X-Ray Photoelectron Spectroscopy Study of Oxide and Te Overlayers on As-Grown and Etched HgCdTe

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X-ray photoelectron spectroscopy has been used to study the low-temperature (<80°C) preparation of HgCdTe surfaces with atomic hydrogen for the purpose of CdTe passivation. Atomic hydrogen was used to etch overlayers and surfaces of liquid phase epitaxy and molecular beam epitaxy HgCdTe, CdTe, HgTe, and Te. Oxide layers were easily removed, while carbon overlayers were resistant to atomic hydrogen etching at low temperature. Both Te and HgTe are etched by atomic hydrogen, with the HgTe etch rate about twice that of Te, while CdTe and ZnTe are not etched. Chemi-mechanical polishing of liquid phase epitaxy HgCdTe left a 10 to 20Å Te overlayer that could be removed with atomic hydrogen. In all cases, exposure of HgCdTe to atomic hydrogen led to surface composition shifts to higher x-value, with an x-value plateau near x ~ 0.6. All observations could be explained in terms of the formation of a 15Å surface layer of CdTe which blocks further etching.

Key words: Atomic hydrogen, etching, HgCdTe, molecular beam epitaxy (MBE), oxide removal, surface preparation, x-ray photoelectron spectroscopy

INTRODUCTION

Exposure to atomic hydrogen has been demonstrated to be an effective method for cleaning many types of substrates prior to epilayer growth. In many cases, the use of atomic hydrogen dramatically reduces process temperatures for the removal of oxides and other overlayers typically left by *ex-situ* cleaning procedures. Atomic hydrogen cleaning may also be of interest in production of HgCdTe infrared detectors as the CdTe passivation layer is usually grown after the HgCdTe surface has undergone processing and exposure to air and/or chemical etching. Unless the CdTe layer is grown as part of a heterostructure, however, it must be deposited after the HgCdTe surface has undergone exposure to air and/or chemical etching of the surface. This allows the formation of an overlayer containing O, C, and possibly elemental Te, which must be removed prior to CdTe growth. Typical thermal oxide removal requires temperatures above 180°C in vacuum. Such temperatures can degrade the surface of the HgCdTe or affect the electrical properties of the epilayer.

We have been studying the use of atomic hydrogen for the preparation of substrates for subsequent growth of II-VI compounds by molecular beam epitaxy (MBE).[1–4] This paper discusses the use of atomic hydrogen for low temperature removal of oxides and other overlayers from HgCdTe. We present the results of a detailed x-ray photoelectron spectroscopy (XPS) study of oxide and Te overlayer formation and removal for chemi-mechanical-polished liquid phase epitaxy (LPE) HgCdTe, and for both as-grown and etched MBE HgCdTe epilayers. XPS was used to measure overlayer and epilayer composition both after chemical etching and after atomic hydrogen cleaning.

GENERAL EXPERIMENTAL DETAILS

XPS measurements were made both at West Virginia University (WVU) and at Forsvarets forskningsinstitutt (Norwegian Defense Research Establishment-FFI). XPS analysis at WVU used the Mg anode (1253.6 eV x-ray line) of a Fisons twin anode

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x-ray source operating at 300 W and a VG100AX hemispherical analyzer in a 1:1 lens mode. Spectra were taken in constant analyzer energy mode at a 20 eV pass energy. The composition and chemical state of the surface were determined by monitoring the Te $3d_{5/2}$, Cd $3d_{5/2}$, and Hg $4f_{7/2}$ photoelectron peaks. Following standard methods described by Moulder et al.,[5] surface composition was determined using peak areas, obtained using Jandel Scientific's PeakFit program, and elemental sensitivity factors. K_{α} satellite peaks were present due to the nonmonochromatic nature of our x-ray sources and were separately included as part of the anlaysis. Sensitivity factors (relative to Te) at WVU were estimated from published results for Hg and by direct measurement of Cd and Te signals from both Ar-ion-etched and atomic-hydrogen-etched bulk CdTe. As reported previously,[3] atomic hydrogen-cleaned and Ar-ion-etched CdTe surfaces were indistinguishable by XPS, indicating a stoichiometric CdTe surface[6] is left after atomic hydrogen exposure. Although a range of sensitivity factors for Hg, Cd, and Te have been published, reflecting various instrumental configurations, the values of Nitz et al.[7] most closely match the results obtained in the WVU system for samples of known composition.

The XPS experiments at FFI were performed in a Riber UHV chamber connected via a Modutrac system to a Riber growth chamber. The Mg anode in a twin-anode Cameca x-ray source was operated at 300W. The x-ray beam was incident at a 45° angle with the sample normal and the emitted electrons were then collected in a Riber EA 150 analyzer at 30° with the sample normal. The data was then retrieved from the Riber MAC control unit by Cameca's Kernel3 program, and analyzed. Since the XPS system at FFI was connected to the HgCdTe MBE growth system, direct measurement of sensitivity factors for Hg and Cd was possible using grown layers of CdTe and HgTe, again relative to Te. Fundamental energies, peak widths, and shapes were determined to minimize free parameters for multiple peak analysis for samples with overlayers. In addition to area sensitivity factors for the Cd $3d_{5/2}$ (0.56), and Hg $4f_{7/2}$ (0.46–0.48) peaks, values were also determined for the Cd $3p_{3/2}$ (0.26–0.27) and Hg $4d_{5/2}$ (0.32–0.36) peaks. The latter set of XPS transitions resulted in lower photoelectron energies with resulting smaller mean free paths, thus permitting a qualitative assessment of near-surface stoichiometry variations. The primary uncertainty was for Hg. Special care had to be taken in terminating the (211)B HgTe or HgCdTe growth to minimize either Hg out-diffusion or Hg condensation by carefully controlling the Hg-overpressure during cool-down. This surface was then stable in vacuum at room temperature. CdTe and CdZnTe sample surfaces were observed to be stable in the vacuum system between the growth temperature and room temperature. Composition determined using XPS on as-grown HgCdTe epilayers agreed well ($\Delta x = \pm 0.02$ with *ex-situ* determination of the sample x-values using Fourier transform infrared (FTIR) spectrsocopy. A relative sensivity for O1s (0.13) was determined by assuming that only TeO_2 formed on an oxidized Te layer. C (0.05) and Zn (0.90) sensitivity factors were extrapolated from previous work.[8]

A commercial atomic hydrogen source (EPI-AHS-L) was used to generate atomic hydrogen.[9] The hydrogen flow used resulted in a beam flux monitor reading of about 3×10^{-6} Torr at WVU, and 2.6×10^{-6} Torr at FFI. The source operating current at WVU was held constant at 9.5 A, while the atomic H flux was varied at FFI by changing the source current. Due to differences in system geometry, it was determined that 8.5 A at FFI resulted in similar etch rates for Te to the 9.5A operating conditions at WVU.

The liquid phase epitaxy (LPE) $Hg_{0.2}Cd_{0.8}Te$ substrates (~1 cm^2) were provided by II-VI, Incorporated (Saxonburg, PA) and had been chemi-mechanically polished. The LPE layers were: degreased in trichloroethylene, acetone, and methanol; etched for 5 s in 0.5% Br:methanol; rinsed in methanol; and then immediately blown dry with high purity helium before being inserted into the XPS chamber. At FFI, Te, CdTe, HgTe, and HgCdTe layers were grown by MBE in a Riber MBE32P equipped with standard CdTe and Te effusion cells, and a Riber MCL160 Hg cell. Selected samples were oxidized in cleanroom ambient atmosphere overnight, while others underwent Br-based etching.

POLISHED AND ETCHED LPE HgCdTe

One of the original goals of this effort was to use atomic hydrogen to remove surface oxides as part of developing a planar diode process for LPE HgCdTe. In particular, the LPE HgCdTe was to be chemi-mechanically polished to remove surface irregularities and inhomogeneities. The etched surface of chemi-mechanical-polished LPE HgCdTe was always found to contain a mixture of metallic Te and Te bound in a HgCdTe matrix as observed previously by Chang et al.,[10] and an oxide overlayer, as indicated in Fig. 1. The LPE samples were smaller than our x-ray beam at WVU, and so the oxide was monitored using only the Te $3d_{5/2}$ signal chemically shifted to 576.3 eV by oxygen bonding (Te-oxide). The O 1s signal, in this case, would contain oxide signals from the mounting block in addition to that from the sample. The presence of elemental, or metallic, Te was signified by a peak at 573.2 eV and easily resolved from the signal for Te in the HgCdTe matrix at 572.9 eV through multiple peak analysis.

Figure 1 shows the results of a simple elemental analysis[5] which, while not strictly appropriate in the presence of overlayers, illustrates the basic details of the measurements. The as-etched samples had a significant surface component of the metallic Te as well as an oxide overlayer. A detailed analysis[11] of the normalized XPS signals using electron mean free paths predicted by the model of Tanuma et al.[12] indicated the typical thickness of metallic Te overlayers ranged between ~ 10 to 20Å, and that the thickness of

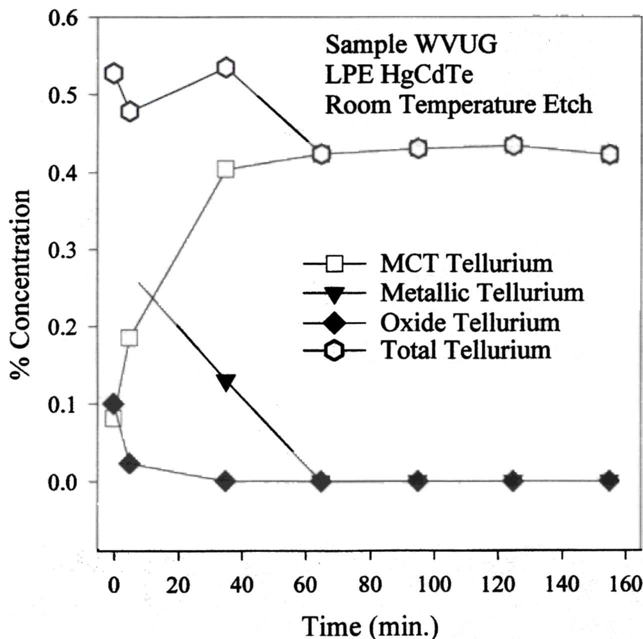

Fig. 1. The graph shows the changes in the near-surface Te composition of chemi-mechanically polished LPE HgCdTe as a function of atomic hydrogen exposure time near room temperature.

the oxide layers was ~1 to 2Å, indicating less than a monolayer oxide coverage. In terms of device passivation, the metallic Te overlayer could cause more problems than the relatively thinner oxide.

Exposure to atomic hydrogen quickly removed the oxide, and continued exposure removed the metallic Te overlayer. At the same time, the "apparent" Cd mole fraction was observed to shift to a higher x-value, indicating Hg loss. The data also indicate an absence of a large stoichiometry change, maintaining an approximate 1:1 correspondence between (Hg + Cd), and Te. The compositional changes reached a plateau after about 30 min of exposure, with analysis suggesting an apparent x-value of 0.5 and 40% atomic concentration of Te. The same trend was seen at FFI, but with a final composition of 50% Te and final x-value of about 0.6. Since the elemental sensitivity factors were measured at FFI, this indicates that our elemental sensitivity factor for Hg at WVU is only approximately correct. A more detailed analysis of compositional change is deferred to later sections. It is useful to compare these results with Ar-ion sputtering of HgCdTe. Previous studies[6,13] indicate Ar-ion sputtering also results in Hg loss, but this Hg-loss is accompanied by the accumulation of excess Te at the surface unlike the atomic hydrogen results.

Several experiments performed in this study as in others[13] indicated that the oxide present on the polished LPE samples after the Br-methanol etch is relatively unstable. In one experiment, an unheated sample was exposed to the light from the hydrogen source filament without hydrogen gas being introduced into the chamber. This alone was sufficient to remove the oxide overlayer as determined with both XPS and reflection high energy electron diffraction (RHEED) in separate experiments in the MBE chamber at WVU. However, continued exposure for up to 60 min did not remove the Te overlayer (XPS and RHEED) or result in an ordered surface (RHEED). On another occasion, the substrate was allowed to remain in the analysis chamber for approximately 48 h without heating after the as-etched surface had been analyzed. Subsequent analysis revealed that the oxide was desorbed during this period.

There is also evidence here and in other studies[13] that more than one type of oxide occurs on HgCdTe. In one hydrogen etching experiment, the HgCdTe sample was re-exposed to atmosphere for 3 h after the Te-oxide peak was removed (i.e., after a 5 min atomic hydrogen etch at room temperature). The relative strengths of the Te-MCT, Te-metallic, and Te-oxide signals for this sample are shown in Fig. 2. The initial H-etched surface had both oxide and metallic Te overlayers. Cleaning removed the oxide and increased the apparent strength of the Te-MCT signal. After the air-exposure, a more intense oxide-Te peak was observed, indicating an oxide layer much thicker than any of our previously analyzed Br-methanol etched samples, including some stored in air for several months. This thicker layer, ~10Å thick, is also more consistent with other results,[6,14] reported in the literature. The increase in oxide formation may be caused by more of the underlying HgCdTe matrix being exposed for oxidation, as suggested by the disappearance of the Te-MCT signal. The second oxide was also more resistant to atomic hydrogen etching, with an etch rate that varied with thickness. The initial removal rate was 0.23Å/min, close to a factor of two slower than typical for all as-etched Br-methanol etched LPE samples, slowing to a rate of 0.13Å/min. Both results indicate that there may indeed be more than one type of oxide formed on an etched HgCdTe surface, depending intimately upon prior surface treatment.

ETCHING STUDIES

Studies of compositional changes from atomic hydrogen exposure using the polished and etched LPE

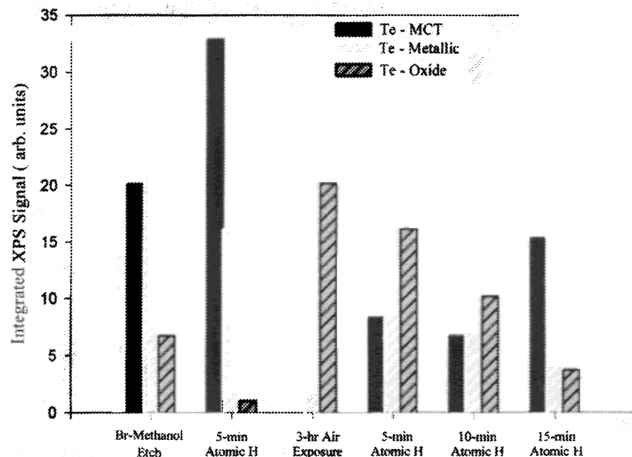

Fig. 2. Relative strength of the XPS signal for Te in different chemical states from an LPE HgCdTe epilayer after various treatments.

layers was complicated by the presence of significant oxide and metallic Te overlayers. At FFI, the XPS chamber was interconnected to the growth chamber, and measurements could be made on as-grown samples without the complication of air exposure. Prior studies[3,4] had indicated that Te was removed with atomic hydrogen, but that both CdTe and ZnTe were not etched by atomic hydrogen at temperatures less than 100°C. The changing x-value for HgCdTe exposed to atomic hydrogen indicated HgTe etching was probable. However, an upper bound for total removed material of ~5 nm was determined for etching of HgCdTe that had been exposed to sufficient atomic hydrogen for the x-value to have reached its steady-state x-value plateau.[3] This indicated that atomic H etching of HgCdTe has a self-limiting mechanism.

At FFI, we could verify that atomic hydrogen indeed etches both Te and HgTe. Te and HgTe were deposited on CdZnTe substrates, and sample thicknesses were obtained from previous calculations of growth flux and measured growth rates. Etching of Te was monitored through measuring the Cd 3d, Zn 3p and Hg 4f XPS transitions. Since the Zn 3p signal was small and the associated photoelectron had a very short mean free path (9Å), detection of Zn indicated etching was almost complete. Final removal was established by observing a steady-state (no longer increasing) signal for Cd, coupled with disappearance of the Hg signal for the HgTe layer. For the thinner Te layers, an independent check on thickness was made by measuring the attenuation of the substrate Cd 3d signal through the grown layer. The attenuation thickness agreed reasonably well with that estimated from the growth flux, with an average variation of ±10%. The agreement provided confidence in both the mean free path model and estimation of thickness from growth flux for thin layers.

As at WVU, Te was readily removed with atomic hydrogen. Based on etch rate, it appears that operating at 8.5A at FFI was similar to 9.5A at WVU due to chamber geometry differences. At a hydrogen source current of 8.5 A, the etch rate was approximately 8Å/min for Te. HgTe was also easily removed with atomic hydrogen, providing the mechanism for x-value change in atomic hydrogen-exposed HgCdTe. HgTe etch rates were approximately twice that for Te, at about 14Å/min for 8.5A source operation. The ability to etch HgTe while CdTe and ZnTe are resistant to etching may be related to the larger Cd-Te and Zn-Te bond strengths.

Figure 3 summarizes the results obtained from exposing as-grown HgCdTe epilayers to an atomic hydrogen flux. Apparent x-values were determined from the Cd $3d_{5/2}$ and Hg $4f_{7/2}$ ("deep"), and the Cd $3p_{3/2}$ and Hg $4d_{5/2}$ ("shallow") XPS peaks. Based on the smaller Cd photoelectron mean free path and taking into account the detector angle, characteristic 1/e sampling depths were estimated as 20Å ("deep") and 16Å ("shallow"). Several features are noteworthy. First, comparison of the two x-values for as-grown layers indicated a slight compositional gradient with

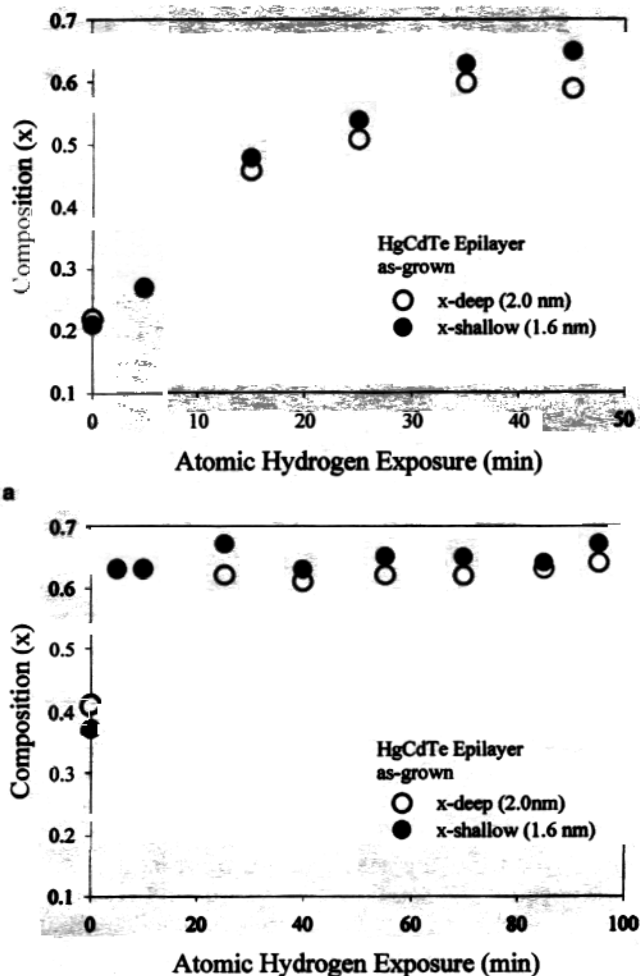

Fig. 3. Composition changes in the near-surface region of x = 0.22 HgCdTe (a) and x = 0.4 (b) epilayers as a function of atomic hydrogen exposure. The H was maintained at 2.6×10^{-6} Torr (system pressure) with the source operated at (a) 7.0 A (first 25 min) and 9.5 A (last 20 min) and (b) 8.5 A (first 85 min) and 9.5 A (last 10 min).

a lower near surface x-value for all layers investigated. This is consistent with and supports the model of Colin and Skauli[15] indicating growth of HgCdTe by MBE takes place under Te-saturated conditions. Under Te-saturated conditions, growth termination under a Hg flux without a CdTe capping layer would lead to a final HgTe-like surface layer, decreasing the apparent surface x-value. Second, the apparent x-value increases with increasing atomic hydrogen exposure, saturating at a plateau of about x ~ 0.6. We believe that this is more indicative of the true apparent x-value than the 0.5 value measured at WVU for LPE layers due to the improved sensitivity factors. Indeed, we found an elemental composition consisting of about 50% Te for these layers, indicating not just Hg removal, but also an equivalent Te removal rate. As indicated in Fig. 3b, this apparent x-value saturation is very stable with respect to long exposures to atomic hydrogen. Comparison of "deep" and "shallow" x-values indicate a trend toward higher x-values toward the surface which is also stable for longer atomic hydrogen exposures.

A scenario which explains all these observations is the extraction of HgTe to form a thin CdTe overlayer which then blocks further etching. Modeling of an abrupt, uniform CdTe overlayer on uniform, x ~ 0.2 HgCdTe indicates ~15Å of CdTe would give an apparent x-value of ~0.6 due to the fairly deep sampling of the photoelectrons. While the near-surface composition is undoubtedly graded, this gives a working number. Analysis based on the presence of such a layer suggests a $\Delta x \sim 0.05$ between the "deep" and "shallow" x-value, consistent with the magnitude and trend observed. Certainly grading would reduce the apparent Δx. Also, 75Å of $Hg_{0.8}Cd_{0.2}Te$ would be needed to give the 15Å of CdTe, implying a decrease in overall layer thickness of ~6 nm. This is consistent with the upper limit of a terminal etch step of about 5 nm determined previously.[3] The larger CdTe bond strength compared to HgTe would then prevent further etching at these low temperatures. The time taken for the apparent x-value saturation is consistent with HgTe etch rates measured before, with the longer time likely due to Hg diffusion to the front surface. An additional observation is that RHEED patterns obtained from these (211)B oriented samples after atomic H etching more closely resembled that of a vicinal (211)B CdTe surface, and not HgCdTe. The presence of surface disorder cannot be ruled out, however. While CdTe overlayer formation is quite plausible, we cannot completely eliminate the possibility of a thicker x ~ 0.6 overlayer, although one questions what characteristics would make this composition stable with respect to atomic H etching. To better address this question, one must perform angle resolved XPS, with the capability to detect photoelectrons ejected from both normal incidence and at angles with the surface normal greater that the 30° of our detector, to probe both deeper and shallower.

OXIDIZED AND ETCHED MBE LAYERS

After the as-grown characteristics were measured, a series of MBE epilayers were oxidized in cleanroom ambient atmosphere overnight at FFI. Table I summarizes the O and C signals from representative samples. The x-ray beam could be focused completely on the sample at FFI, since the layers were grown on substrates larger than the measurement spot, and the O 1s and C 1s were thus indicative of the layers. As noted in Table I, a sensitivity factor for O was determined by assuming the oxide on elemental Te was strictly TeO_2. The oxide layer formed on the polycrystalline Te layer was the thickest of any studied. Oxide thickness was determined using the ratio of the Te-oxide signal to the Te signal representative of the matrix based on a simple model of an abrupt oxide layer on uniform "bulk" material.

Table I also summarizes results for as-grown CdTe, HgTe, and HgCdTe oxidized overnight in the cleanroom ambient atmosphere. As shown in the fourth column, the ratio of the total (Cd + Hg) signal to that of total Te was nearly unity indicating the oxide layers contained almost equal amounts of (Cd + Hg) and Te and is not simply TeO_2. The values for oxide on HgTe and HgCdTe are consistent with the formation of $Hg(Cd)TeO_3$, which has been reported for both ozone oxidation[6] and oxide formation during Br:methanol etching.[13] Of considerable interest is that room temperature oxidation also caused a significant amount of C to be present. A sensitivity factor was not directly measured for the C 1s signal, and the value used (0.05) was scaled from prior studies.[8] The normalized ratio of the C to total Te (i.e., the Te in the oxide plus the Te in the matrix) was quite large. Note that the oxide formed on CdTe is significantly different from that on HgTe or HgCdTe as it contains about five O atoms for each Te participating in a Te-O bond. Coupled with the large amount of C present, this suggests that "oxidation" may be caused in part by reactions with CO_2 from the air, with C being incorporated within the oxide layer. $CdCO_3$ is a stable compound, and so a reaction with Cd is quite feasible. A mixture of $CdCO_3$ and TeO_2 would explain the observed O 1s signal. However, this suggested mechanism remains speculative as there were no XPS signals clearly representative of the bond shifts previously reported for $CdCO_3$. Certainly it appears that oxidation in ambient atmosphere leads to the formation of complex layers.

In all cases, the oxide was easily removed at temperatures below 80°C with atomic hydrogen. Table II summarizes measured etch rates. The oxide layers were relatively thin, and the rate of removal fast enough that rates could only be reliably determined for lower atomic H flux. While the oxide on Te had a higher etch rate, there was not a significant difference between the oxide formed on CdTe, HgTe, or HgCdTe.

Table I. Summary of Oxygen and Carbon XPS Signals from MBE Epilayers Oxidized Overnight in Air at 40% Humidity

Sample	Oxide Thick.	O_{1s}/ Te-Oxide	(Cd+Hg)/ Total Te	C_{1s}/ Total Te
Te*	27Å	2.0†	—	0.2
CdTe	4.3Å	4.6	1.1	0.3
HgTe	6.0Å	2.6	0.7	0.3
$Hg_{0.8}Cd_{0.2}Te$	7.2Å	2.9	1.0	0.2

*Polycrystalline, grown on clean substrate block. †By definition, used to determine O_{1s}/Te-oxide sensitivity factor.

Table II. Oxide Etch Rates on As-Grown MBE Layers

Sample	H-Source Current	Attenuation Thickness	Attenuation Avg. Rate
Te Oxide	8.5 A	27Å	2Å/min
HgTe Oxide	7.0 A	5.0Å	0.5Å/min
HgTe Oxide	8.5 A	6.0Å	1.1Å/min
CdTe Oxide	7.0 A	5.3Å	0.3Å/min
CdTe Oxide	7.0 A	1.7Å	0.3Å/min
HgCdTe Oxide	7.0 A	7.2Å	0.3Å/min

In contrast to the polished LPE layers, the oxides on the as-grown MBE layers were quite stable with respect to both light exposure and vacuum storage. Carbon removal proved significantly more problematic at these temperatures (<80°C), and was not removed for any of the oxidized samples we looked at, although it was somewhat reduced for some samples etched with larger atomic hydrogen flux (i.e., higher source operating current). Longer exposure at high flux may remove the carbon from oxidized layers as was seen on some chemically etched MCT samples and substrates.

HgCdTe layers with nominal x-values of 0.2 were subjected to Br-based etching of appropriate times and concentrations to mimic device-processing steps. Both Br-methanol and Br-HBr were utilized. The as-etched layers were analyzed via XPS, and then exposed to atomic H flux. Figure 4 indicates the results obtained for a sample etched in Br-HBr. The trend shown was typical for samples receiving either treatment with some variation in starting surface composition. In some cases, a near surface lowering of the x-value was observed immediately after etching, with comparison between "deep" and "shallow" compositions indicating severe surface depletion of Cd. Other etched samples exhibited surfaces with an increased x-value. Neither case was unique to Br-HBR or Br-methanol etching. Seelman-Eggebert and Richter[13] previously reported similar phenomenon, concluding that surface x-value can vary widely in an unpredictable fashion for Br-based etching. In contrast to the polished LPE layers, little O or metallic Te was observed on the surface of properly prepared samples. When these surface contaminants were present in trace amounts, they were easily removed by low temperature atomic hydrogen cleaning. Removal of C, present on all etched surfaces, again proved problematic. Exposure to atomic hydrogen at high fluence for 20–30 min sometimes, but not always, removed the C at low temperature. Exposure to atomic hydrogen again increased the near-surface x-value, with the observed leveling to an x-value close to 0.6. When the etch depletes the surface of Cd, it would be possible to regain surface stoichiometry with atomic H exposure. In all cases, the observed increase in surface x-value may actually prove beneficial for device technology based on CdTe passivation.

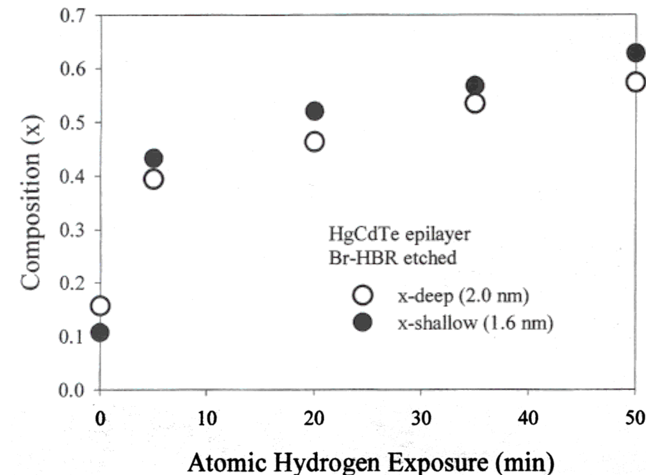

Fig. 4. Composition changes in the near-surface region of a Br-HBr-etched HgCdTe epilayer (x = 0.22) as a function of atomic hydrogen exposure. The H was maintained at 2.6×10^{-6} Torr (system pressure) with the source operated at 8.5 A (first 30 min) and 9.5 A (last 15 min).

SUMMARY

A detailed XPS study of atomic hydrogen etching of the HgCdTe alloy system was performed. Both Te and HgTe are etched with atomic hydrogen, with the HgTe etch rate about twice that of Te. Atomic hydrogen etching of HgCdTe produces an apparent saturation of x-value at 0.6. A simple model of a thin CdTe overlayer which blocks further etching explains this result, as well as the prior observation of self-limiting atomic hydrogen etching of HgCdTe. Air oxidation of CdTe produced a complex oxide significantly different than TeO_2 or $CdTeO_3$, while oxides on HgTe and HgCdTe were probably a mixture of TeO_2 and $Hg(Cd)TeO_3$. Consistent with prior work, oxides on as-grown CdTe, HgTe, HgCdTe and Te were easily removed with atomic H, while the C that was present on all oxidized and etched samples required a longer exposure at higher flux and was not always removed. At present, atomic hydrogen remains a promising tool for low-temperature oxide and overlayer removal from HgCdTe for CdTe passivation.

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