- [2] C.R.Eddy, Jr, C.A Hoffman, J.R Meyer, and E.A.Dobisz.1993, JEM.22, pp1055.
- [3] C.R.Eddy, Jr, E.A.Dobisz, J.R Meyer and C.A Hoffman. 1993. J.Vac.Sci Tech. A, 11(4), pp1763
- [4] E.P.G Smith, J.K Gleason, L.T. Pham, E.A Patten, and M.S Welkowsky. 2003, JEM,32, pp816.
- [5] C.R.Eddy, D. Leonhardt, V.A Shamamian, J.R. Meyer, C.A Hoffman, and J.E Butler. 1999, JEM, 28

[6] J.E. Spencer, T.R. Scimert, J.H. Dinan,
D. Endres and T.R. Hayes. 1990 J.Vac.Sci
Tech. A,8, pp 1690

[7] R.C. Keller, M. Seelmann-Eggebert,
and H.J Richter. 1995, JEM.24,
No9,pp1155