EDX Intensity

Identify primary factors influencing spectra:

energy

electron dose

thickness

composition

$$I(E) = \alpha(E) \cdot D_e \cdot n \cdot T \cdot A(T,E) \cdot \sum_k x_k \cdot g_k(E)$$

measured intensity

geometric factor

atomic concentration

absorption correction

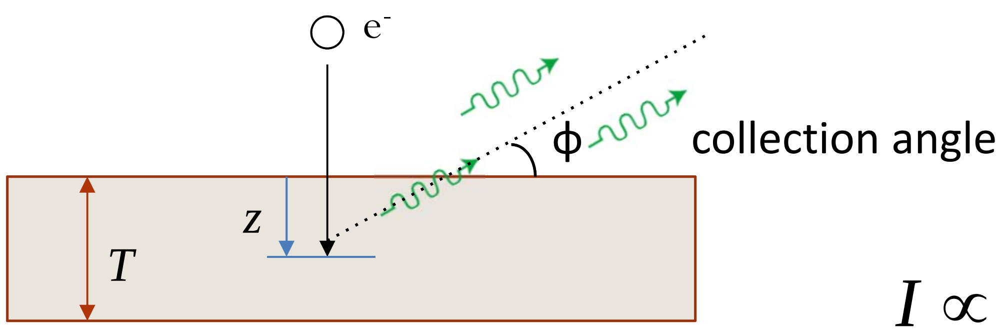
elements

generation rate

X-ray absorption

X-rays generated below the surface of the TEM foil can be absorbed before escaping.

Assume the electron beam is unattenuated.



$$I \propto \int_{z=0}^{T} e^{-\mu(E)\cdot\csc\phi\cdot z} \cdot dz$$

$$A(T,E) = \frac{1 - e^{-\mu(E)\cdot\csc\phi\cdot T}}{\mu(E)\cdot\csc\phi}$$

Absorption correction

attenuation coefficient for an element

$$\mu(E) = n \cdot \sigma_k(E) = \frac{N_A \cdot \rho \cdot \sigma_k(E)}{M_k}$$

mass-attenuation coefficient for an element

$$\left(\frac{\mu(E)}{\rho}\right)_k = \frac{N_A \cdot \sigma_k(E)}{M_k}$$

attenuation coefficient for a composite

$$\mu(E) = \sum_k n_k \cdot \sigma_k(E)$$

concentration of an element in a composite

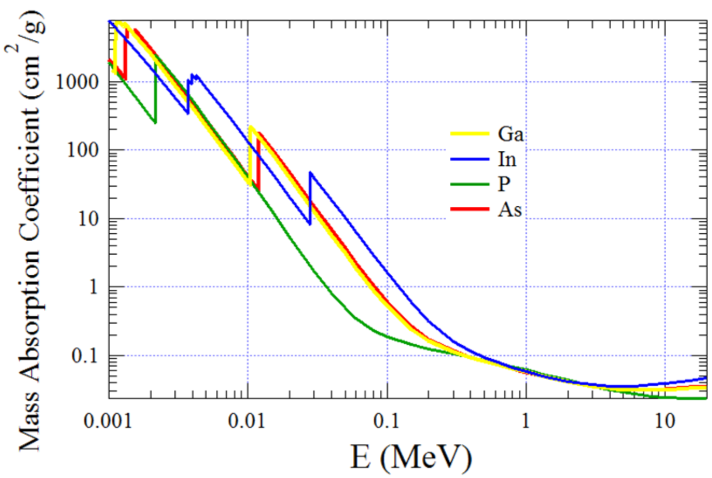
$$n_k = \frac{N_A \cdot \rho \cdot x_k}{\sum_\ell x_\ell \cdot M_\ell}$$

mass-attenuation coefficient of a composite

$$\frac{\mu(E)}{\rho} = \frac{\sum_k N_A \cdot x_k \cdot \sigma_k(E)}{\sum_\ell x_\ell \cdot M_\ell}$$

scattering cross-section for an element

$$\sigma_k(E) = \frac{M_k}{N_A} \cdot \left(\frac{\mu(E)}{\rho}\right)_k$$



https://www.nist.gov/pml/x-ray-mass-attenuation-coefficients

mass-attenuation coefficient of a composite

$$\frac{\mu(E)}{\rho} = \sum_k \left[\frac{x_k \cdot M_k}{\sum_\ell x_\ell \cdot M_\ell} \cdot \left(\frac{\mu(E)}{\rho}\right)_k\right] = \sum_k y_k \cdot \left(\frac{\mu(E)}{\rho}\right)_k$$

mass ratios: $$y_k = \frac{x_k \cdot M_k}{\sum_\ell x_\ell \cdot M_\ell}$$

k-factors

Consider intensity at two energies associated with different elements:

$$I(E_1) = \alpha(E_1)\cdot D_e \cdot n \cdot T \cdot A(T, E_1)\cdot g_1(E_1)\cdot x_1$$

$$I(E_2) = \alpha(E_2)\cdot D_e \cdot n \cdot T \cdot A(T, E_2)\cdot g_2(E_2)\cdot x_2$$

$$\frac{I(E_2)}{I(E_1)} = \frac{\alpha(E_2)\cdot \cancel{D_e \cdot n \cdot T} \cdot A(T, E_2)\cdot g_2(E_2)\cdot x_2}{\alpha(E_1)\cdot \cancel{D_e \cdot n \cdot T} \cdot A(T, E_1)\cdot g_1(E_1)\cdot x_1}$$

$$\frac{I_2}{I_1} = \frac{1}{k_{12}}\cdot\frac{x_2}{x_1}$$

$$\frac{x_2}{x_1} = k_{12}\cdot\frac{I_2}{I_1}$$

//Cliff-Lorimer (1975)

ζ-factors

$$\frac{I_2}{I_1} = \frac{x_2/\zeta_2}{x_1/\zeta_1}$$

Use known relationships among the constituent compositions:

$$x_1 + x_2 = 1$$

$$\frac{x_2}{x_1} = \frac{\zeta_2 \cdot I_2}{\zeta_1 \cdot I_1} \longrightarrow \frac{1 - x_1}{x_1} = \frac{\zeta_2}{\zeta_1} \cdot \frac{I_2}{I_1}$$

$$x_1 = \frac{\zeta_1 \cdot I_1}{\zeta_1 \cdot I_1 + \zeta_2 \cdot I_2}$$

$$x_2 = \frac{\zeta_2 \cdot I_2}{\zeta_1 \cdot I_1 + \zeta_2 \cdot I_2}$$

In general:

$$x_i = \frac{\zeta_i \cdot I_i}{\sum_j \zeta_j \cdot I_j}$$

//Watanabe-Williams (2006)

Relating pairs of elements

$\underline{A_{1-x}B_x}$

$$\frac{x}{1-x}=\frac{\zeta_B}{\zeta_A}\cdot\frac{I_B}{I_A}$$

$$\frac{\zeta_B}{\zeta_A}=\frac{x}{1-x}\cdot\left(\frac{I_B}{I_A}\right)^{-1}$$

$\underline{A_{1-y}C_y}$

$$\frac{y}{1-y}=\frac{\zeta_C}{\zeta_A}\cdot\frac{I_C}{I_A}$$

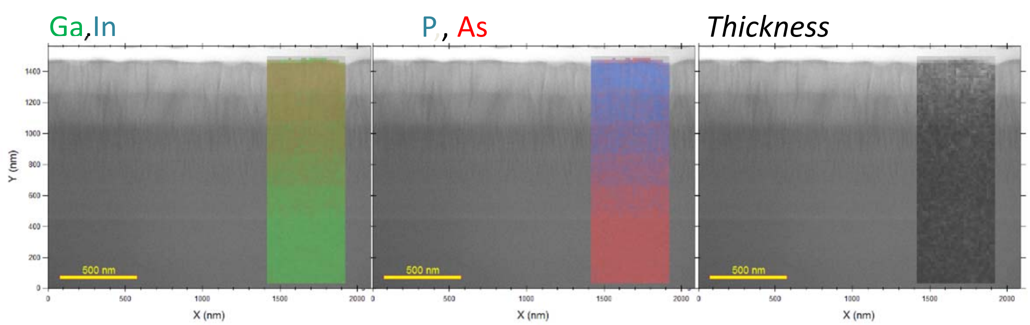
$$\frac{\zeta_C}{\zeta_A}=\frac{y}{1-y}\cdot\left(\frac{I_C}{I_A}\right)^{-1}$$

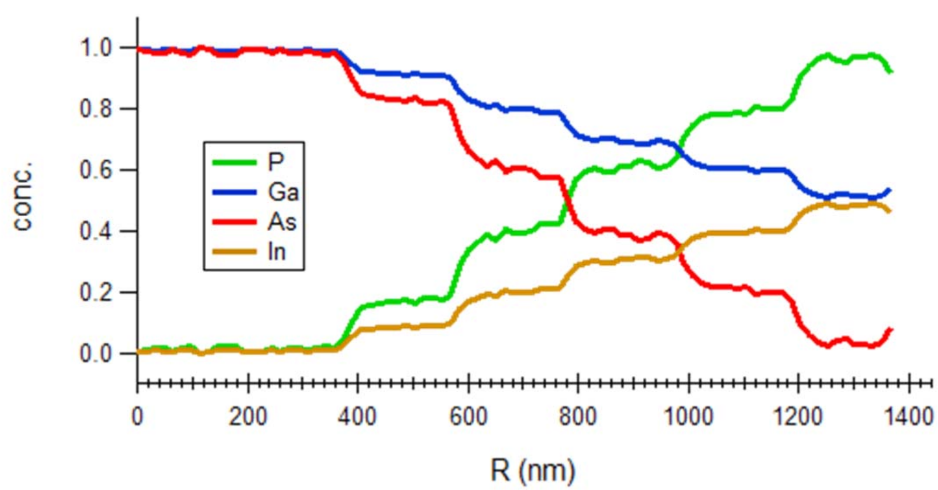
$\underline{B_{1-z}C_z}$

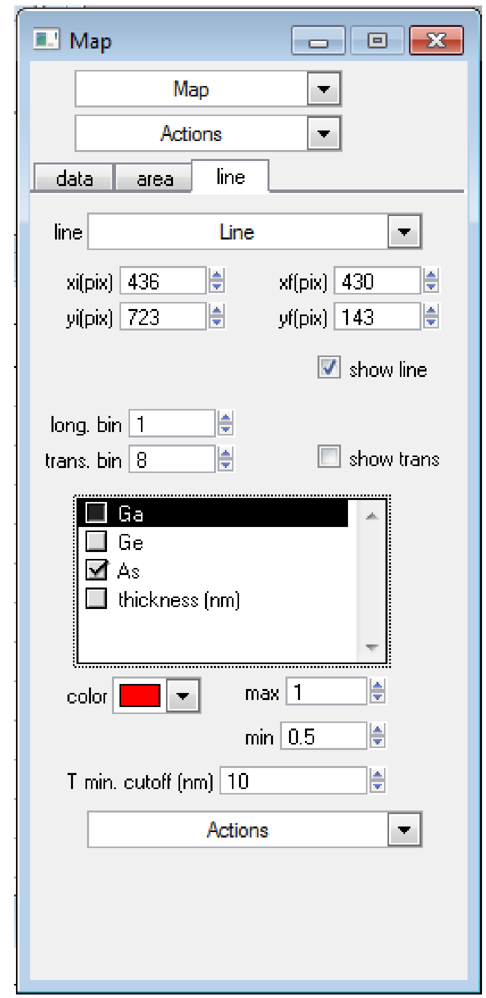
$$\frac{z}{1-z}=\frac{\zeta_C}{\zeta_B}\cdot\frac{I_C}{I_B}$$

$$\frac{\zeta_C}{\zeta_B}=\frac{\zeta_C}{\zeta_A}\cdot\frac{\zeta_A}{\zeta_B}$$

EDX Mapping


Ga,In
P, As
Thickness
500 nm
500 nm
500 nm
Y (nm)
X (nm)
X (nm)
X (nm)


1.0
0.8
0.6
0.4
0.2
0.0
conc.
P
Ga
As
In
0
200
400
600
800
1000
1200
1400
R (nm)


Map
Map
Actions
data
area
line
line
Line
xi(pix) 436
xf(pix) 430
yi(pix) 723
yf(pix) 143
show line
long. bin 1
trans. bin 8
show trans
Ga
Ge
As
thickness (nm)
color
max 1
min 0.5
T min. cutoff (nm) 10
Actions