

Thin Film Measurement solution Software, sensors, custom development and integration

CIGS and CdS/CIGS measurement.

Several samples of CIGS and CdS/CIGS on Mo substrates were measured using MProbe VisNIR. Reflectance measurements were taken in 400-1700nm range. The visible range (400-900nm) was primarily used to determine CdS thickness and surface roughness, IR range (900-1700nm) is used to determine CIGS thickness (CIGS in most cases is opaque in the visible range). Transition region: 800-1000nm is important for determining CIGS composition.

CIGS is a quaternary alloy but the critical composition parameter (for production monitoring) is, typically, a ratio: Ga/(In+Ga) that we refer here as a "composition". The optimal composition is approximately in 34% to 45% range. Given that Cu is normally maintained at ~ 20% and Se at ~ 50%; this gives Cu/(In+Ga) ~ 0.9 to1.0 and Se/(In+Ga+Cu) at ~ 1.0- 1.1.

For composition analysis, CIGS is represented using a compound model that uses available n,k dispersion for different compositions (Ga/(In+Ga)) and allows determine unknown composition by interpolating between known compositions (see Fig.1).



Fig. 1 n,k dispersion spectra for different compositions of CIGS

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I. <u>Measurement of CIGS layer on Mo substrate.</u>

Basic model for CIGS filmstack: CIGS_rough.em2/2.5 um CIGS_mis.comp/Mo Where **CIGS_mix.comp** is a compound model that interpolates between known CIGS compositions; **CIGS_rough.em2** is a layer representing surface roughness (an effective-medium approximation of CIGS + void).

Details:

a). CIGS in the main layer (layer 1) and in roughness layer is the same material, so materials in these two layer are linked.

b). CIGS_rough.em2 represents only part of the roughness effect i.e. effective layer, however, it does not represent light scattering. The scattering effect is modeled using Kirchoff approximation.

c). Reflectivity below 500nm is very low (<0.5 %), so the measurement in 400-500nm is not very useful and was removed.

Calculated parameters:

- 1. Thickness of CIGS layer (d1)
- 2. CIGS composition
- 3. Thickness of roughness layer(d2)
- 4. Composition of roughness layer (volume fraction of void)
- 5. RMS roughness from scattering (it is approximately the same as d2 but need to be calculated separately)

Measurement results presented at Fig. 1-6 show excellent fit to the measured data and consistent determination of the parameters. In fact, correlation between measured parameters is quite good indicating that they can be determined accurately (Table 1) The only exception is the correlation between roughness layer EMA (2_fv) and scattering (2_rough) parameters, but they represent essentially the same physical layer and are expected to be correlated.

👫 Parameters Correlation Data					×
1_Thickness	1_Composition	2_Thickness	2_fv[1]	2_Rough	1
1.000	0.310	0.581	0.504	0.368	
0.310	1.000	0.295	0.436	0.466	
0.581	0.295	1.000	0.329	0.229	1
0.504	0.436	0.329	1.000	0.915	1
0.368	0.466	0.229	0.915	1.000	
	relation Data 1_Thickness 1.000 0.310 0.581 0.504 0.368	I_Thickness I_Composition 1.000 0.310 0.310 1.000 0.581 0.295 0.504 0.436 0.368 0.466	I_Composition 2_Thickness 1_Thickness 1_Composition 2_Thickness 1.000 0.310 0.581 0.310 1.000 0.295 0.581 0.295 1.000 0.504 0.436 0.329 0.368 0.466 0.229	I_Thickness I_Composition 2_Thickness 2_fv[1] 1.000 0.310 0.581 0.504 0.310 1.000 0.295 0.436 0.581 0.295 1.000 0.329 0.504 0.436 0.329 1.000 0.504 0.436 0.229 0.915	I_Composition 2_Thickness 2_fv[1] 2_Rough 1.000 0.310 0.581 0.504 0.368 0.310 1.000 0.295 0.436 0.466 0.504 0.295 1.000 0.329 0.229 0.504 0.436 0.329 0.915 1.000 0.504 0.436 0.329 1.000 0.915

Table 1. Correlation between measured parameters of CIGS sample.



Fig. 2 Sample 1. Measured and calculated data fit. CIGS thickness 2.58um + roughness (93nm). CIGS Composition: 44%. RMS ~ 85nm



Fig, 3. Zoomed chart (from Fig, 2) shows excellent fit between measured and calculated data.

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Fig. 5 Sample 3. Measured and calculated data fit. CIGS thickness 2.3um + roughness (97nm). CIGS Composition: 35%. RMS ~ 97nm

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Fig. 6 Sample 4. Measured and calculated data fit. CIGS thickness 1.7um + roughness (100nm). CIGS Composition: 27%. RMS ~ 97nm



Fig, 7 Sample 4 SEM measurement shows thickness of 1.8 um that is consistent with the results above (1.7um +0.1um (roughness))

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II Measurement of CdS/CIGS stack on Mo substrate

CdS is deposited on top of rough CIGS surface. The top roughness layer is conformal with the CIGS surface roughness but, as compared with a pure CIGS layer, the roughness layer is now more complicated – it is a mixture of CIGS, CdS and void. The following filmstack is used for data analysis: 100nm CdS (rough)/1.7um CIGS/Mo.

The results of the measurement of 3 samples (CdS_1, CdS_2. CdS_3) are presented on Fig. 8-10



Fig. 8 Sample CdS_1. Measured and calculated data fit. CIGS thickness:1.54um, CdS thickness: 77nm, RMA: 61nm, CIGS composition: 45%, void fraction in CdS roughness layer: 20%



Fig. 9 Sample CdS_2. Measured and calculated data fit. CIGS thickness:1.82um, CdS thickness: 95nm, RMA: 95nm, CIGS composition: 51%, void fraction in CdS roughness layer: 8%



Fig. 10 Sample CdS_3. Measured and calculated data fit. CIGS thickness:1.77um, CdS thickness: 87nm, RMA: 81nm, CIGS composition: 51%, void fraction in CdS roughness layer: 18%