SAND2018-8758PE

Research Update 8/16/18

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3 Main Tasks

- Defining surface parameter(s) that affect thermal emissivity
- Determine range of values for surface parameter(s) of produced AM parts and how that translates to range of emissivity values
- In-situ surface texture measurement for in build adjustment of emissivity for thermal monitoring instruments

Task 1: Define Surface parameter(s) that affects emissivity

- Simulation Work
  - Validate past literature
  - Discover surface characteristics that affect emissivity
- Experimental Measurements
  - Make samples
  - Measure surface topography
  - Measure emissivity

Simulation Strategy

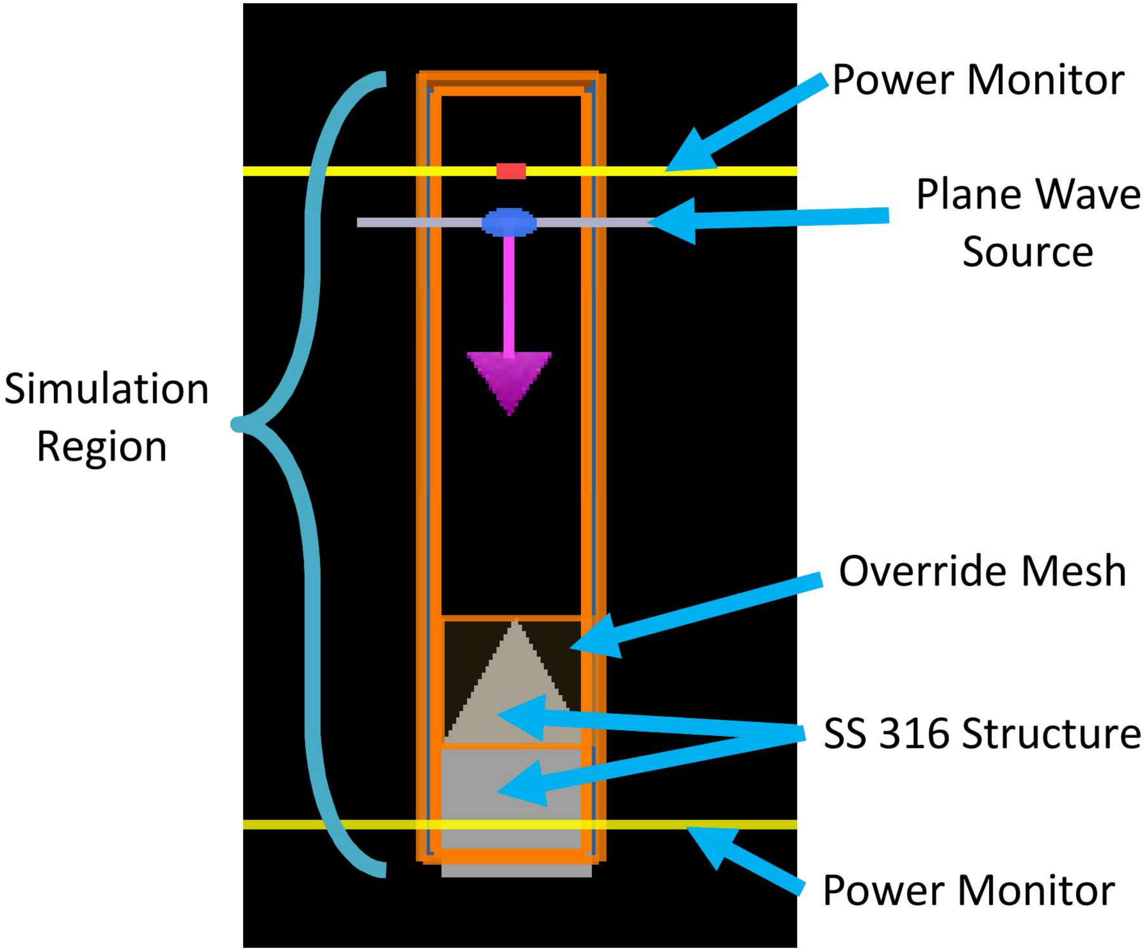
- Lumerical FDTD – Maxwell Solver
- Basic 2D periodic geometries were chosen for initial simulations
  - Less computation time and simplified calculations
- Parameter sweeps of key dimensions to cause a range of geometries that would result in emissivity changes
- Literature review would be basis for initial trend investigations
  - R_a
  - Slope
- Measured emissivity from 1-14 microns to look at IR camera wavelength ranges

Simulation – Material Data

- Drude model for material optical properties to calculate absorptivity
  - Commonly used for metallic materials
  - Model assumes that the material consists of free electrons bouncing around the stationary positively charged particles
- 304 SS was the closest material that data could be found
- 316 SS reference emissivity data from look up tables matches for room temperature polished case for simulated 304 SS material
- Material is not as critical when looking at geometry trends affecting emissivity changes – have a close match in stainless steel data

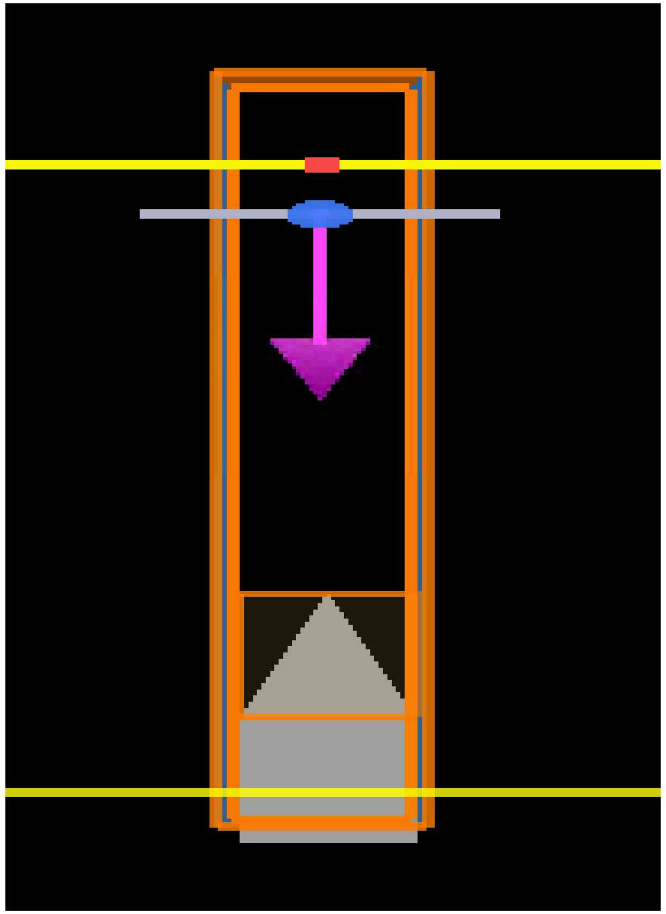
Simulation Set Up

- Periodic Boundaries
- Power Monitors above and below surface to measure reflection and transmission to calculate emissivity
- Plane wave source
- 2D geometry (z plane goes to infinity)
  - Isosceles Triangles
  - Skewed Triangles
  - Flat Valley between triangles
  - Multi-sized Triangles
    - Width range
    - Height range

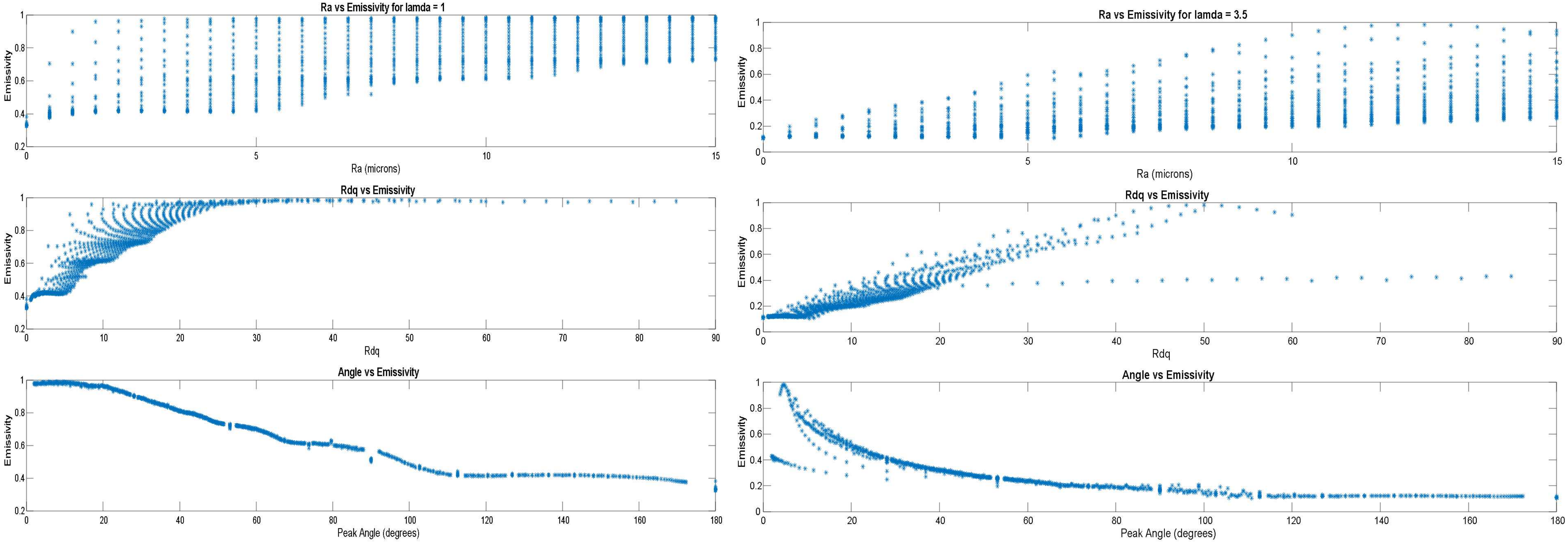


Periodic Triangle Set Up

- Isosceles Triangle
- Periodic Boundaries
- Variables
  - Height: 0-30 microns
  - Width: 0-30 microns



Periodic Triangle Results



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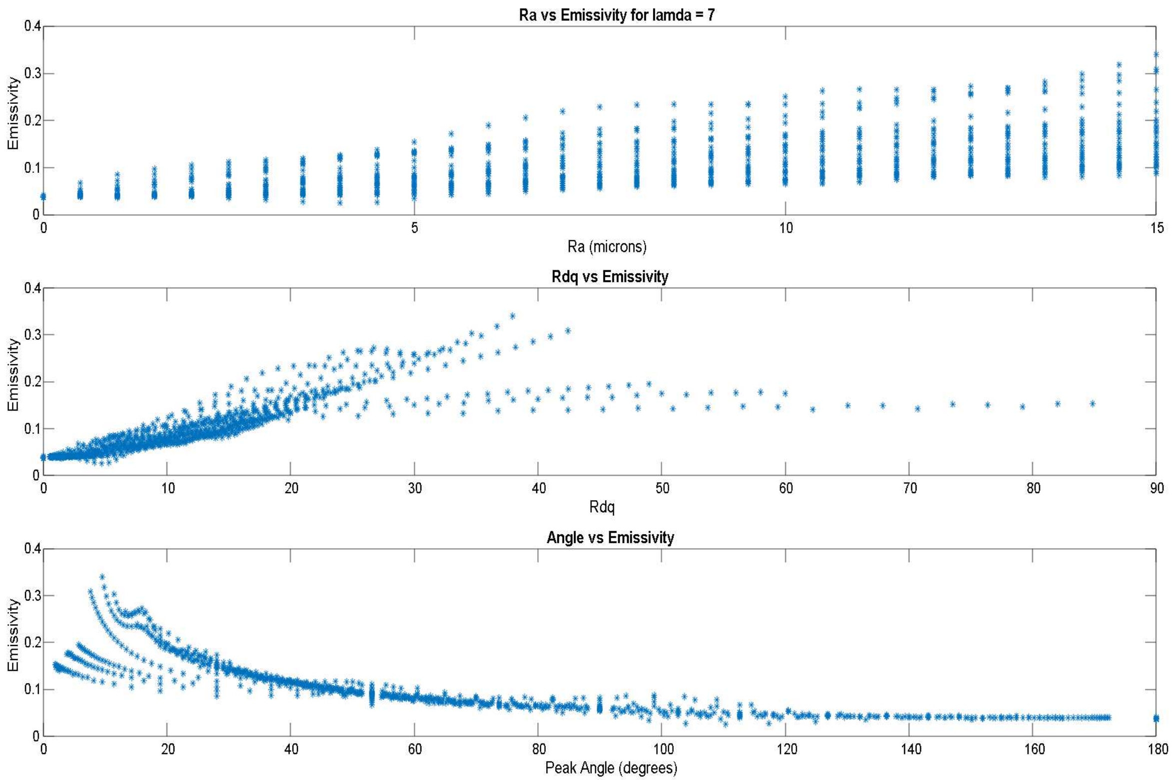
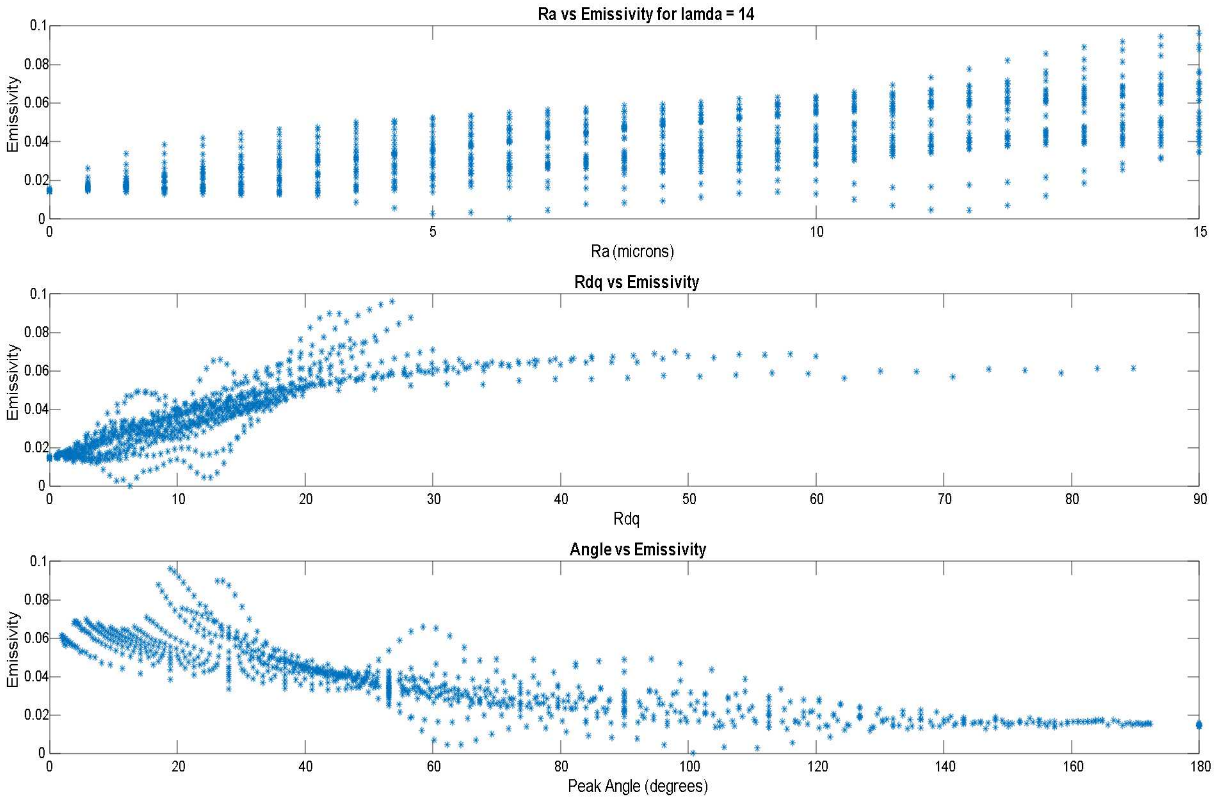
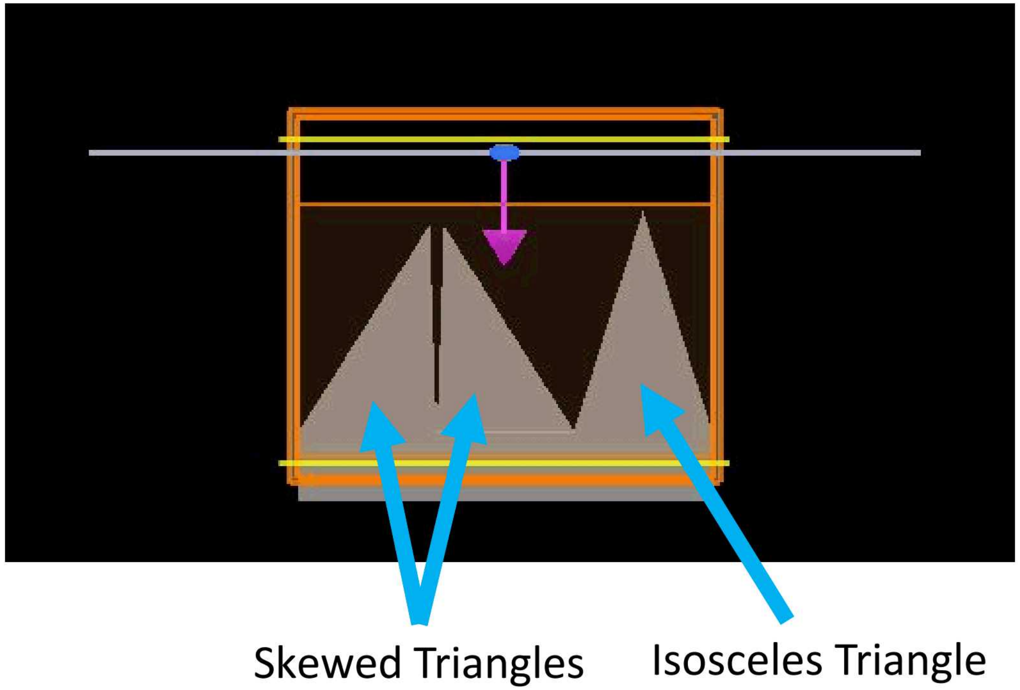


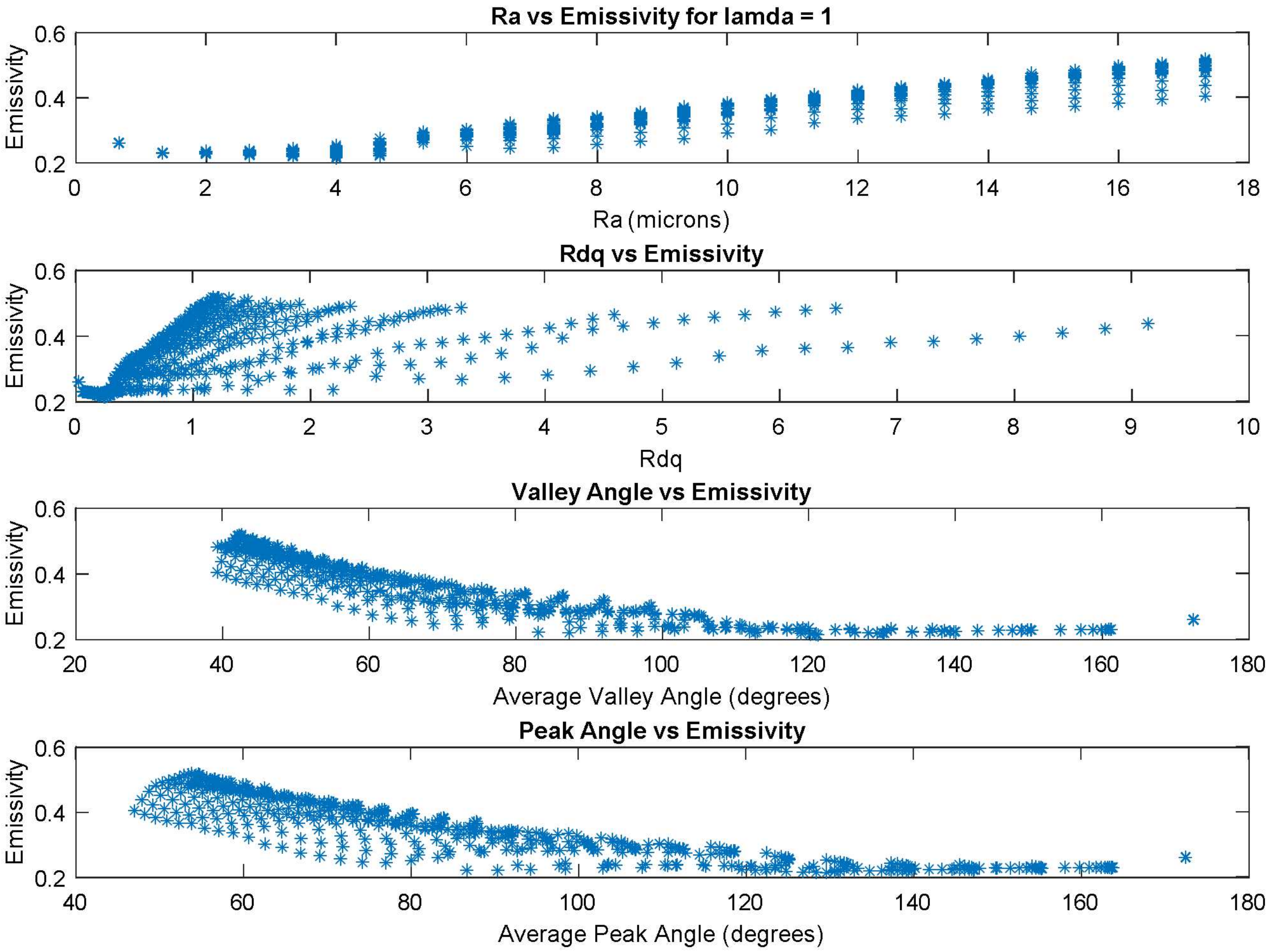


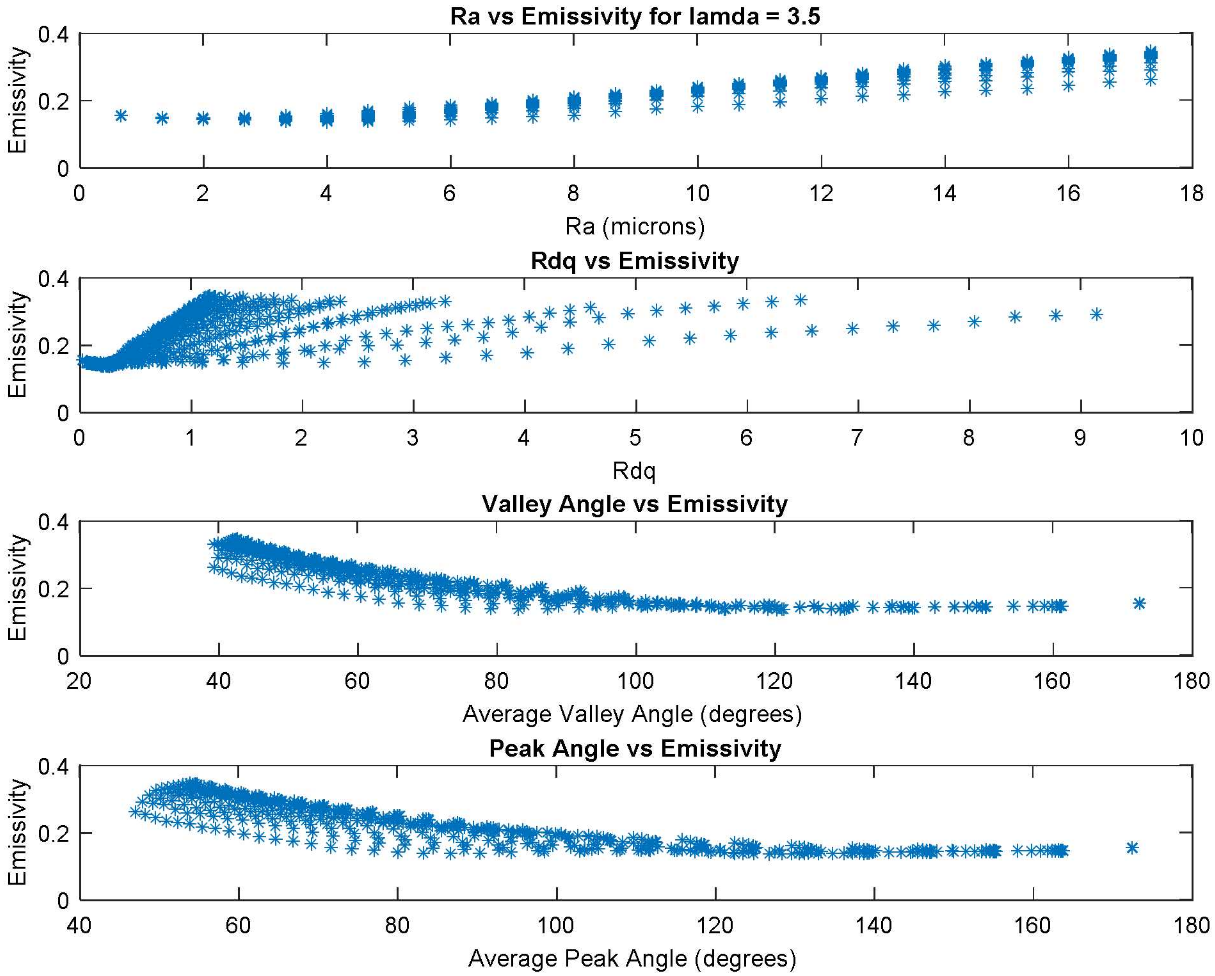
Skewed Triangle Set Up

- 2 Skewed Triangles + variable height isosceles triangle
- Periodic Boundaries
- Variables
  - Height: 0-25 microns
  - X position of skewed triangle peaks: 0-20 microns



Skewed Triangle Results





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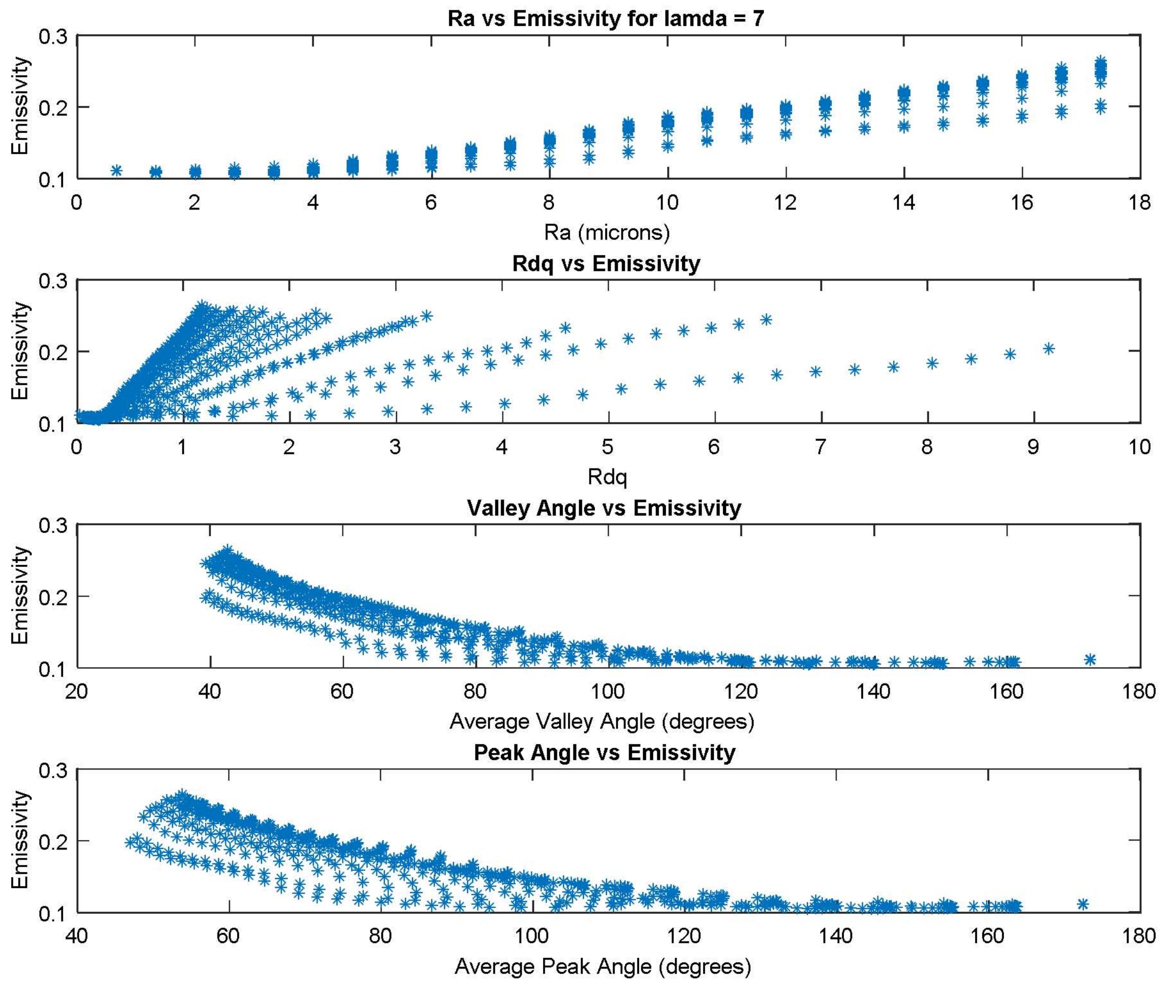
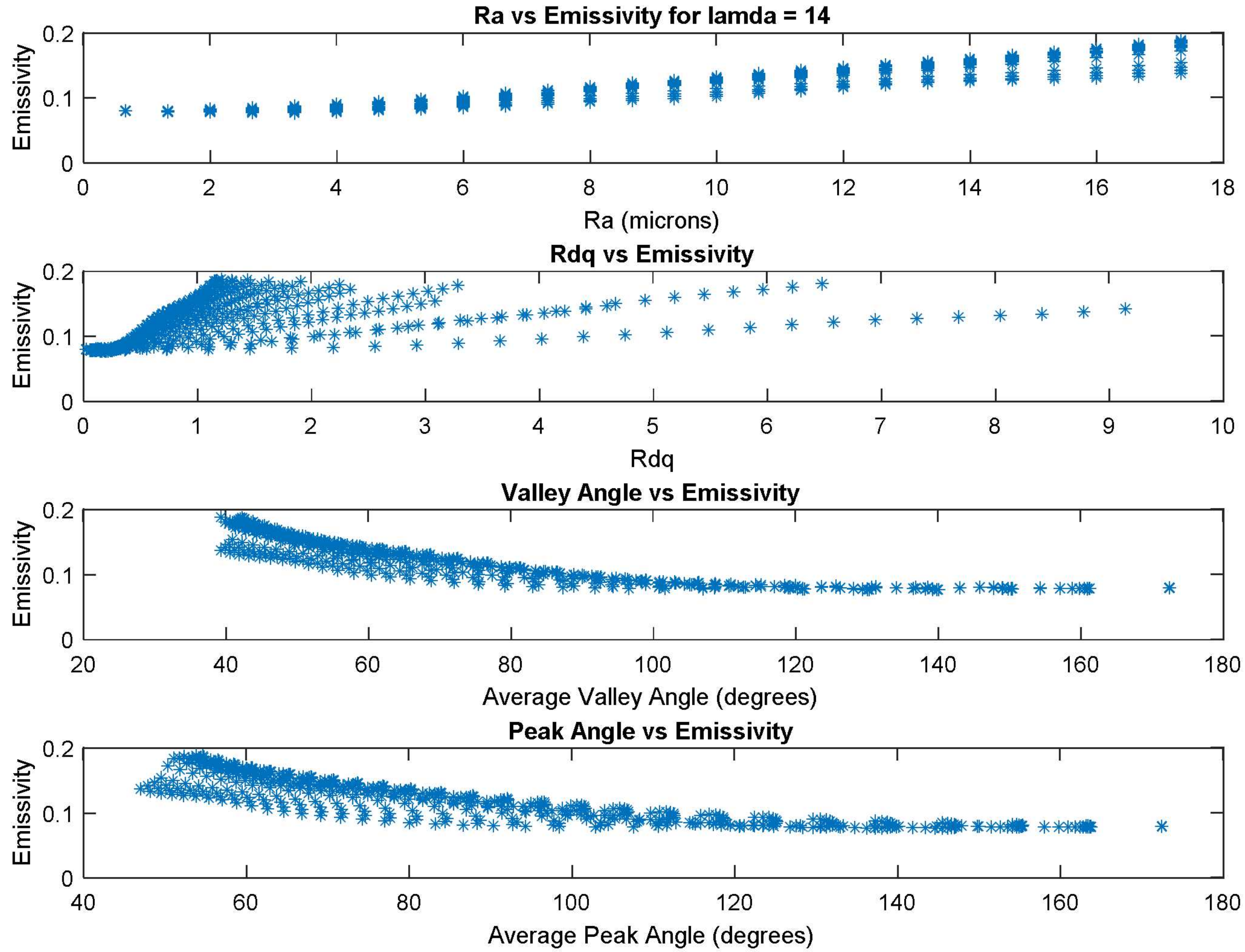
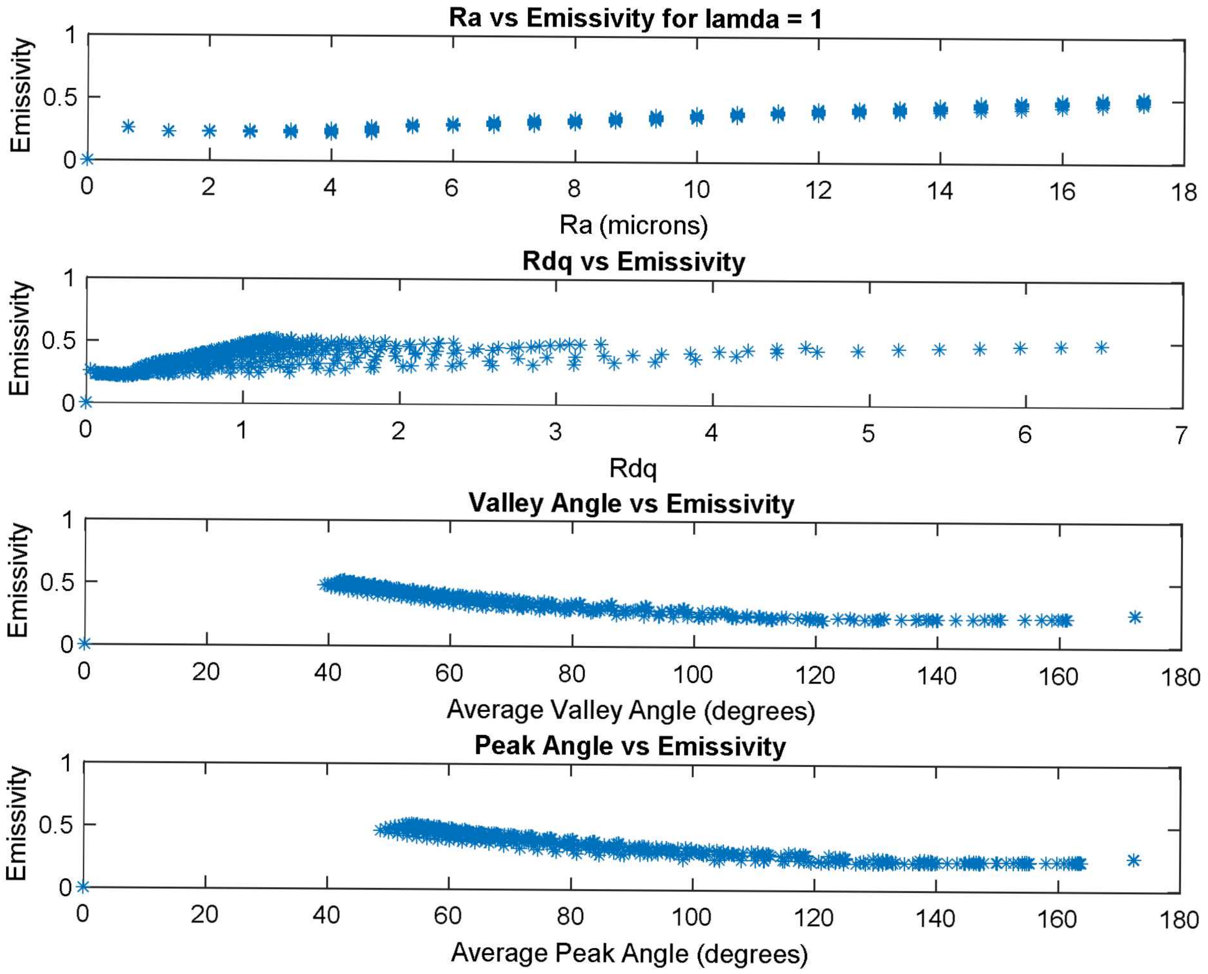
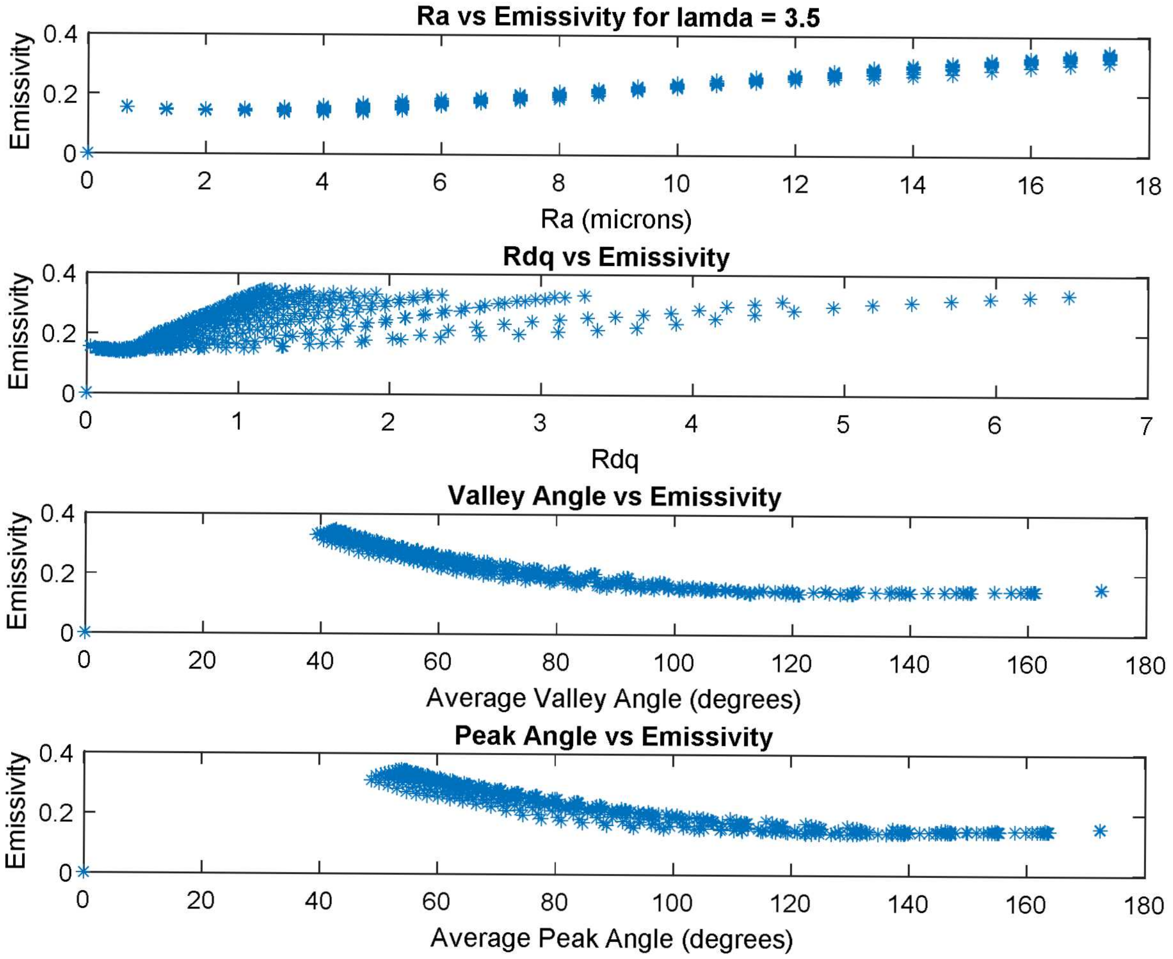




Skewed Triangle Results (w = 3-30)





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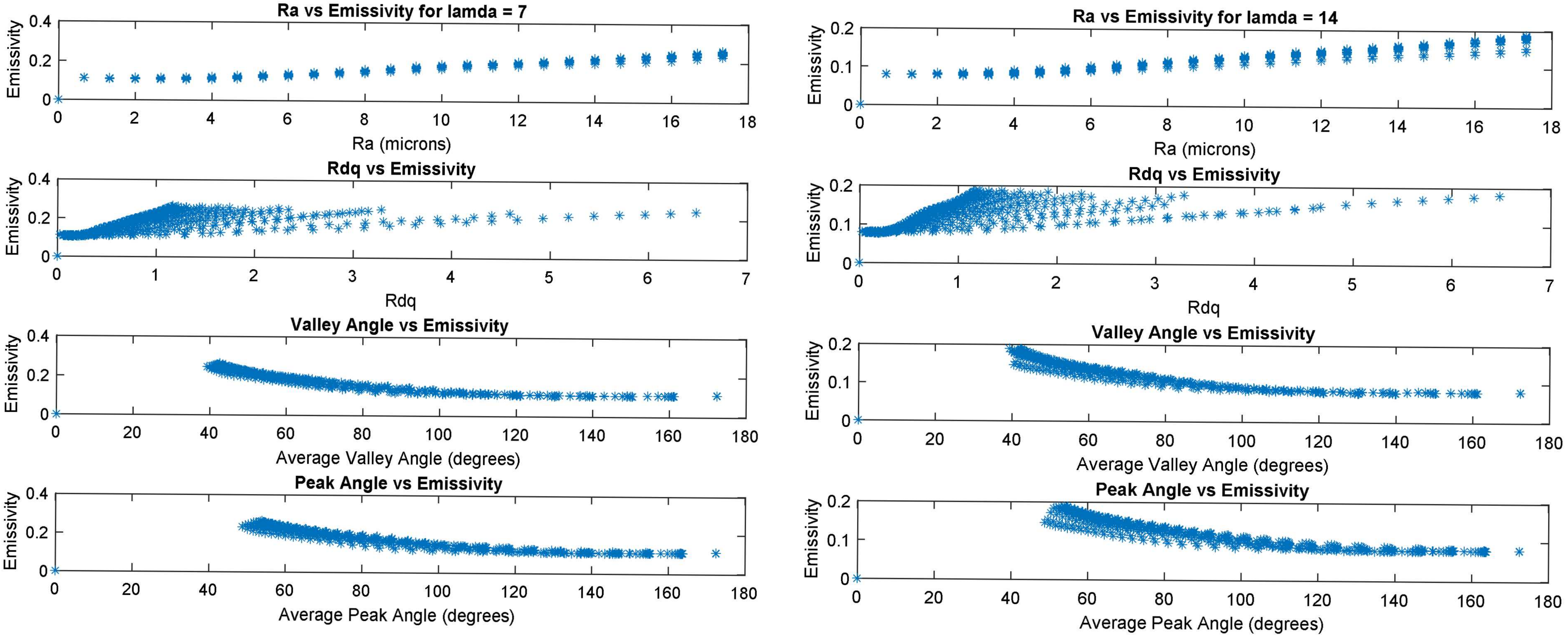
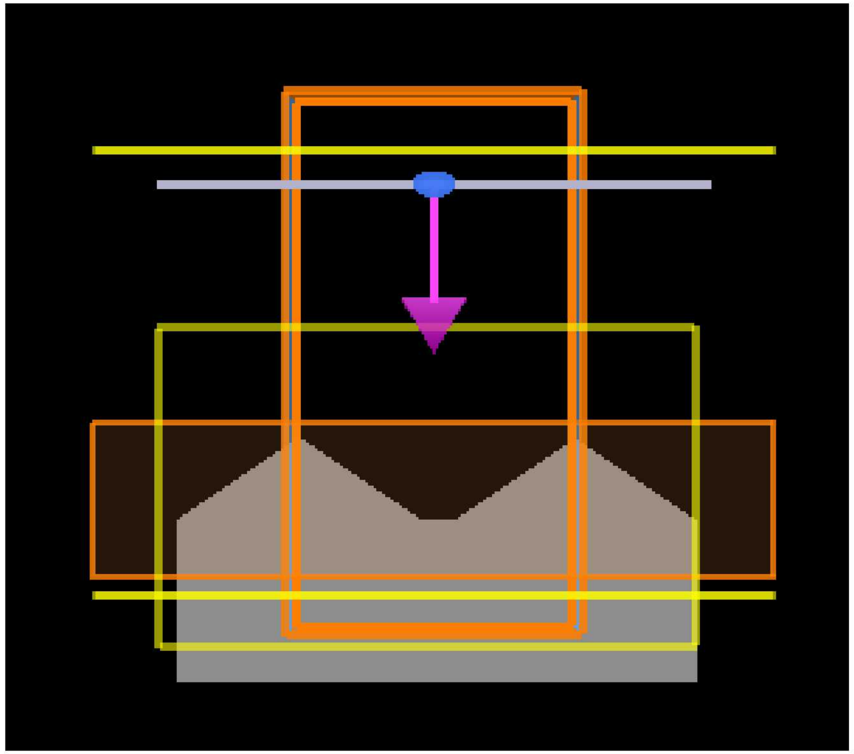


Flat Valley Set Up

- 2 isosceles triangle + flat valley in between
- Periodic Boundaries
- Variables
  - Height of triangles: 5-30 microns
  - Valley width: 5-20 microns



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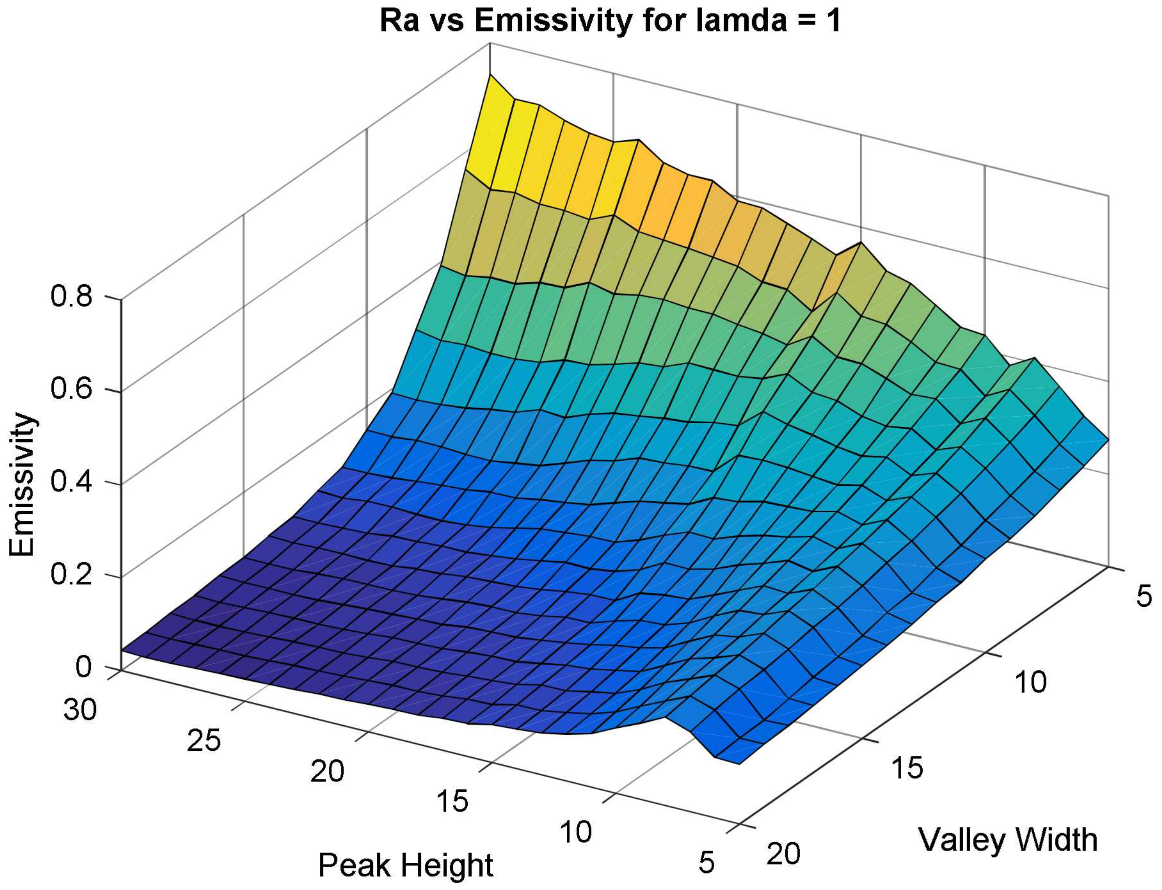
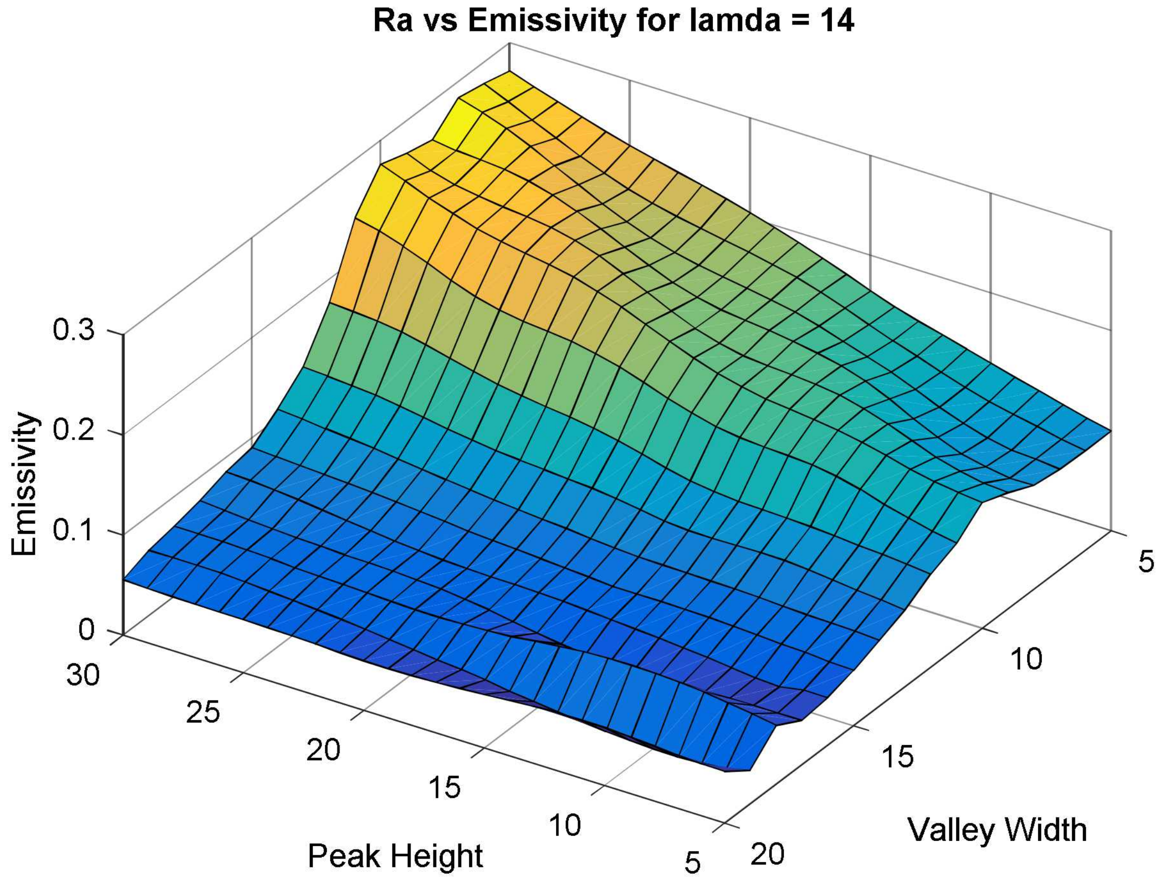
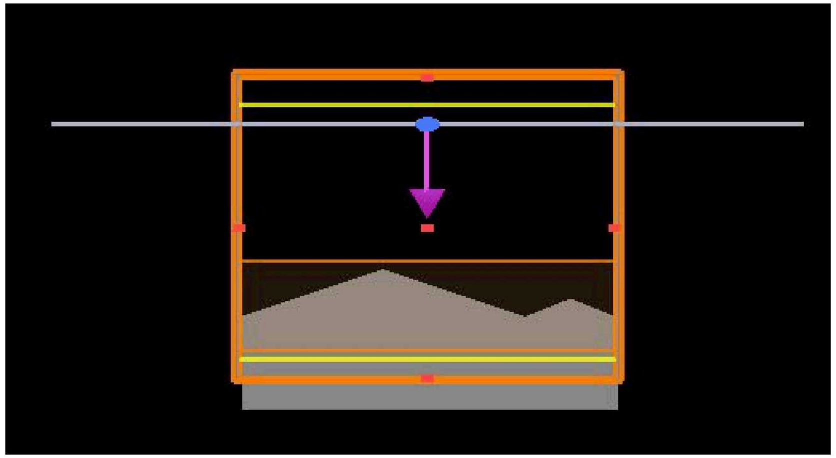
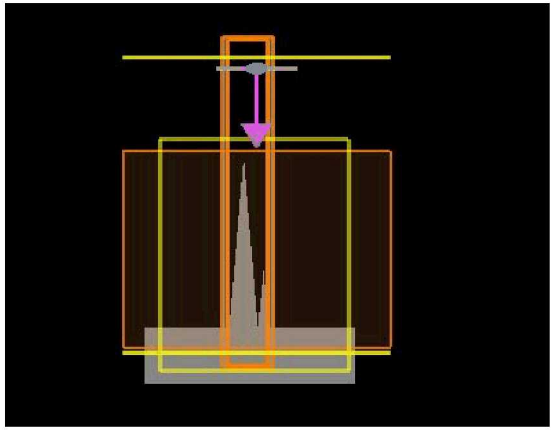




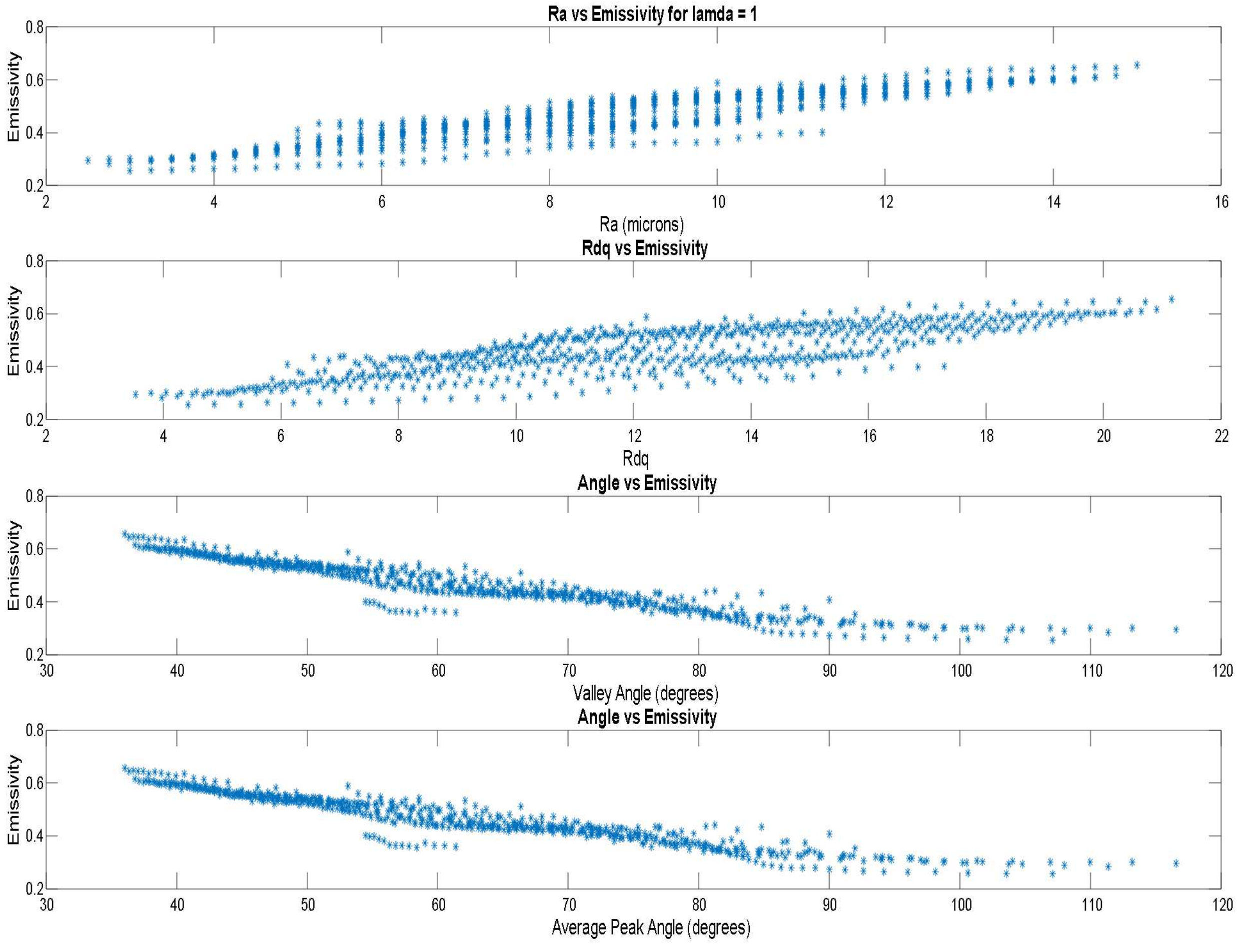
Multi-Sized Triangle Set Up

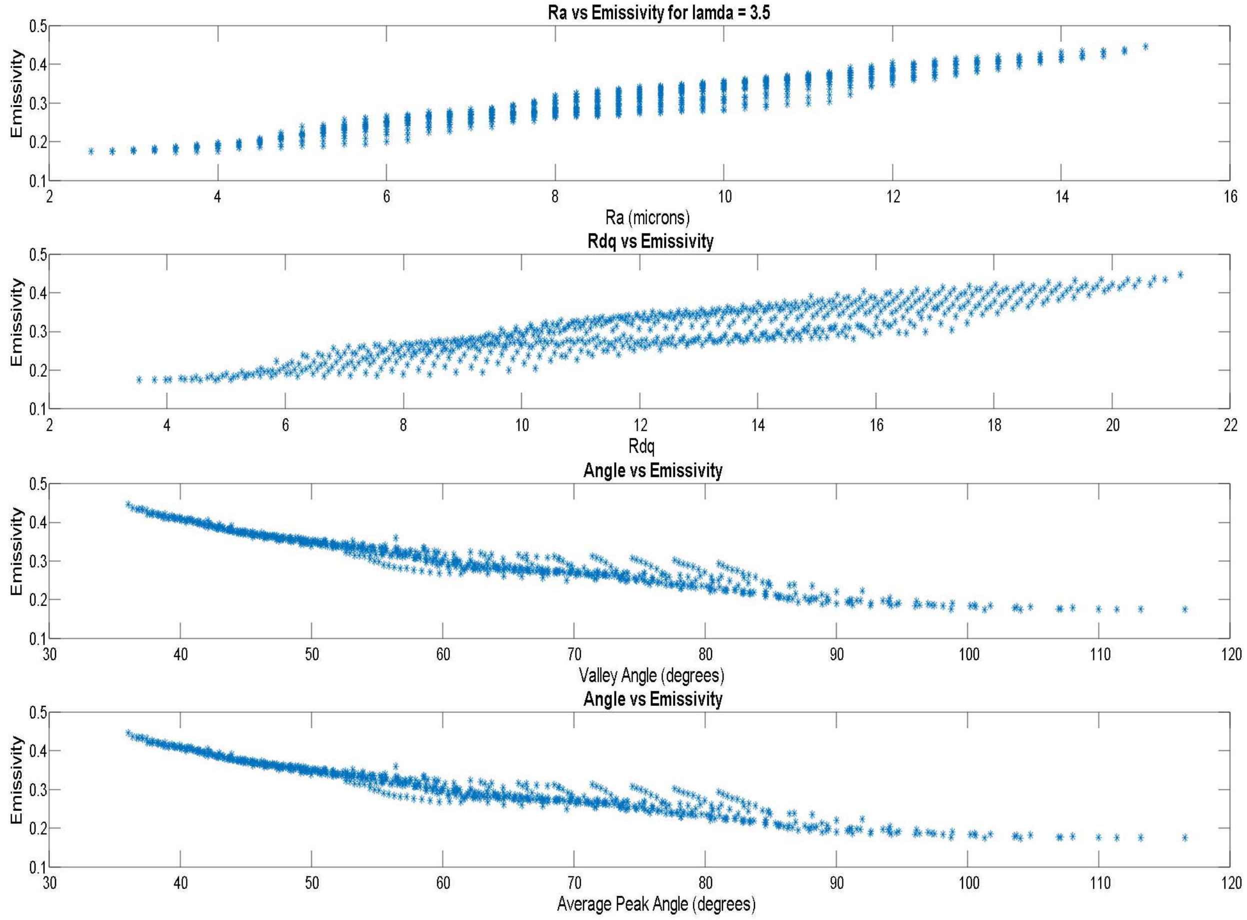
- 2 isosceles triangle with difference heights and widths
- Periodic Boundaries
- Variables (Height or Width)
  - Large triangle: 5-30 microns
  - Small triangle: 5-30 microns
  - Constant Width/Height
    - Small triangle: 10 microns
    - Large triangle: 10 microns





Multi-Sized Triangle Results – Height Change





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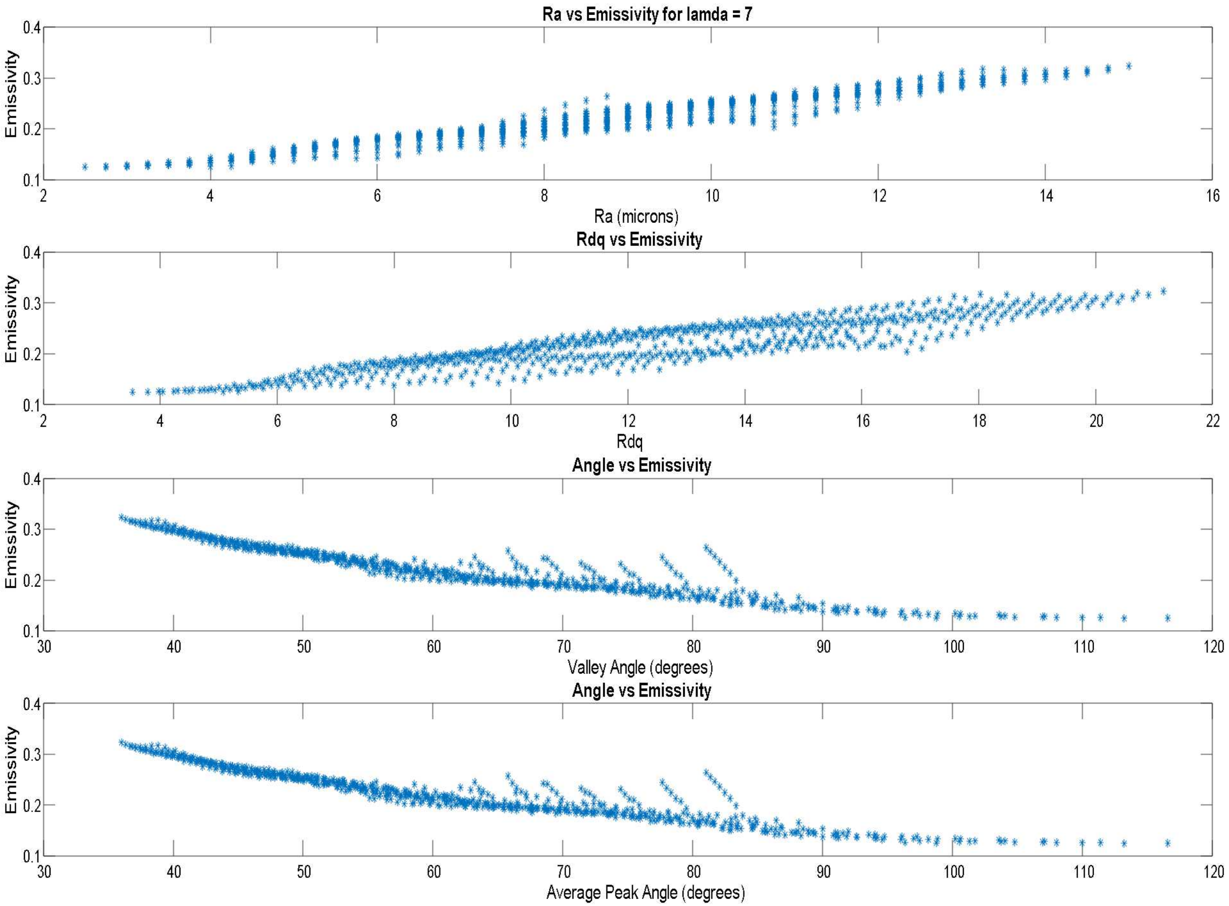
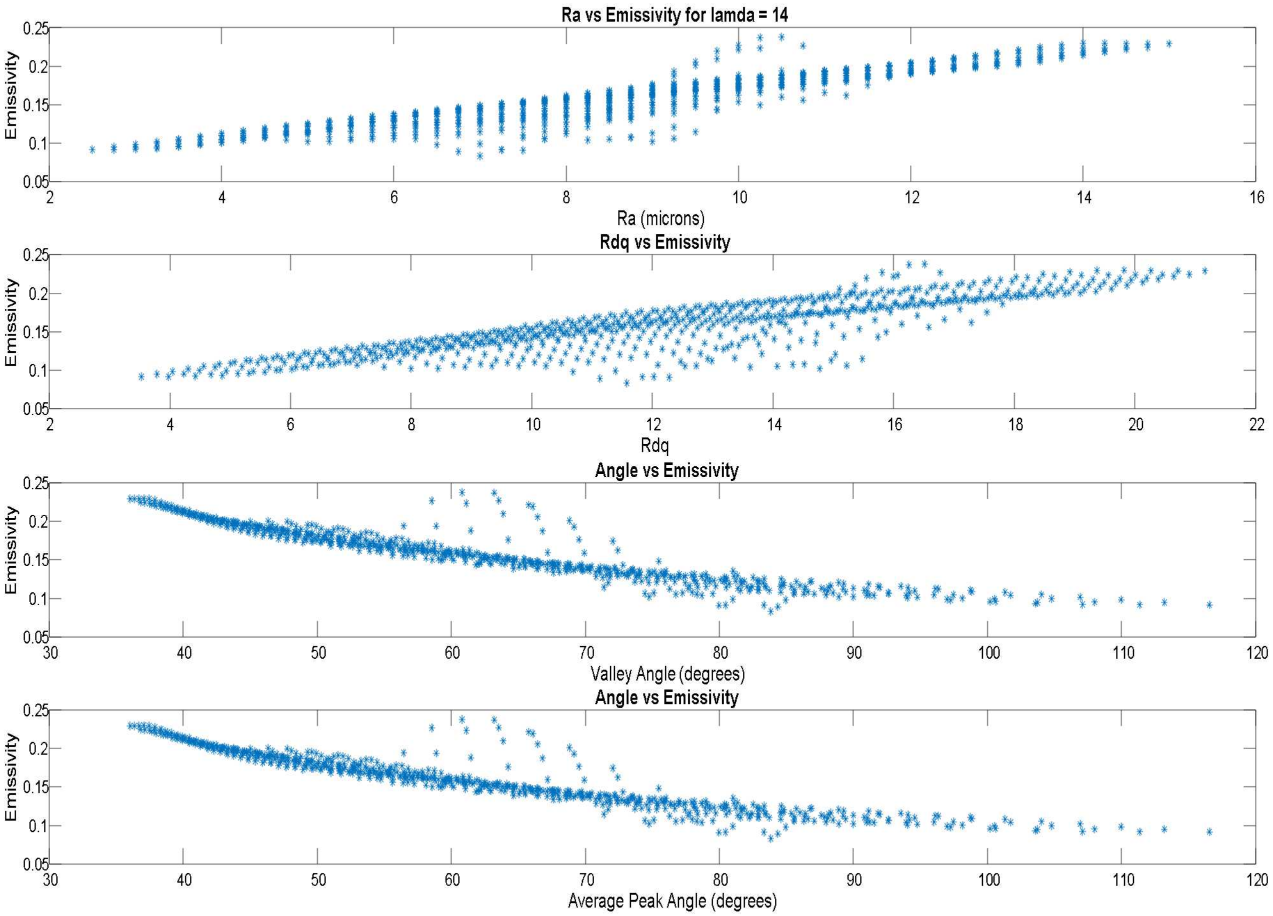
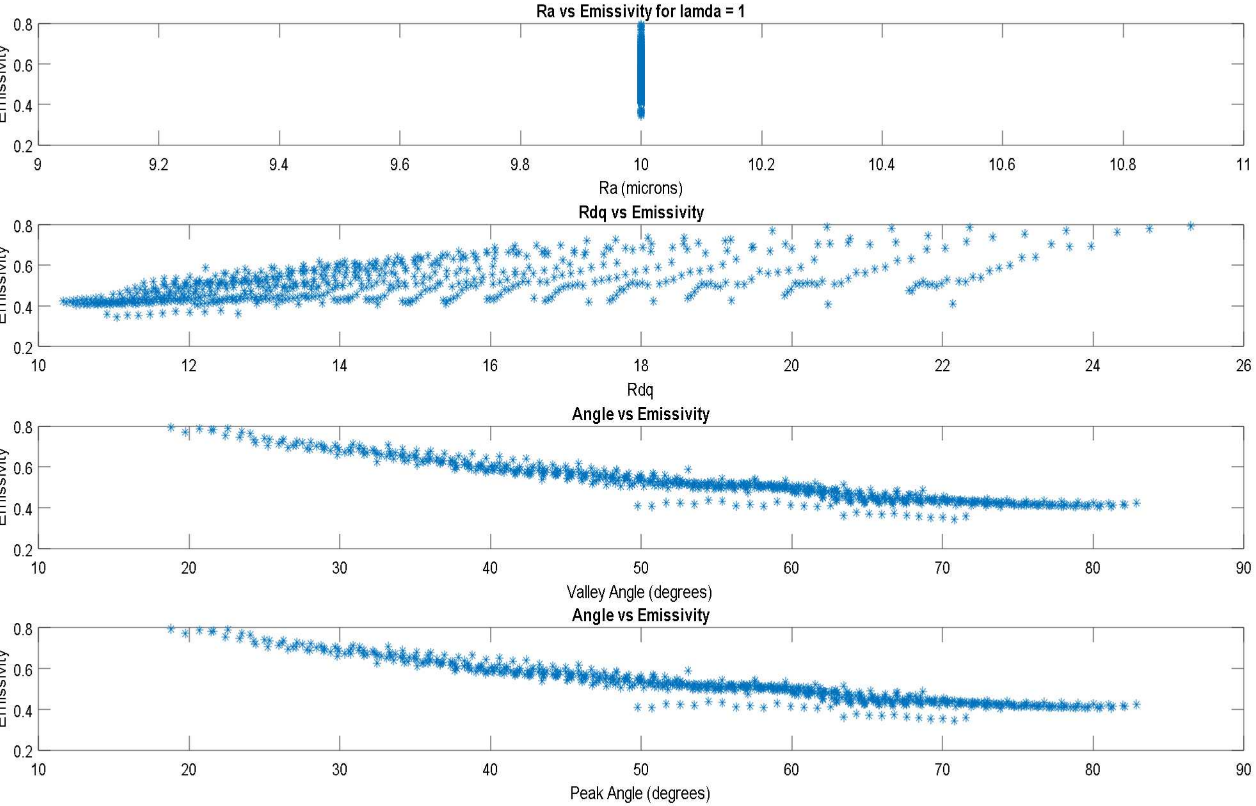
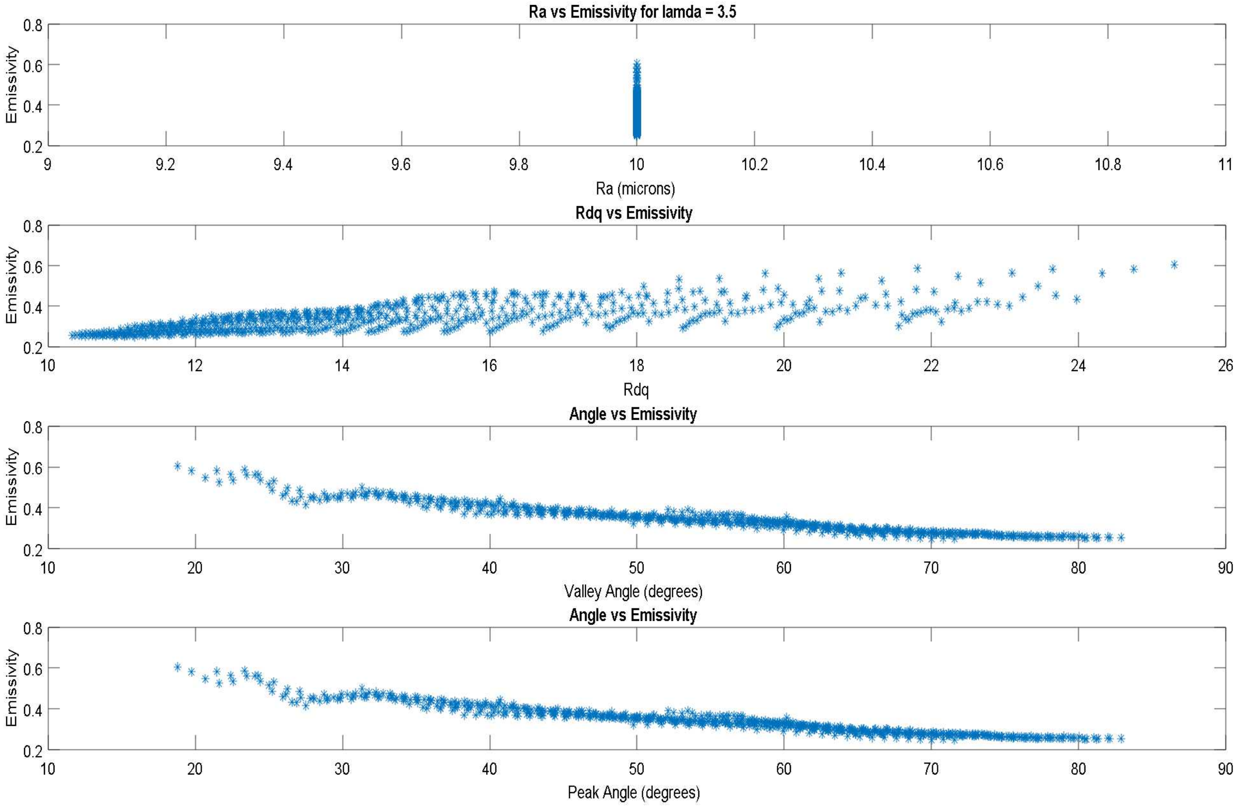


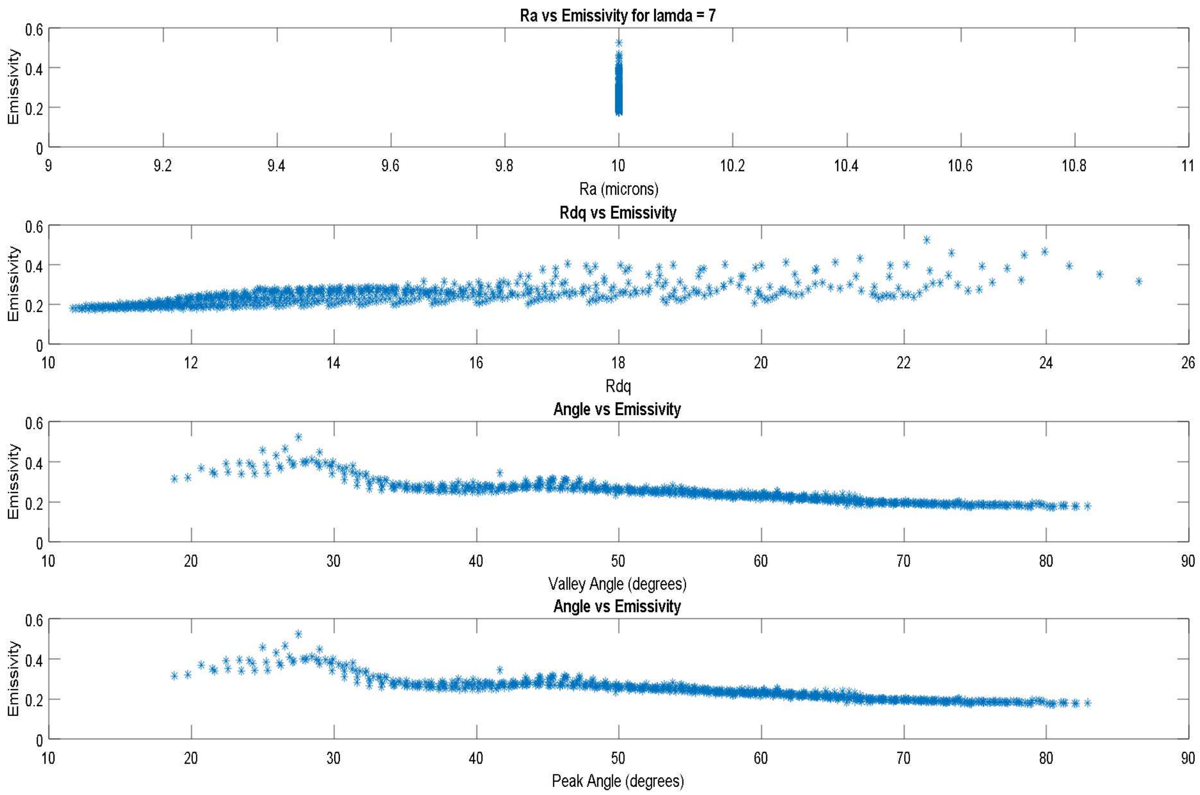


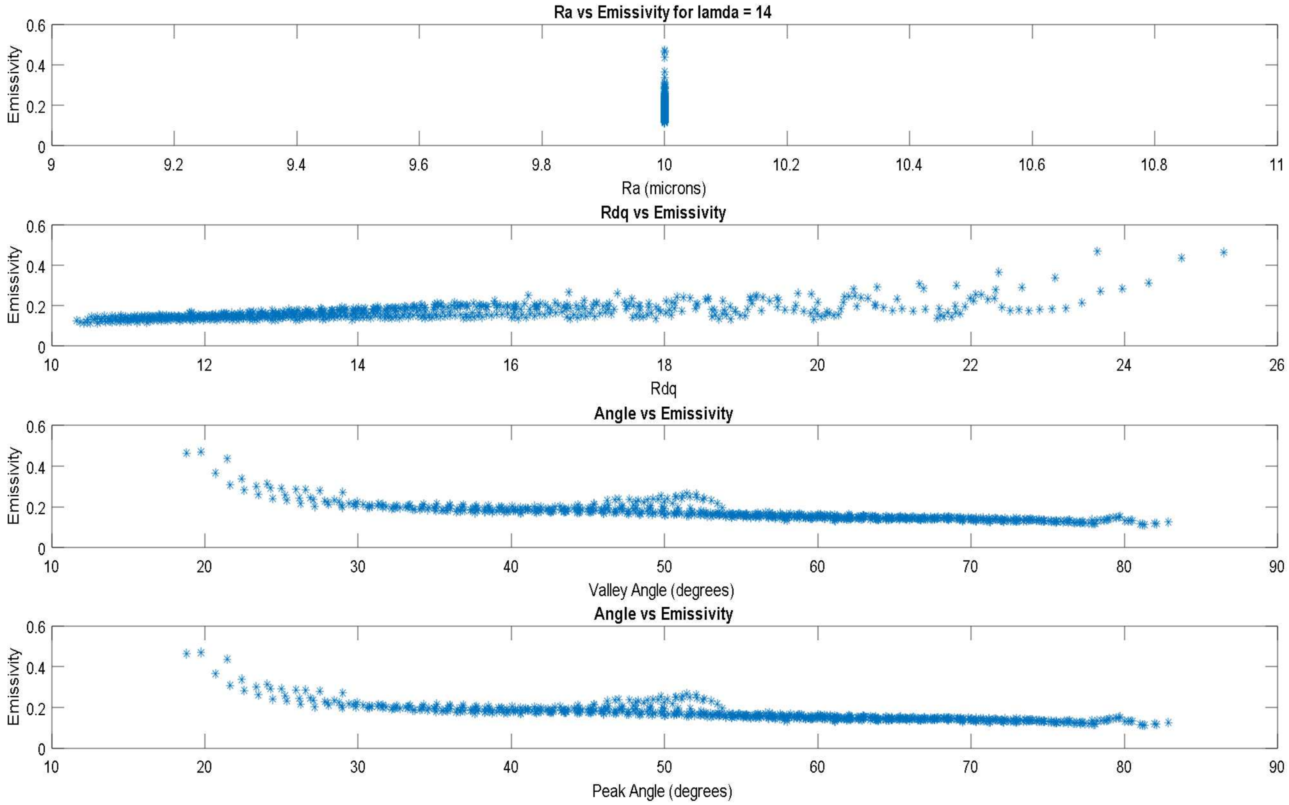
Multi-Sized Triangle Results – Width Change





Multi-Sized Triangle Results – Width Change



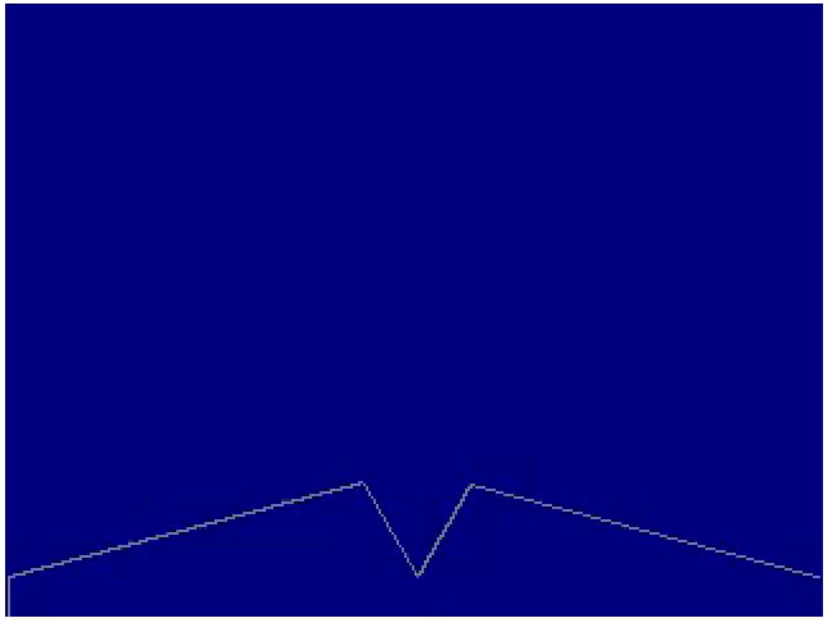


Simulation Conclusions

- R_a is related to underlying surface aspects that affect emissivity, but is not a good indicator
- R_{dq} has a better relationship to emissivity changes, but still not best indicator
- Angle of valleys has best relationship with emissivity changes due to phenomena of internal reflections being the cause for increased emissivity

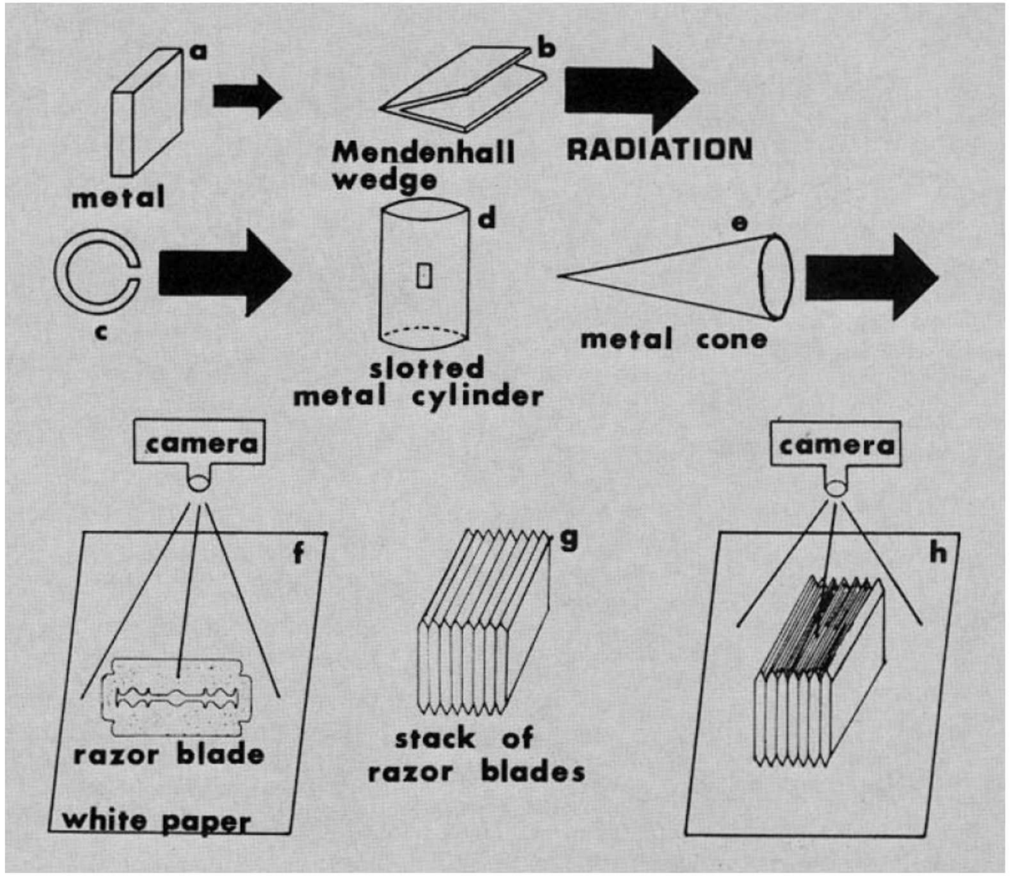
Phenomenological Explanation

- Internal reflections increase as angle of valley decreases
- Mendenhall Wedge Effect (1911) – narrow wedges formed from a strip of material that cause black body-like behavior
- “By forming a wedge one is causing incident radiation to undergo more reflections, and hence more absorption, and hence approaching more and more closely what is called a ‘blackbody’”(Taylor 1987)



Phenomenological Explanation

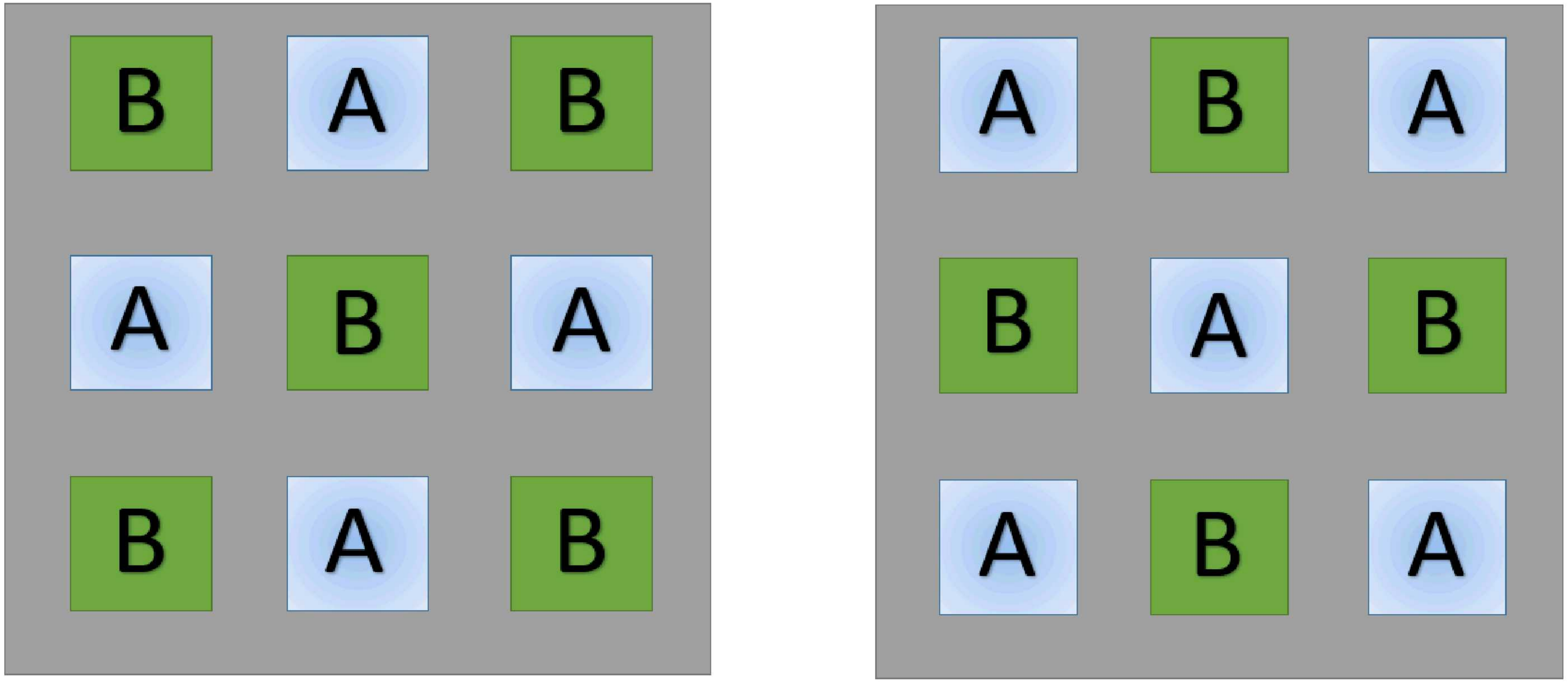
- Size of arrow increases with increasing emissivity
- Mendenhall postulated in 1911 that if a wedge was created with sufficiently small angle, that it would behave like a black body due to internal reflections and a small aperture



Experimental Emissivity Measurements

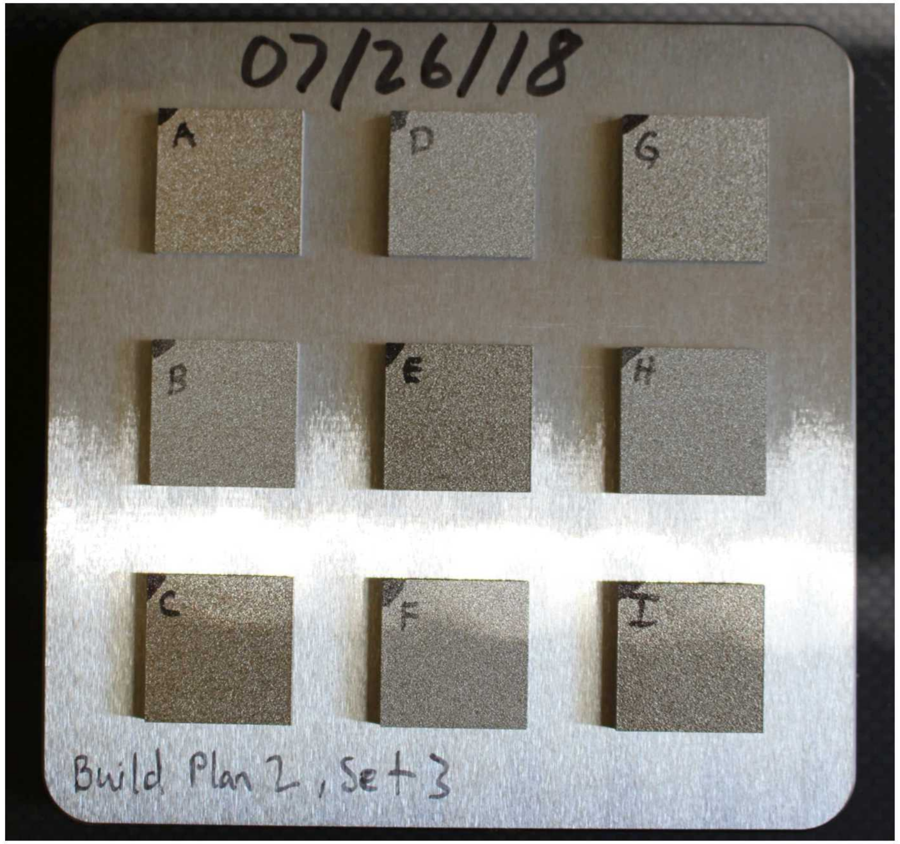
- Sample Geometry
  - 25 mm square, 6 mm thick (constrained by measurement methods)
- Material: 316 Stainless Steel
- Made with ProX 200
- 6 sets of laser parameter combinations with 9 parts for each set
  - Laser parameter sets chosen based on surface data gathered from a process map exploration by building cubes with the ProX 200
  - Surface roughness parameter S_{dq} (related to slope of peaks and valleys) is basis for parameter combination decisions
  - Each set either has scan speed or power in common to look at effects of both on surface roughness

Build Layouts



Sample Completion to Date

- 4 builds completed
- 36 samples made so far
- All remain on build platen for surface measurements
- As pictured:
  - 100 W / 1400 mm/s
  - 100 W / 2000 mm/s

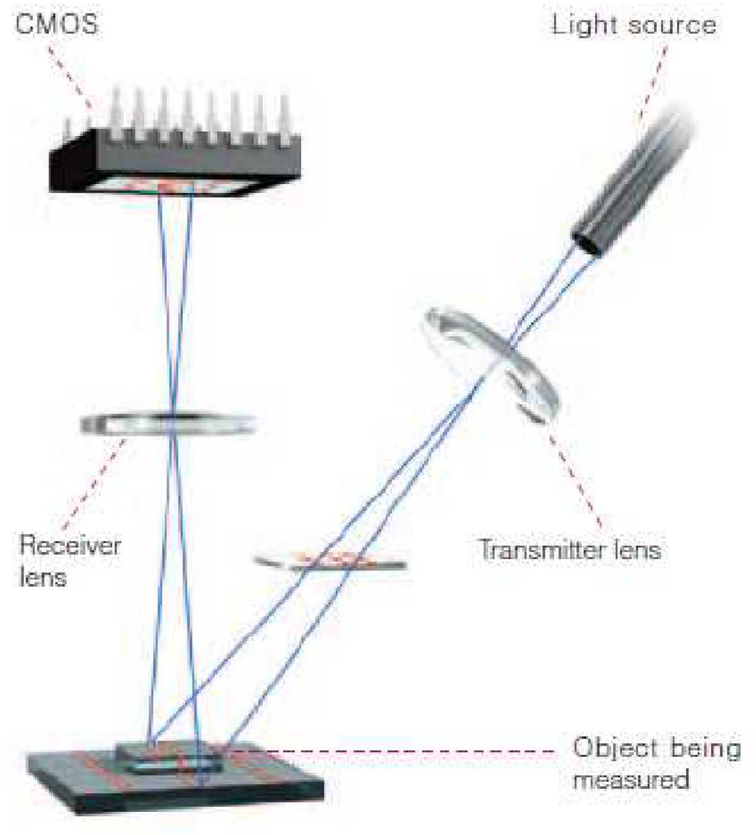


Surface Roughness Measurements

- XCT – not viable
  - DMLS and LENS parts were x-rayed to test viability
  - Reported minimum resolution was 15 microns (more towards 25 microns)
- Keyence VR-3100 Visual Microscope
  - Measurable Height – 1 mm (high mag 40-160x) and 10 mm (low mag 12-50x)
  - Measurable area – 2 mm square (160 x) to ~25 mm square (12x)
  - Reported Height Resolution - .1 micron
  - Limited by extreme rough surfaces for data acquisition (not likely to encounter due to narrowed process parameter space for experiments)
- Contact Profilometry – DektakXT
  - Will be used to verify measurements

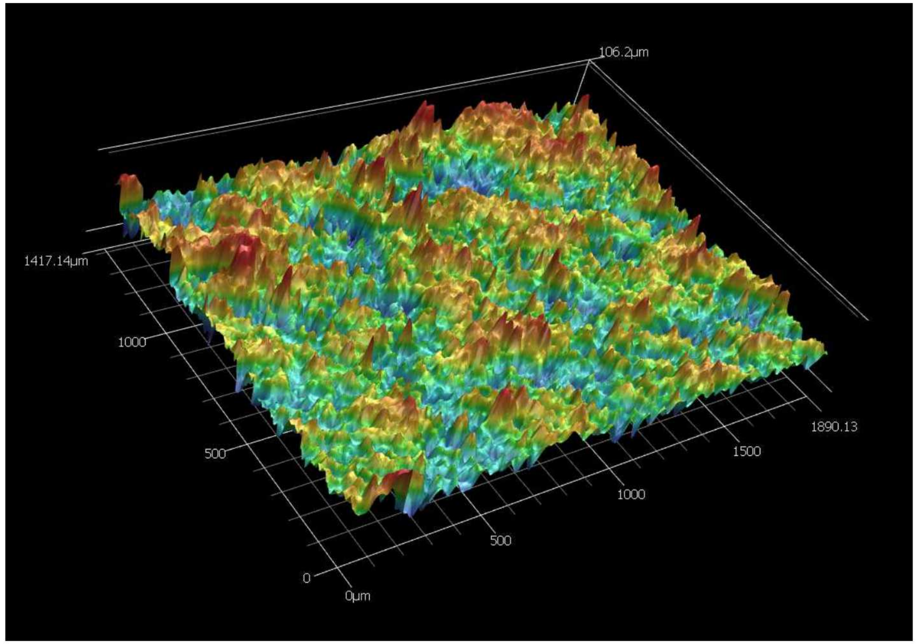
Keyence VR3100 Microscope

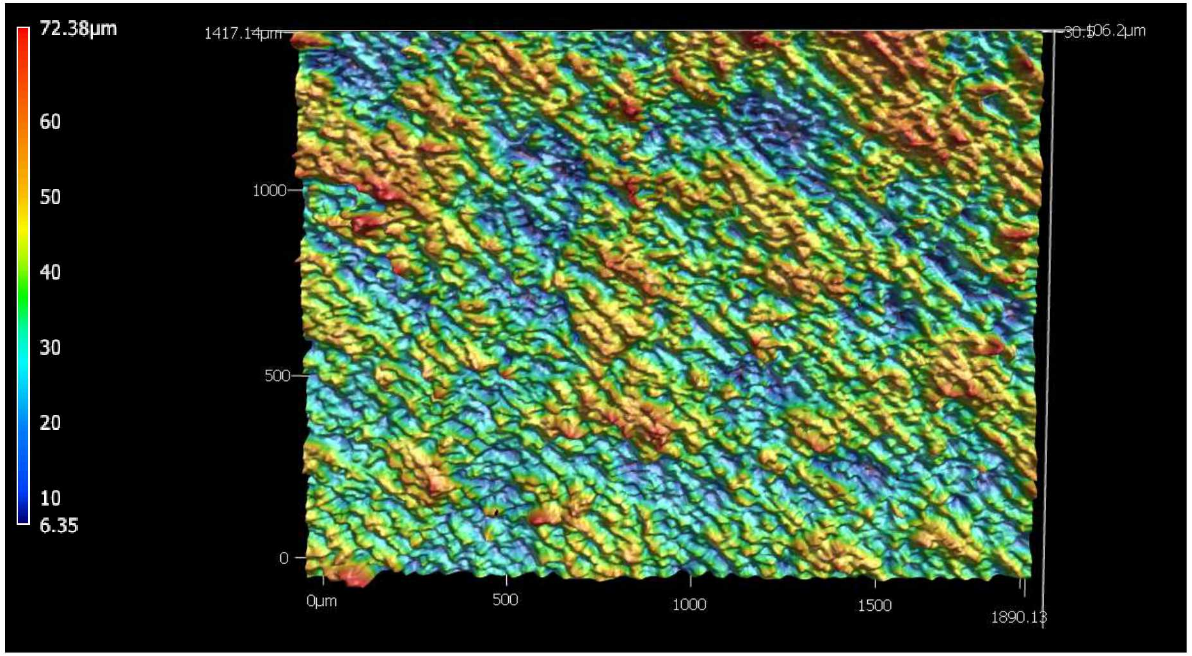
- Uses light triangulation to measure height of samples
- Light bands are illuminated onto surface and CMOS sensor looks at light distortion to calculate height map
- Can measure height differences up to +/-5 mm
- Can measure up to 3 cm square with no distortion due to specialized lenses
- Raw surfaces can be output as CAD files or excel files



Keyence VR3100 Microscope

- Generates 2D color and 3D height maps
- Can export surfaces as CAD files for future processing

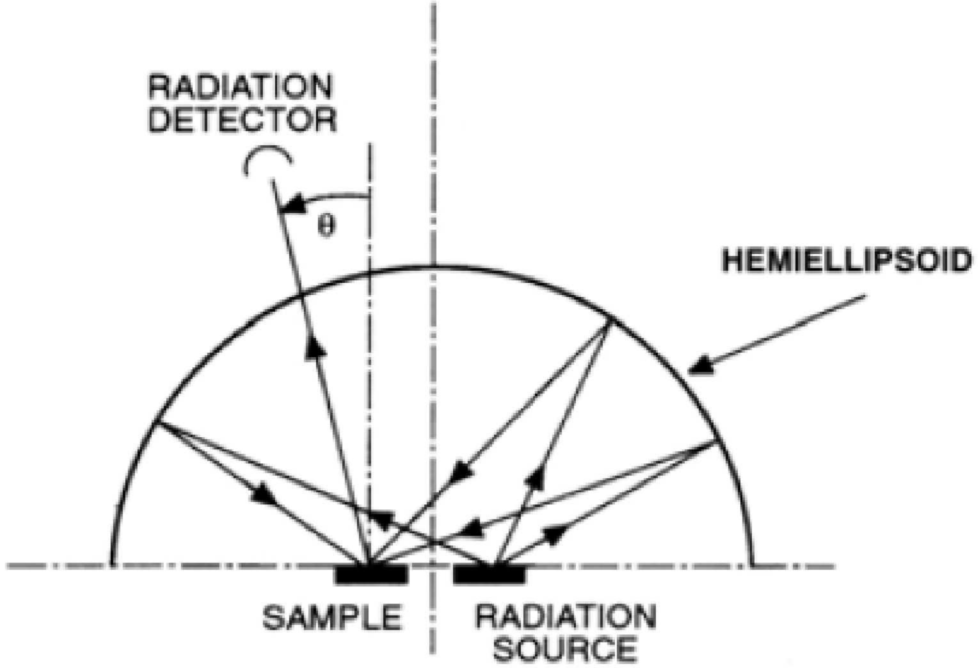




DMLS Surface Measured with Keyence VR3100 (Zoom 160x)

Emissivity Measurements

- Hemispherical Directional Reflectometer (HDR)
  - The source radiates the sample uniformly
  - Directional Emissivity is measured at 5-10 degree increments
  - Radiation reflected from sample is directed by a mirror that directs radiation to the connected FTIR
  - Wavelength Range: 2.5-25 microns



Second Task – Vacuum Furnace IR Measurements

- Max temperature – 750 C from literature review of thermal simulations and discussion with technicians
- Acquiring high temperature type K thermocouples with ceramic insulator beads for flexibility
- Designed experiment fixtures that will hold samples at constant angles in crucible during heating
- Sample holders will be made of 316 stainless steel with ProX 200 and post processed machined
  - Angles will be 0, 30, and 45 degrees from normal (majority of literature had cameras that were 25-45 degrees from normal)
  - 0 degrees is included for both normal emissivity validation for simulations, but also for bore-sighted thermal measurement techniques

Third Task – In Situ Measurements

- OCT – viable method for measuring surface topography in metal DMLS
- Ibo Matthews from LLNL agreed to participate in collaboration
- Recently published paper – "In situ measurements of layer roughness during laser powder bed fusion additive manufacturing using low coherence scanning interferometry"

Schedule Moving Forward

- Late Summer
  - Finish making samples
  - Measure surface topography
  - Start HDR measurements
- Fall
  - Finish HDR measurements
  - Process SR + emissivity data
  - Re-run any needed simulations
  - Vacuum furnace experiments
- Spring
  - Finish vacuum furnace experiments
  - Analyze data
  - Collaboration
- Summer
  - Write

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