

Result Summary of CCQM K-129

Measurement of mole fractions of Cu, In, Ga and Se in Cu(In,Ga)Se₂ Films

Object: Measurement of average mole fractions of Cu, In, Ga and Se in a CIGS film.

Measurand: Average mole fractions of Cu, In, Ga and Se of a CIGS film in the unit of mol/mol

1. Average mole fraction of Cu in a CIGS film

(1) Laboratory individual measurements

Measurand: average mole fraction of Cu in a CIGS film expressed as a mole fraction (Unit: mol/mol)

x_i : result of measurement carried out by laboratory i

U_i : expanded uncertainty of laboratory i for a 95 % confidence interval

Lab i	Method	x_i / mol/mol	U_i / mol/mol
BAM	AES	0.2464	0.0069
KRISS	XPS	0.2448	0.0068
NIM	XPS	0.2448	0.0065
NIST	SIMS	0.2544	0.0069
NMIJ	AES	0.2426	0.0078
PTB	XRF	0.2380	0.0083

(2) Equivalence statements

Measurand: average mole fraction of Cu in a CIGS film expressed as a mole fraction (Unit: mol/mol)

The key comparison reference values, x_R , are calculated by the uncertainty-weighted mean of the arithmetic mean (x_{SDP}) for the SDP results (BAM, KRISS, NIM, NIST and NMIJ) and the reported mole fraction by reference-free XRF data (x_{XRF}) by PTB.

The expanded uncertainty of key comparison reference values, U_R , are also calculated by the uncertainty-weighted mean of the SDP results (U_{SDP}) and the uncertainty for the reference-free XRF data (U_{XRF})

$$x_R = 0.2424 \text{ mol/mol}, U_R = 0.0058 \text{ mol/mol}$$

The degree of equivalence of laboratory i (D_i) relative to the key comparison reference value is given by a pair of terms, both expressed in "mol/mol": $D_i = (x_i - x_R)$ and its expanded uncertainty $U(D_i) = (U_i^2 + U_R^2)^{1/2}$, where U_i is the expanded uncertainty of x_i evaluated at a 95 % level of confidence.

(3) Degrees of equivalence

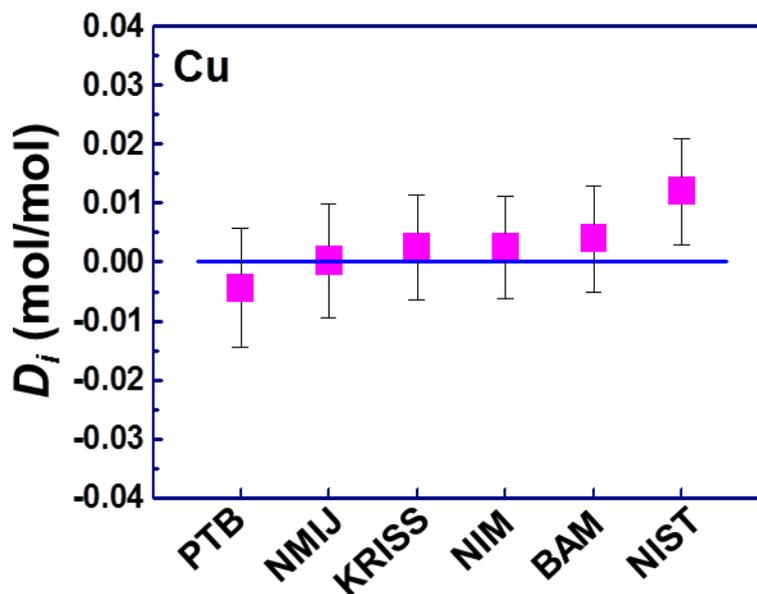
Measurand: average mole fraction of Cu in a CIGS film expressed as a mole fraction (Unit: mol/mol)

Lab <i>i</i>	Method	D_i	$U(D_i)$
BAM	AES	0.0040	0.0090
KRISS	XPS	0.0024	0.0087
NIM	XPS	0.0120	0.0090
NIST	SIMS	0.0002	0.0097
NMIJ	AES	-0.0044	0.0101
PTB	XRF	0.0040	0.0090

(4) Graph of equivalence

Measurand: average mole fraction of Cu in a CIGS film expressed as a mole fraction (Unit: mol/mol)

Degrees of equivalence: $D_i = (x_i - x_R)$ and expanded uncertainty ($U(D_i)$) expressed in mol/mol.



$$x_R = 0.2424 \text{ mol/mol}, U_R = 0.0058 \text{ mol/mol}$$

2. Average mole fraction of In in a CIGS film

(1) Laboratory individual measurements

Measurand: average mole fraction of In in a CIGS film expressed as a mole fraction (Unit: mol/mol)

x_i : result of measurement carried out by laboratory i

U_i : expanded uncertainty of laboratory i for a 95 % confidence interval

Lab i	Method	x_i / mol/mol	U_i / mol/mol
BAM	AES	0.1683	0.0058
KRISS	XPS	0.1718	0.0049
NIM	XPS	0.1734	0.0058
NIST	SIMS	0.1554	0.0048
NMIJ	AES	0.1745	0.0063
PTB	XRF	0.1807	0.0187

(2) Equivalence statements

Measurand: average mole fraction of In in a CIGS film expressed as a mole fraction (Unit: mol/mol)

The key comparison reference values, x_R , are calculated by the uncertainty-weighted mean of the arithmetic mean (x_{SDP}) for the SDP results (BAM, KRISS, NIM, NIST and NMIJ) and the reported mole fraction by reference-free XRF data (x_{XRF}) by PTB.

The expanded uncertainty of key comparison reference values, U_R , are also calculated by the uncertainty-weighted mean of the SDP results (U_{SDP}) and the uncertainty for the reference-free XRF data (U_{XRF})

$$x_R = \mathbf{0.1715 \text{ mol/mol}}, U_R = \mathbf{0.0091 \text{ mol/mol}}$$

The degree of equivalence of laboratory i (D_i) relative to the key comparison reference value is given by a pair of terms, both expressed in "mol/mol": $D_i = (x_i - x_R)$ and its expanded uncertainty $U(D_i) = (U_i^2 + U_R^2)^{1/2}$, where U_i is the expanded uncertainty of x_i evaluated at a 95 % level of confidence.

(3) Degrees of equivalence

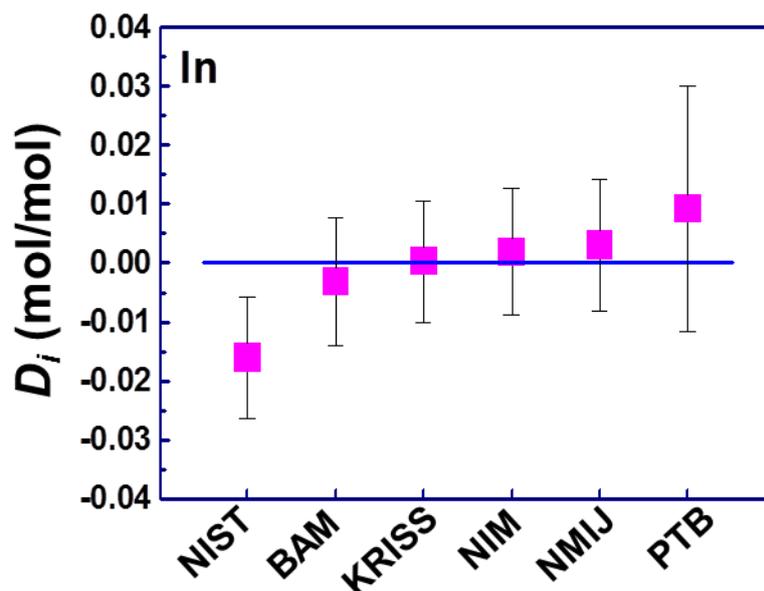
Measurand: average mole fraction of In in a CIGS film expressed as a mole fraction (Unit: mol/mol)

Lab i	Method	D_i	$U(D_i)$
BAM	AES	-0.0032	0.0108
KRISS	XPS	0.0019	0.0108
NIM	XPS	-0.0161	0.0103
NIST	SIMS	0.0030	0.0111
NMIJ	AES	0.0092	0.0208
PTB	XRF	-0.0032	0.0108

(4) Graph of equivalence

Measurand: average mole fraction of In in a CIGS film expressed as a mole fraction (Unit: mol/mol)

Degrees of equivalence: $D_i = (x_i - x_R)$ and expanded uncertainty ($U(D_i)$) expressed in mol/mol



$$x_R = 0.1715 \text{ mol/mol}, U_R = 0.0091 \text{ mol/mol}$$

3. Average mole fraction of Ga in a CIGS film

(1) Laboratory individual measurements

Measurand: average mole fraction of Ga in a CIGS film expressed as a mole fraction (Unit: mol/mol)

x_i : result of measurement carried out by laboratory i

U_i : expanded uncertainty of laboratory i for a 95 % confidence interval

Lab i	Method	x_i / mol/mol	U_i / mol/mol
BAM	AES	0.0855	0.0081
KRISS	XPS	0.0872	0.0027
NIM	XPS	0.0827	0.0028
NIST	SIMS	0.0824	0.0020
NMIJ	AES	0.0835	0.0032
PTB	XRF	0.0765	0.0047

(2) Equivalence statements

Measurand: average mole fraction of Ga in a CIGS film expressed as a mole fraction (Unit: mol/mol)

The key comparison reference values, x_R , are calculated by the uncertainty-weighted mean of the arithmetic mean (x_{SDP}) for the SDP results (BAM, KRISS, NIM, NIST and NMIJ) and the reported mole fraction by reference-free XRF data (x_{XRF}) by PTB.

The expanded uncertainty of key comparison reference values, U_R , are also calculated by the uncertainty-weighted mean of the SDP results (U_{SDP}) and the uncertainty for the reference-free XRF data (U_{XRF})

$$x_R = 0.0823 \text{ mol/mol}, U_R = 0.0024 \text{ mol/mol}$$

The degree of equivalence of laboratory i (D_i) relative to the key comparison reference value is given by a pair of terms, both expressed in "mol/mol": $D_i = (x_i - x_R)$ and its expanded uncertainty $U(D_i) = (U_i^2 + U_R^2)^{1/2}$, where U_i is the expanded uncertainty of x_i evaluated at a 95 % level of confidence.

(3) Degrees of equivalence

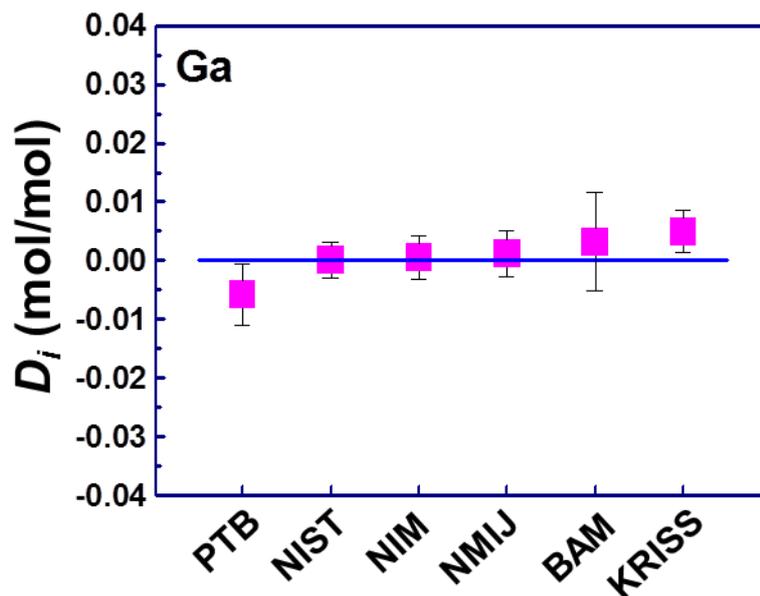
Measurand: average mole fraction of Ga in a CIGS film expressed as a mole fraction (Unit: mol/mol)

Lab i	Method	D_i	$U(D_i)$
BAM	AES	0.0032	0.0084
KRISS	XPS	0.0005	0.0037
NIM	XPS	0.0001	0.0031
NIST	SIMS	0.0012	0.0040
NMIJ	AES	-0.0058	0.0053
PTB	XRF	0.0032	0.0084

(4) Graph of equivalence

Measurand: average mole fraction of Ga in a CIGS film expressed as a mole fraction (Unit: mol/mol)

Degrees of equivalence: $D_i = (x_i - x_R)$ and expanded uncertainty ($U(D_i)$) expressed in mol/mol



$$x_R = 0.0823 \text{ mol/mol}, U_R = 0.0024 \text{ mol/mol}$$

4. Average mole fraction of Se in a CIGS film

(1) Laboratory individual measurements

Measurand: average mole fraction of Se in a CIGS film expressed as a mole fraction (Unit: mol/mol)

x_i : result of measurement carried out by laboratory i

U_i : expanded uncertainty of laboratory i for a 95 % confidence interval

Lab i	Method	x_i / mol/mol	U_i / mol/mol
BAM	AES	0.4998	0.0176
KRISS	XPS	0.4962	0.0236
NIM	XPS	0.4991	0.0177
NIST	SIMS	0.5078	0.0162
NMIJ	AES	0.4993	0.0172
PTB	XRF	0.5048	0.0209

(2) Equivalence statements

Measurand: average mole fraction of Se in a CIGS film expressed as a mole fraction (Unit: mol/mol)

The key comparison reference values, x_R , are calculated by the uncertainty-weighted mean of the arithmetic mean (x_{SDP}) for the SDP results (BAM, KRISS, NIM, NIST and NMIJ) and the reported mole fraction by reference-free XRF data (x_{XRF}) by PTB.

The expanded uncertainty of key comparison reference values, U_R , are also calculated by the uncertainty-weighted mean of the SDP results (U_{SDP}) and the uncertainty for the reference-free XRF data (U_{XRF})

$$x_R = \mathbf{0.5021 \text{ mol/mol}}, U_R = \mathbf{0.0127 \text{ mol/mol}}$$

The degree of equivalence of laboratory i (D_i) relative to the key comparison reference value is given by a pair of terms, both expressed in "mol/mol": $D_i = (x_i - x_R)$ and its expanded uncertainty $U(D_i) = (U_i^2 + U_R^2)^{1/2}$, where U_i is the expanded uncertainty of x_i evaluated at a 95 % level of confidence.

(3) Degrees of equivalence

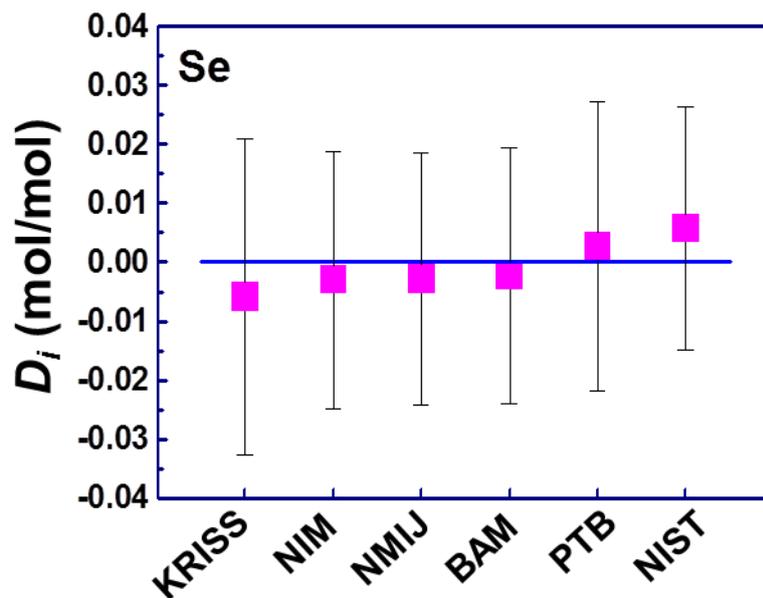
Measurand: average mole fraction of Se in a CIGS film expressed as a mole fraction (Unit: mol/mol)

Lab i	Method	D_i	$U(D_i)$
BAM	AES	-0.0023	0.0217
KRISS	XPS	-0.0030	0.0218
NIM	XPS	0.0057	0.0206
NIST	SIMS	-0.0028	0.0214
NMIJ	AES	0.0027	0.0245
PTB	XRF	-0.0023	0.0217

(4) Graph of equivalence

Measurand: average mole fraction of Se in a CIGS film expressed as a mole fraction (Unit: mol/mol)

Degrees of equivalence: $D_i = (x_i - x_R)$ and expanded uncertainty ($U(D_i)$) expressed in mol/mol



$$x_R = 0.5021 \text{ mol/mol}, U_R = 0.0127 \text{ mol/mol}$$