Figure 1.1.

A. Spatially averaged characterization.
B. Microcharacterization
Figure 2A. Scanning Probe.

Figure 2B. Global imaging
<table>
<thead>
<tr>
<th>SENSE</th>
<th>PROBE</th>
<th>MICROSCOPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIGHT</td>
<td>Electromagnetic Radiation</td>
<td>Light, electron. ion, tunneling</td>
</tr>
<tr>
<td>SOUND</td>
<td>Acoustical Radiation</td>
<td>Acoustical</td>
</tr>
<tr>
<td>TOUCH</td>
<td>Mechanical Atomic Forces</td>
<td>AFM, STM, stylus</td>
</tr>
<tr>
<td>SMELL</td>
<td>Chemical</td>
<td>Ion Conductance</td>
</tr>
</tbody>
</table>

Table 1.1
How We See the World?
What is a Trace Technique?

\[(1 \mu m)^3 \Rightarrow \text{volume } V = 10^{12} \text{ Å}^3\]

\[n = 0.06 \text{ atoms/Å}^3 \text{ for Aluminum}\]

\[\therefore N_{Al} \text{ in } (1 \mu m)^3 = 6 \times 10^{10} \text{ atoms}\]

1 PPM = \(6 \times 10^4\) atoms
1 PPB = 60 atoms

BUT,

\[(1 \text{ nm})^3 \Rightarrow \text{volume } V = 10^3 \text{ Å}^3\]

\[\therefore N_{Al} \text{ in } (1 \text{ nm})^3 = 60 \text{ atoms}!\]

The minimum detectable concentration, \(\text{MDC} \geq \frac{1}{N}\)

\[\therefore \text{at } (1 \text{ nm})^3 \Rightarrow \text{MDC} \geq 1.62 \times 10^{-2}.\]

less than 2%
Figure 1.3
The detectable concentration in a cube of volume = $d^3$.
$N =$ minimum number of atoms detectable.
Particle Scattering

Probability that an interaction occurs in $dx = P$
$P = \sigma \, ndx$, $\sigma$ = effective interaction area/”cross-section”
Particle Scattering

Figure 1.4. Schematic of the scattering process.

\[
\frac{dJ}{dx} = -J \sigma n dx
\]

\[
\int_{J(0)}^{J(t)} \frac{dJ}{J} = - \int_{0}^{t} \sigma n dx
\]

\[
J(t)/J(0) = e^{-n \sigma t}
\]
Figure 1.5
Geometry of collection of X-Rays around probed area.
Sample Calculation

\[ S = NT \delta \gamma F \]

\[
\text{take } J = 10^3 \text{ amp/cm}^2 \times 6 \times 10^{18} \text{ elec/sec/amp} = 6 \times 10^{21} \text{ elec/sec/cm}^2
\]

\[
\text{cross sectm } = 2.8 \times 10^{-21} \text{ cm}^2 \text{ with 100keV electrons,}
\]

\[
\text{fluorine yield } \gamma = \omega_k^{Al} = 2.5 \times 10^{-2}
\]

If X-ray detector area \( A = 30 \text{ mm}^2 \) and
detector is \( d = 10 \text{ mm from point probe hits sample.} \)

\[
F = \frac{I_{\text{collected}}}{4 \pi} = \frac{30 \text{ mm}^2}{(10 \text{ mm})^2} = 2.4 \times 10^{-2} \text{ sterads}
\]

\[
F = \frac{I_{\text{collected}} \cdot I_{\text{detector}}}{I_{\text{det}}}
\]

\[
= 2.4 \times 10^{-2} \text{ assuming } I_{\text{det}} = 1
\]

\[
\therefore S = \frac{(6 \times 10^{21} \text{ elec/sec})(2.8 \times 10^{-21} \text{ cm}^2)(2.5 \times 10^{-2})(2.4 \times 10^{-2})}{N_{Al}}
\]

\[
\frac{S}{N_{Al}} = 1.01 \times 10^{-2} \text{ cts/sec/atom}
\]

If sample 100\% thick, probe diameter = 100 \( \text{\AA} \), then \( N = 23.6 \times 10^4 \text{ atoms} \)

\[
\therefore S = 1.01 \times 10^{-2} \times 23.6 \times 10^4 = 2.36 \times 10^3 \text{ cts/sec for pure Al}
\]

\[
\frac{S}{N_{Al}} = 23.6 \text{ cts/sec for 1\% concentration}
\]
Figure 1. Micrographs of thin carbon films prepared by evaporation of spectroscopically pure graphite onto NaCl substrates: (a) 6.6Å average thickness, substrate temperature 75°C; (b) 14Å, Tsub ≤ 50°C; (c) 6.6Å, Tsub ≤ 150°C.

Figure 2. Micrograph of gold atoms (from a dilute AuCl₃ solution) deposited on a carbon film similar to that in figure 1(b). The micrographs shown in Figs. 1 and 2 were obtained using the annular detector signal.

M.Isaacson, M.Ohtsuki and M.Utlaut. 1979
O. Krivanek et al. 2012, Ultramicroscopy in press. (O. Krivanek and M. Isaacson, eds.)
\[ S = NJ\sigma YF \]

\( S \) = signal in counts/sec  
\( N \) = \# atoms in volume probed  
\( J \) = current density in probe (\#/area/sec)  
\( \sigma \) = cross section for interaction (area)  
\( Y \) = yield of process to be detected  
\( F \) = efficiency of collection
\[ S = N J \sigma Y F \]

- **S** = signal in counts/sec
- **N** = \# atoms in volume probed
- **J** = current density in probe (\#/area/sec)
- \( \sigma \) = cross section for interaction (area)
- **Y** = yield of process to be detected
- **F** = efficiency of collection

Sample parameters, Interaction process

Experimental parameters

sample
\[ N_A = \frac{S_A}{J_A \sigma_A Y_A F_A} \]

\[ \frac{N_A}{N_B} = \frac{S_A}{S_B} \left[ \frac{\sigma_B}{\sigma_A} \left( \frac{Y_B F_B}{Y_A F_A} \right) \right] J_B / J_A \]
\[ N_A = S_A / J_A \sigma_A Y_A F_A \]

\[ \frac{N_A}{N_B} = \frac{S_A}{S_B} \left[ \frac{\sigma_B}{\sigma_A} \left( \frac{Y_B F_B}{Y_A F_A} \right) \right] J_B J_A \]

\[ \frac{N_A}{N_B} = \frac{S_A}{S_B} \left[ \frac{\sigma_B}{\sigma_A} \left( \frac{Y_B F_B}{Y_A F_A} \right) \right] \]
\[ S = NJ\sigma YF \]

\[ K_{AB} = \frac{\sigma_B}{\sigma_A} \left( \frac{Y_B F_B}{Y_A F_A} \right) \]

\[ \frac{N_A}{N_B} = K_{AB} \frac{S_A}{S_B} \]
Electron beam interactions

- forward scattering
- backscattering
- secondary electrons
- other secondary “particles”
Auger electrons, secondary electrons

backscattered electrons

e

\( e^- \)

e

\( d_{beam} \)

light, x-rays

escape depth

sample

range

maximum diameter of excitation volume

almost all incident energy is deposited within this volume
100 nm Aluminum Film Self-Supported on Silicon Fingers

*secondary electron image*

M. Isaacson and K. Lin