

Accurate determination of matrix composition profile of $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$ by SIMS

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Abstract

In this report, we present a new Secondary Ion Mass Spectrometry (SIMS) analysis technique to provide accurate Cd composition profiles based on the measurement of HgCs^+ and CdCs^+ cluster ions. Study of $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$ samples with different x values shows that $x/(1-x)$ is linearly proportional to $\text{HgCs}^+/\text{CdCs}^+$ over the range of $x=0.2$ to $x=0.9$. This technique allows us to obtain an accurate Cd profile for a multi-layer HgCdTe sample with different x-values for each layer using a single standard with known x-value.

Key words: **SIMS, HgCdTe, Cd composition, x-value, composition analysis, depth calibration**

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Introduction

Secondary Ion Mass Spectrometry (SIMS) is a powerful chemical analysis technique that employs mass spectrometry to analyze solid samples. One advantage of SIMS over many other techniques is its depth profiling capability for accurate dopant and composition analysis ⁽¹⁾.

Accurate determination of Cd composition distribution in $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$ layer is important to provide feedback on both growth and process. Previous approaches ⁽²⁾ which utilize Te^- ion or CdCs^+ ions provide good information on the general trend of composition variation through the layer, but do not provide accurate Cd composition for the layer except the region where composition closely match the standard used. In this report, we present a new technique to provide accurate Cd composition profile for the layer with different x values using a single composition standard.

This new technique is based on the measurement of both HgCs^+ and CdCs^+ together with the assumption that $(x+y)=0.5$ in $\text{Hg}_x\text{Cd}_y\text{Te}_{0.5}$. This technique has been successfully used in SIMS analysis of III-V compound to determine alloy composition ⁽³⁾. The study and adoption of the technique in analysis of this II-VI compound was previously prohibited by mass range limitation of Cameca 4f instruments. The maximum mass range on Cameca 4f instrument is ~ 280 amu, but HgCs^+ measurement requires mass range of 330 or higher. Similar to the previous technique⁽³⁾, As can be analyzed together with Cd composition, and point by point sputtering rate correction can be done with excellent accuracy.

Experiment

SIMS analyses were performed on a Cameca IMF-6f double focusing magnetic sector instrument. The laminated magnet has mass range of 500 amu, much greater than 280 amu on the IMS-4f instrument that we used in previous studies (2,4). The samples are bombarded by a focused Cs^+ primary ion beam with net impact energy of 5 keV and about 100 nA of beam

current. The beam is rastered over a square area of 200 μm on a side. The secondary ions formed from the sputtering process are accelerated away from the sample surface by a nominal sample voltage of 5 kV. A fraction of secondary ions are collected from a circular region centered in the rastered area.

Results and Discussion

The composition x of $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$ can be determined from:

$$X_{\text{Cd}} = R_{\text{Cd}} \times \text{CdCs}^+ / \text{TeCs}^+$$

$$X_{\text{Hg}} = 1 - X_{\text{Cd}} = 1 - R_{\text{Hg}} \times \text{HgCs}^+ / \text{TeCs}^+$$

This leads to:

$$X_{\text{Cd}} = 1 / \{1 + (R_{\text{Cd}}/R_{\text{Hg}}) \times (\text{CdCs}^+ / \text{HgCs}^+)\}$$

Or

$$(1 - X_{\text{Cd}}) / X_{\text{Cd}} = (R_{\text{Cd}}/R_{\text{Hg}}) \times (\text{CdCs}^+ / \text{HgCs}^+) \quad (1)$$

Where R_{Cd} and R_{Hg} are Relative Sensitivity Factors (RSF) for CdCs^+ and HgCs^+ , respectively, and can be determined from standard.

Figure 1 shows plot of $(\text{CdCs}^+ / \text{HgCs}^+)$ vs. $X_{\text{Cd}} / (1 - X_{\text{Cd}})$ for seven HgCdTe samples with x -values between 0.2 to 0.9. The plot shows that of $(\text{CdCs}^+ / \text{HgCs}^+)$ proportion linearly with

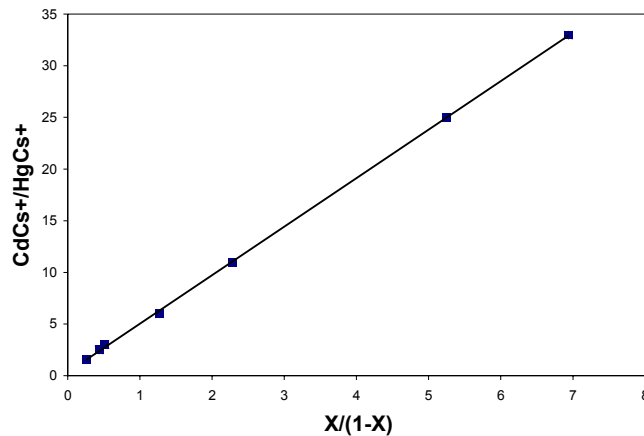


Figure 1. $(\text{CdCs}^+ / \text{HgCs}^+)$ vs. $X_{\text{Cd}} / (1 - X_{\text{Cd}})$ for x between 0.2 to 0.9.

$(1 - X_{\text{Cd}}) / X_{\text{Cd}}$, indicating that the ratio of R_{Cd} and R_{Hg} is independent of X -value. This relationship allows us to use a single standard to determine composition of a HgCdTe sample with unknown composition.

Figure 2 shows Cd composition of a multi composition HgCdTe sample, with X-value of 0.331, 0.550 and 0.857. The SIMS profile of Cd, based on a standard of $x=0.208$, shows very good agreement with these values. Figure 3 shows Cd profile of a LPE grown sample

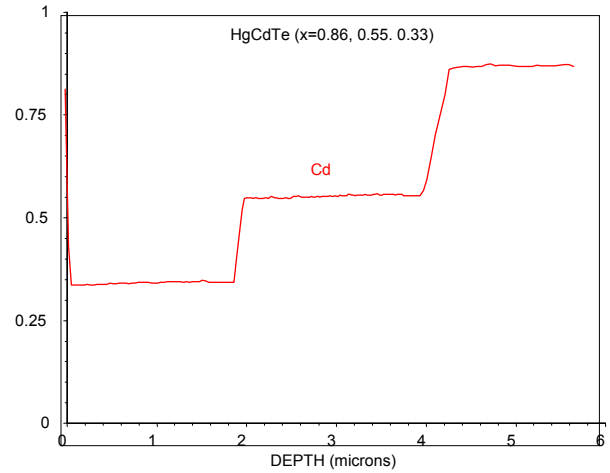


Figure 2. Cd profile with different x-values determined from a single standard of

calibrated using two different standards: $x=0.208$ and $x=0.411$. The Cd profiles with Cd composition varying continuously through the layer, shows excellent agreement for the entire curve using these two different standards. The maximum difference of Cd determined from two standards is 0.0021.

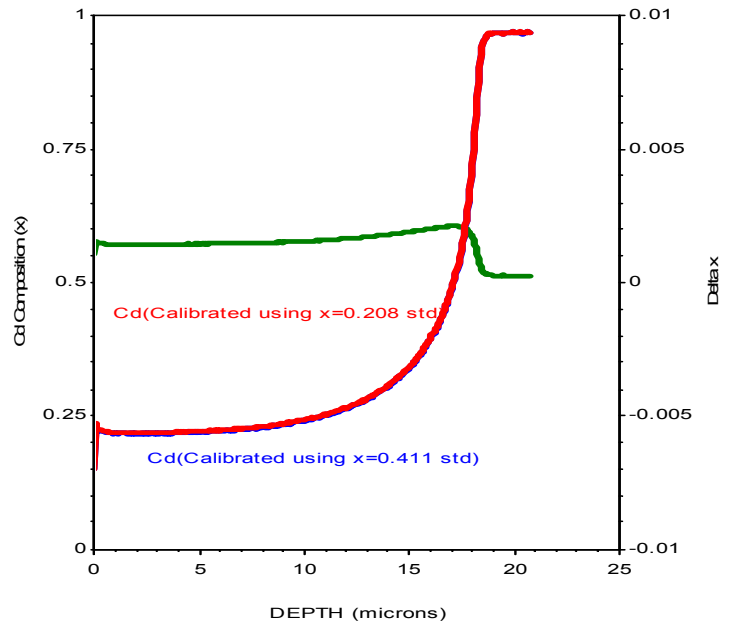


Figure 3. Cd composition profile of LPE HgCdTe sample. Composition calibrated using two standards with different x values $x=0.208$ and $x=0.411$. Δx from two standards are shown in the right hand axis.

Additional data confirming the accuracy of the X-value measurement was taken from modeled detector cutoff wavelengths. An accurate model which takes into account both compositional grading and diode geometries has been developed ⁽⁴⁾. However, only until compositional profiles have been measured using this technique, and included into the model, has there been excellent agreement between modeled and measured cutoff wavelengths, for LWIR HgCdTe detectors using LPE growth technique. Because the measured cutoff wavelength of LWIR detectors is very sensitive to X-value the modeled spectral characteristics can be used to

determine the accuracy of the X-value profiles, for the most important region which are the low X-values of the profile. As an example a change in X-value from 0.22 to 0.21 can change the measured cutoff wavelength of the detector, at $T = 78\text{K}$, from $10.82\ \mu\text{m}$ to $12.60\ \mu\text{m}$. A summary table of the detectors measured and the shift in X-value to obtain a good cutoff wavelength correlation is shown in Table 1, which indicates the X-value SIMS data are accurate to within ± 0.005 .

Table 1. Summary of Modeled Spectral Sample and X-value Adjustment to fit Model

Program	Wafer ID	Measured Cutoff at 78K (μm)	Modeled Cutoff using SIMS Cd measurements for X-Profiles	Equivalent X-Value Measured	X-Value adjusted to fit spectral	Delta X
A	598	10.64	10.63	0.2212	0.2213	0.000
A	599	10.60	11.68	0.2215	0.2148	0.007
A	614	10.75	12.49	0.2205	0.2105	0.010
A	625	10.80	12.80	0.2201	0.209	0.011
A	635	10.76	11.69	0.2204	0.2147	0.006
B	878	10.85	13.59	0.2198	0.2056	0.014
B	962	10.61	12.49	0.2214	0.2105	0.011
					Avg	0.008
					Stdev	0.005

These results are consistent with the precision of a SIMS analysis under these conditions. For a typical SIMS analysis of Cd composition, the analysis precision is $\pm 2\%$ based on calibration using an external standard. Much better precision ($< 0.5\%$) can be achieved using High Precision analysis conditions. If an internal reference point of X-value (for example, sample surface) is provided on a Cd profile, the precision for the other part of Cd profile calibration is 0.3% to 0.5%, limited mainly by the signal to noise ratio of the HgCs^+ profile. If the X-value on one portion of Cd needs re-adjustment, the entire Cd profile should be re-calibrated based on raw CdCs^+ and HgCs^+ profiles using equation (1). Arithmetic operations to adjust a portion of Cd composition to a desired value will result error in other portion of Cd profile, and affect the measurement of Δx ,

as shown in figure 4.

As with the previous $\text{CdCs}^+/\text{TeCs}^+$ method, the As can be measured together with Cd composition and point by point sputtering rate correction can be made to the entire profile (2). With an accurate Cd composition profile for the entire HgCdTe layer, more accurate depth correction can be obtained.

Summary

The technique of measuring the Cd composition

profile using CdCs^+ and HgCs^+ secondary ions provides an accurate method for Cd composition profiling. The total error on Cd composition is still subject to accuracy of the standard and SIMS analysis precision. Profiles calibrated using an internal X-value reference point can provide Cd profiles with much better precision.

References

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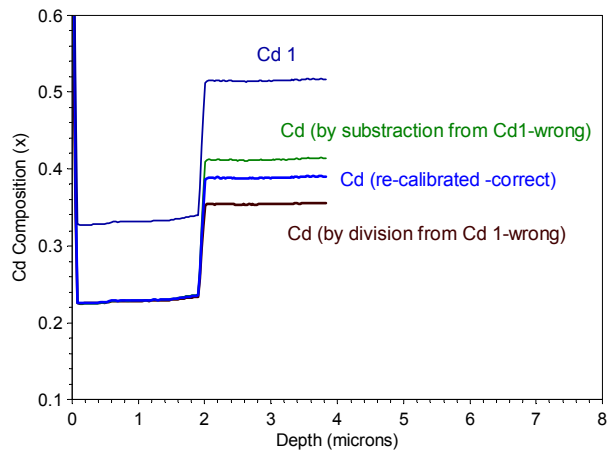


Figure 4. Due to $x/(1-x)$ function used for Cd calculation, Cd profile should NOT be shifted or scaled up or down to match X value of a certain layer. A re-calculation based on HgCs/CdCs profiles is required.