

Scanning Electron Microscopy in Real-World Environments

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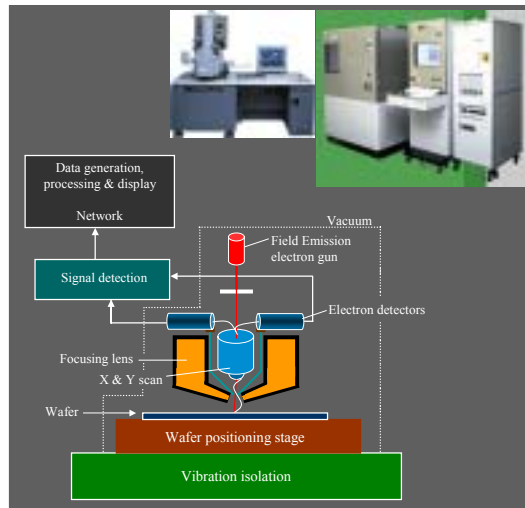
Scanning Electron Microscopy in Real-World Environments

SEMs

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Scanning Electron Microscopes

- imaging microscopes
- metrology instruments
- E-beam-based manufacturing
- work with electron beam
- 1 nm or better resolution
- general purpose or customized
- motorized (laser) stage
- large samples, small features
- high vacuum or low vacuum
- very large set of possible samples (bio, charging, etc.)
- further improvements possible



Courtesy of Hitachi HT

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SEMs and their Environment

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- Electron microscopes' resolution is at atomic dimensions and it is expected that they are going to be key imaging and metrology tools for nanotechnology.
- The "classical" or Compton electron radius is approximately 3 fm
- Why cannot we shoot the electrons into a few pm diameter spot?
- There are several reasons, but for sure, SEMs are limited in their performance by the bad vibrations and electromagnetic (EM) fields of their environment.
- Usually it is possible to achieve significantly better performance than the specification of these instruments by the proper design of their environment and by the use of supplementary compensatory methods.

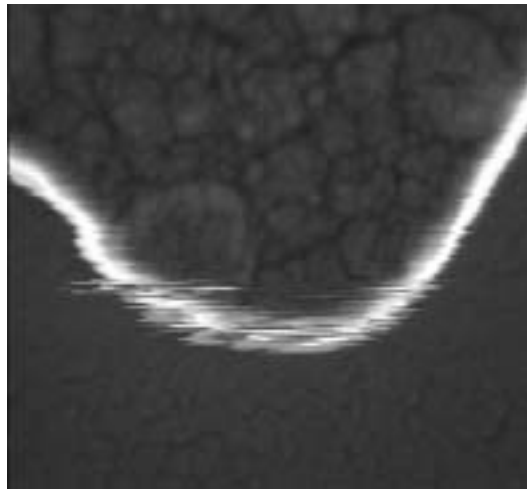
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Vibration & SEM Performance

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Effect of a short,
mechanical impulse
(gentle tap) to the SEM
electron optical column

(500 000 x magnification)

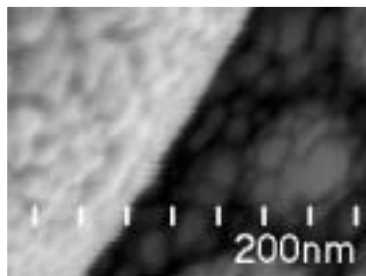
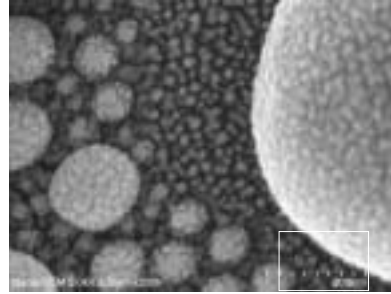
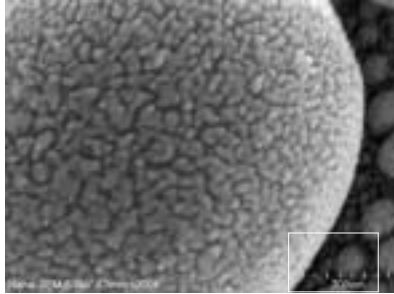
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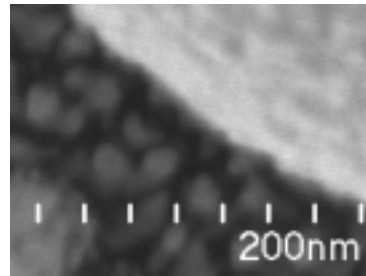
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EMI-RFI/Vibration & SEM Performance

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Morning



Late afternoon

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SEMs and their Environment

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- The best is to avoid the problems: build good SEMs and make good laboratory rooms for them
 - Build microscopes less susceptible to environmental disturbances
 - Electron-optical column –shielding, sample stage –locking, general –vibration and EM isolation and proper electrical design
 - Make the SEM itself quiet
 - Make good rooms for SEMs
 - Design, survey, selection
 - Electromagnetic interference (EMI), radiofrequency interference (RFI)
 - Mechanical vibration of structures, water, air (sound) – high and low frequency
- The 2nd best is to explore the problems and implement compensatory measures
 - Vibration
 - Vibration isolation platforms, passive and active
 - EMI/RFI
 - Passive – shields, grounding, design
 - Active, electromagnetic field compensation may alleviate the problems caused by strong magnetic fields.

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EMI-RFI & SEM Performance

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- Avoid locations subject to strong electromagnetic fields.
- The microscope is most affected by stray fields in the horizontal plane.
- The resolution of the scanning electron microscope depends on:
 - The accelerating voltage
 - The working distance
 - The external vertical and horizontal electromagnetic fields
- The influence of the electromagnetic field depends on the energy of the electrons

$$M_x = M_{30} \sqrt{\frac{30}{x}}$$

Where: M_x = influence at x kV

M_{30} = influence at 30 kV (max. Acc. voltage)

x = selected Acc. voltage (kV)

- The maximum tolerable interfering electromagnetic field at which the guaranteed resolving power can be achieved is
 - 100 - 300 nT_{p-p} at 50/60 Hz. (both X and Y directions)
 - 80 - 100 nT_{p-p} at other frequencies, starting from DC (both X and Y directions)
 - An intensity curve of frequencies from DC

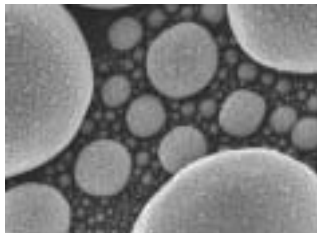
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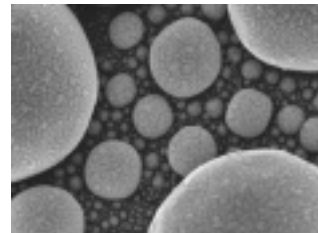
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EMI-RFI/Vibration & SEM Performance

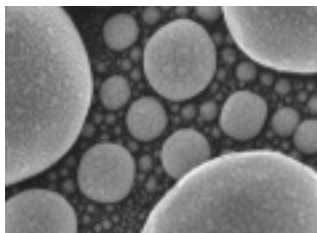
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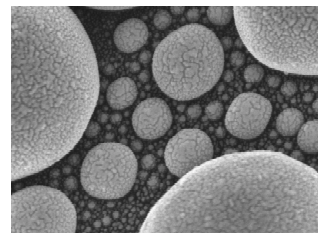
Late afternoon



Noon



Morning



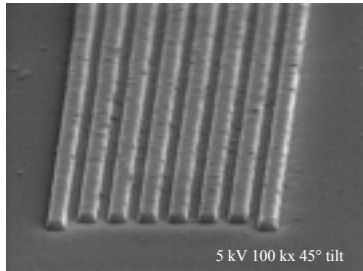
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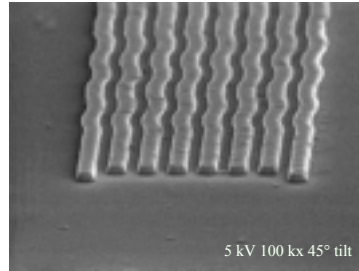
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DC Magnetic Field and SEM Performance

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Chair motionless



Chair tilted back and forth

Large DC magnetic fields can be easily changed by moving metal objects. The changing EM field moves the electron beam, the SEM image becomes distorted.



Steelcase TB 116 Chair

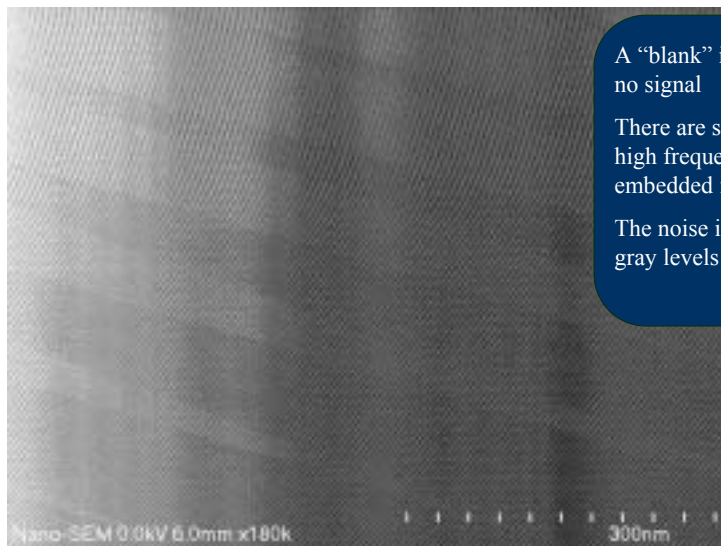
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EMI/RFI and SEM Performance

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A "blank" image taken with no signal

There are several low and high frequency noises embedded in every image

The noise intensity is about 4 gray levels (1.5%)

Contrast stretched image

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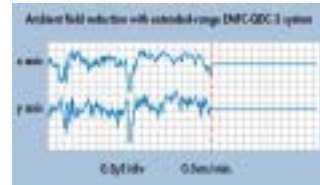
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EMI/RFI Isolation

- Build shielding enclosures – very expensive
- Compensate or cancel the EM fields at the electron optical column of the SEM.
- The compensation must be done for all 3D.
- Sensors, automatic electronics, compensation coil sets
- Initial set-up, continuous operation
- Specifications:
 - 3 axis sensor
 - 5 m³ minimum protected volume
 - > 30 dB (factor of 32) attenuation
 - 3 mT_{avg} (30 mG_{avg}) max. compensation
 - 0.001 Hz to 1 kHz bandwidth
 - 1 nT_{avg} (10 mG_{avg}) noise floor



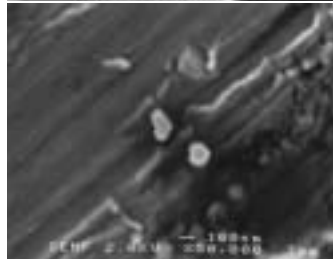
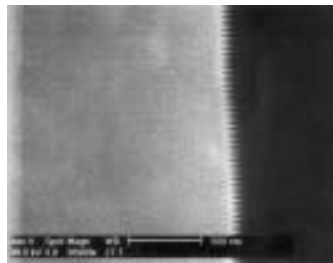
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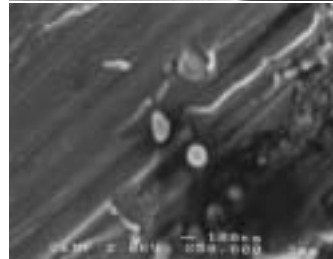
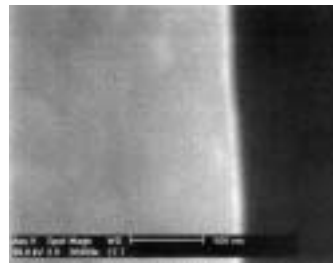
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EMI Compensation



No compensation



Compensation turned on

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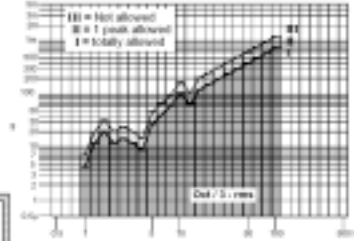
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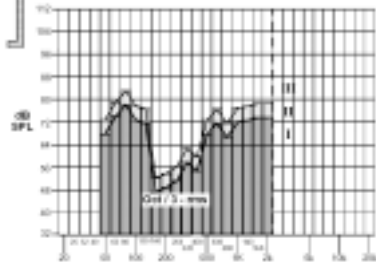
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Vibrations & SEM Performance

- Avoid locations subject to strong vibrations.
- The microscope is most affected by vibrations in the horizontal plane.
- Survey – find the sweet spot
 - Several measurements, 3D
 - Vibration
 - Sound
 - Other (water supply, air cond.)
 - Levels
 - Changes of levels – peaks & drift
- Use passive and active compensation
- Do not count on easy success



Vibration specification



Sound level specification

Courtesy of FEI, Inc.

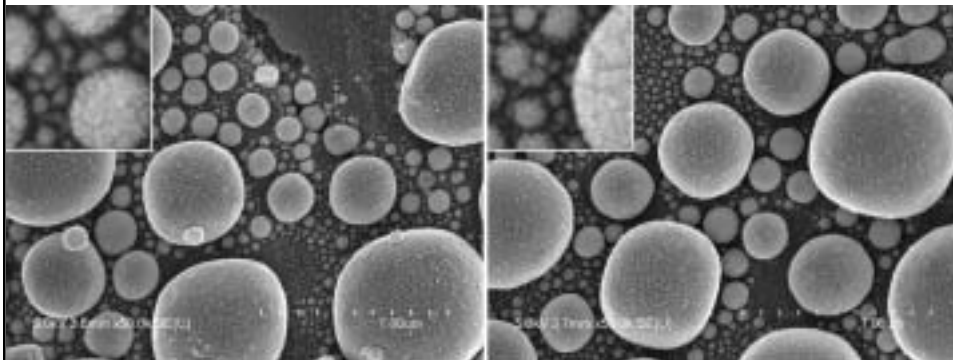
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Sample Stage and SEM Performance



Stage lock on

Stage unlocked

Stage made by E. Fjeld Co.

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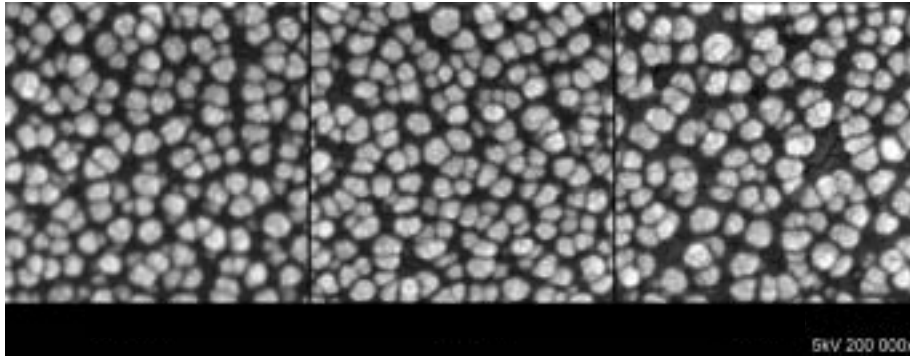
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Cooling Water & SEM Performance

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Cooling water for the objective lens and diffusion pump



Old pump

New pump

City water supply

Re-circulated water

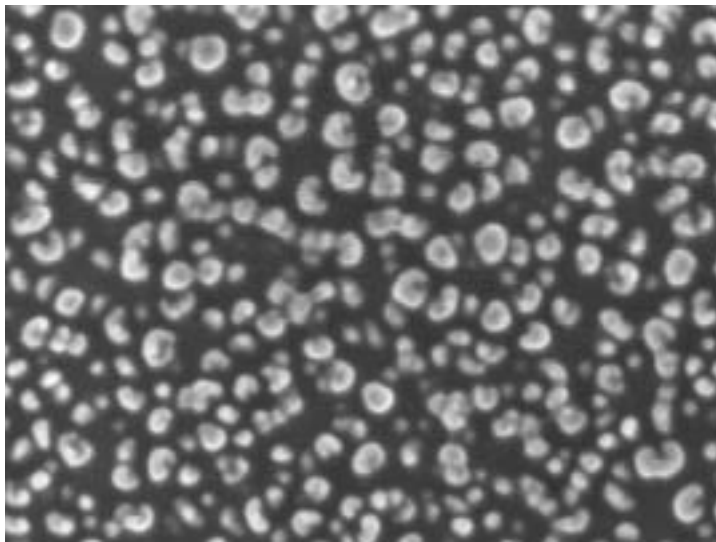
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Sound & SEM Performance

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Sound on

Sound off

Computer speakers
at moderate loudness

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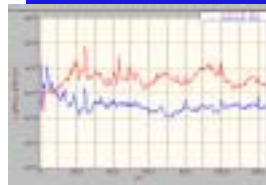
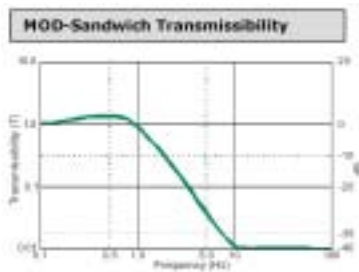
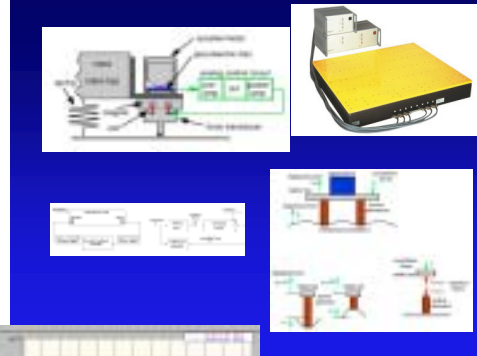
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Vibration Isolation

Rigid platform

- Up to 1200 kg load
- Piezo accelerometers
- Electrodynamic transducers
- Less than 50 ng noise
- Up to 40 dB isolation



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Conclusions

- Electron microscopes are key imaging and metrology tools
- They are limited in their performance by the vibrations and electromagnetic (EM) fields of their environment.
- Usually it is possible to achieve significantly better performance.
- Proper design of the SEMs and their environment and the use of compensatory methods are essential.
- It is not easy and inexpensive to obtain the best results
- Performance enhancement and enabling is a new field to explore

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