Modeling Surface Roughness

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My Question:

How do different length scales of roughness affect the reflectance of a mirror?

- Height
- Integral
Applications

Thin films and Extreme Ultra Violet Radiation

- Space imaging
  - Mirror on IMAGE satellite
  - Two helium emission lines
- Seeing into Stars
Outline

• Basic Ideas
• Program
• Surfaces
• Results
How does roughness affect our thin film measurements?

Rough Surfaces

Fitting our data
How does roughness affect our thin film measurements?

• In the beginning:
  - Individual atoms
How does roughness affect our thing film measurements?

- At the end:
  - Surface of “Huygen dots”
The Method

- Created a Java program
Basic Idea

Incoming Plane Wave

(x,y)

Outgoing Plane Wave in the Far Field

Scattering Points
The Program
Assumptions

- **S shaped radiation**

- **Looking only at reflection**

```
s-shaped
p-shaped
Reflection
Transmission
```
The Program
Assumptions

- Rows of atoms are in a vacuum
- Looking at the wave in the far field
The Program
Assumptions

- Single frequency radiation
- No phase shift upon reflection
- Reflection off a scattering point is not affected by another point's radiation
The Program
Math

• **Phase**

\[ \phi = \vec{k} \cdot \vec{x} \]

• **Electric Field**

\[ E = E_0 e^{-i\phi} \]
The Program
Method - Overview

1) Create a row of scattering points
2) Calculate the phase at each point
3) Calculate the electric field
4) Add all the fields from all the atoms
5) Compute the Intensity
6) Repeat for many angles
7) Calculate height and integral
The Program
Surfaces

- Create an array of gaussian random numbers
- Multiply by a scaling factor
- Fourier Transform
- Apply filter
- Inverse Fourier Transform
The Program
Surfaces

Filters: Multiply the Fourier Transform by:

\[ e^{-\frac{x^2}{100}} \]

\[ \frac{N}{N} \]

\[ (1 - \frac{e^{-\frac{x^2}{100}}}{N}) \]
The Program
Surfaces

Scattering Points ($10^{-1}$ wavelengths)

Variation in $Y$

Low Pass Filtered Surface

High Pass Filtered Surface
Results

Reflection Peaks

High Roughness

Low Roughness
Results

Reflection Peaks

• Reasons for peaks

  1) Constructive/destructive interference between fields of different atoms

  2) Roughness changes the direction of the field
Results

Maximum Spectral Peak Height

-0.5 0 0.5 1 1.5 2 2.5

height (1/10 wavelengths)

0 2 4 6 8 10 12

rms roughness over range of 100 wavelengths

-0.5 0 0.5 1 1.5 2 2.5

high filter
medium filter
low filter
Results

Integral of Spectral Peak

integral (1/10 wavelengths)^2

rms roughness over range of 100 wavelengths

high filter
medium filter
low filter
Future Developments

- Add multiple rows of scattering points
- Reflected radiation from scattering points affect the other points
- Compare to data from ALS and the reflectometer
- Use numerical integration to make more efficient
- Create a surface using a cubic spline method
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The Program
Calculating Phases

\( \text{phase 1} = 0 \)
\( \text{phase 2} = k( x \cos(a) - y \sin(a) ) \)
\( \text{phase 3} = \text{phase 2} + k( -x \cos(b) + y \sin(b) ) \)
The Program

Classes

- Atom
- AtomModel (main class)
- Complex
- CorrelatedY
- EvenX
- OutPlaneWave
- PlaneWave
- Play
- RandomAroundX
- RandomFromLastX

- ResultsChart
- Scale
- SetLicense
- VaryY
- WriteArray