Investigation into Methodologies for Mitigating the Effect of High Energy Laser Weapons

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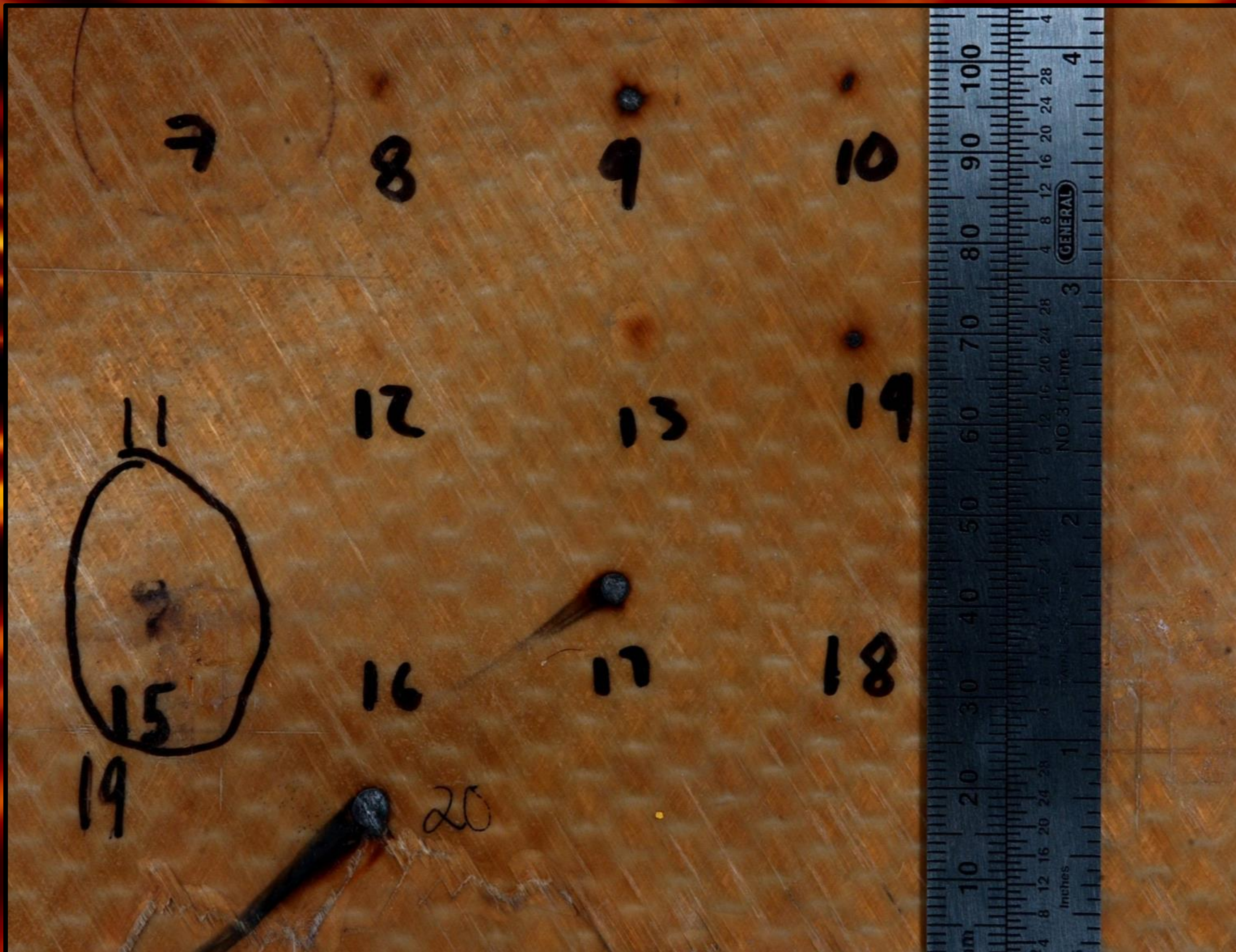
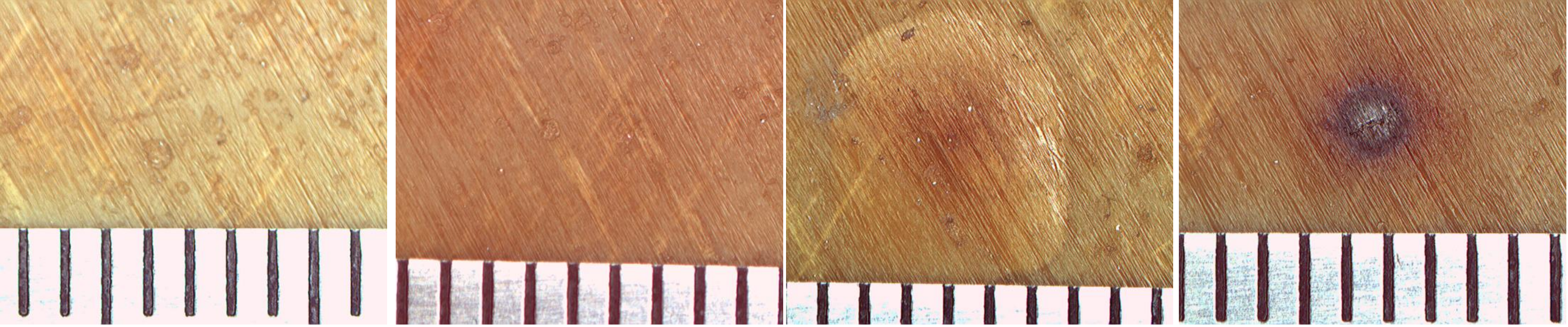
Preliminary Laser Damage Tests



Testing performed at Precision MicroFab in Severna Park, MD, thanks to Mr. Chris Selley



5s #11 | 7s #12 | 9s #13 | 11s #14

Burn Time

Power = 20 W, Spot size = 5 mm dia.

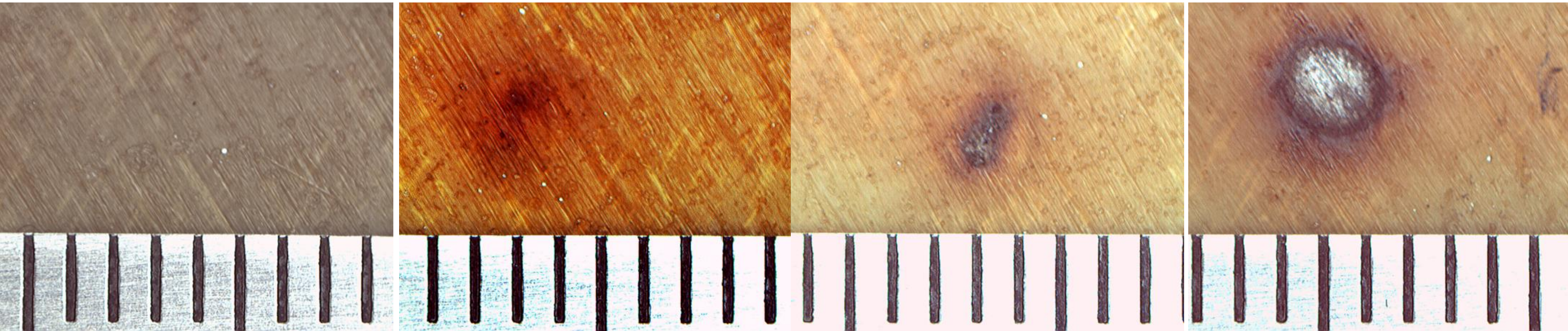
Irradiance = 1.02 W/mm^2

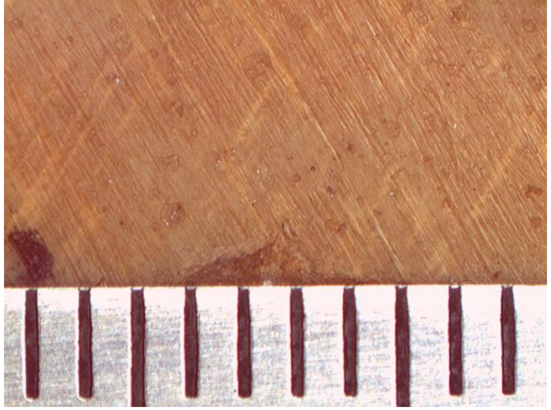
Power = 30 W, Spot size = 5 mm dia.

Irradiance = 1.53 W/mm^2

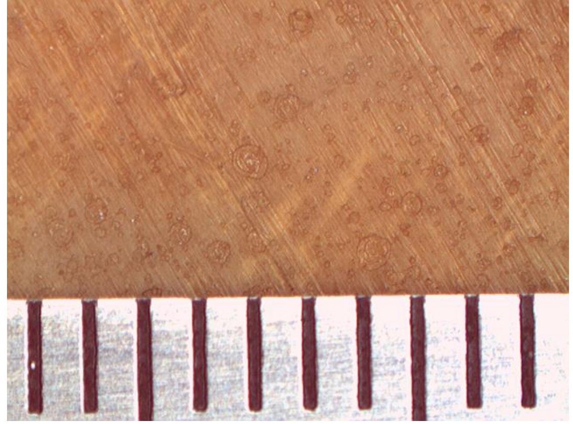
Burn Time

3s #7 | 5s #8 | 6s #10 | 7s #9

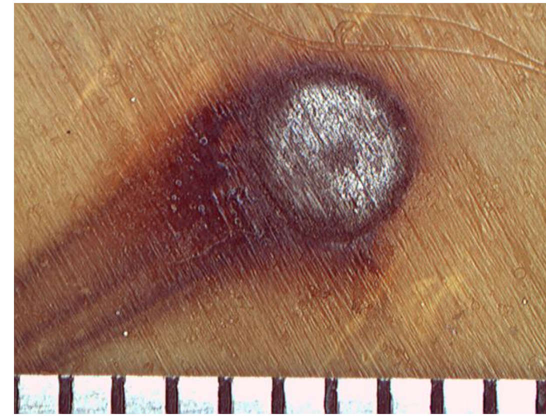




1s #15



3s #16



5s #17

Burn Time

Power = 40 W, Spot size = 5 mm dia.

Irradiance = 2.04 W/mm^2

Power = 50 W, Spot size = 5 mm dia.

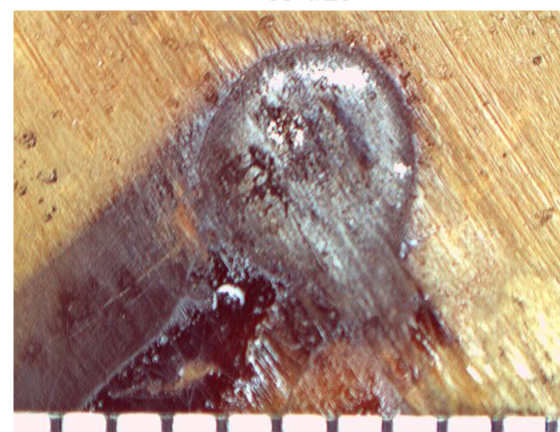
Irradiance = 2.55 W/mm^2

Burn Time

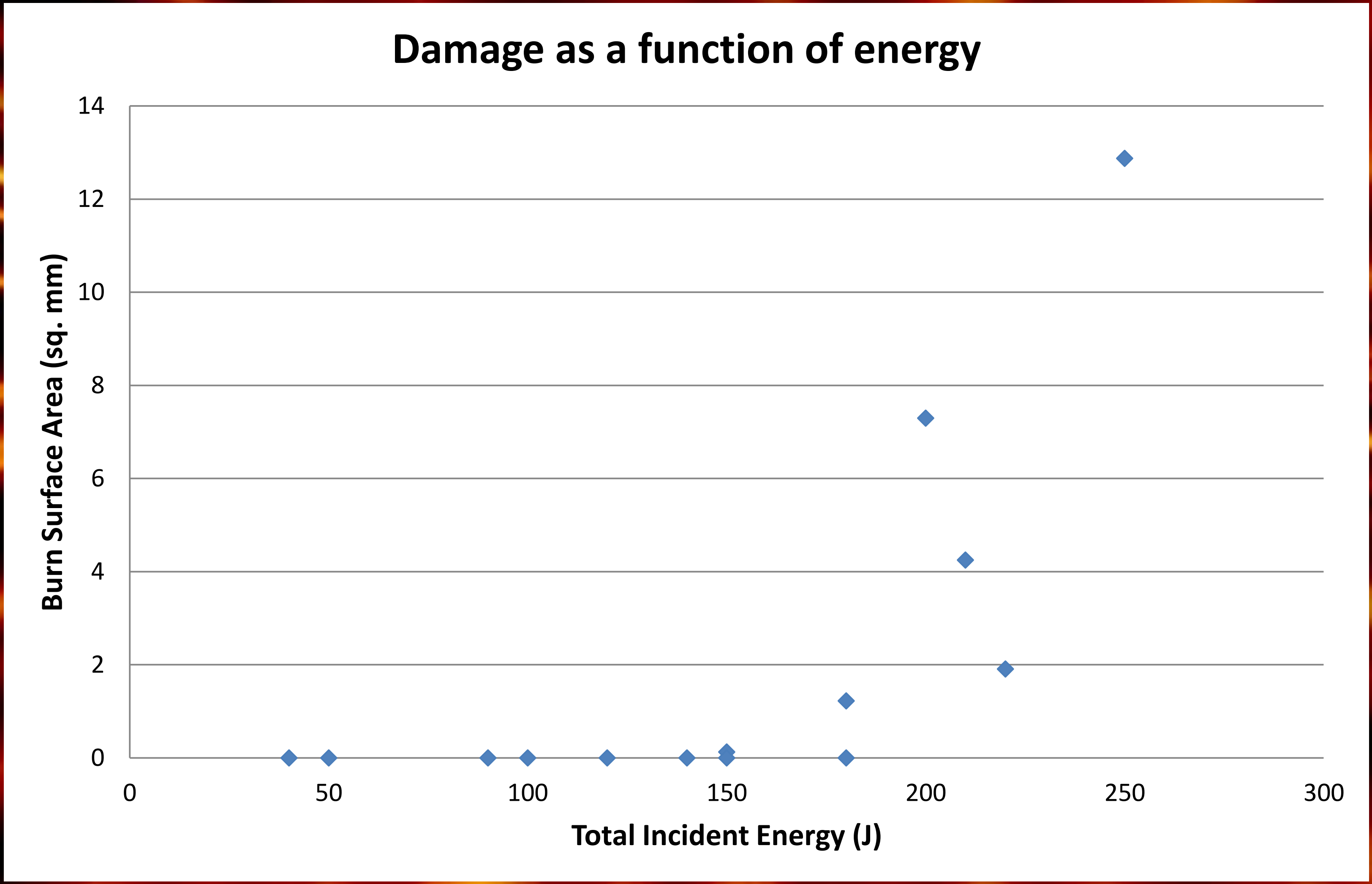
1s #18

3s #19

5s #20



Preliminary Laser Damage Tests



Literature Survey
Laser Damage of Polymer Composites

- “Residual Strength of Laser-Damaged Graphite Composites” by Kibler, Carter, and Eisenmann (1974)
- “Response of Graphite Composites to Laser Radiations” by Kibler, Carter, and Eisenmann (1977)
- “Infrared Laser Ablation of Polymers”, by Cozzens and Fox (1978)
- “Degradation of Tensile and Shear Properties of Composites Exposed to Fire or High Temperatures” by Pering, Farrell, and Springer (1979)
- “Laser-Induced Damage Mechanisms of Kevlar 49-Epoxy Composites” by Morgan, Kong, and Lepper (1988)

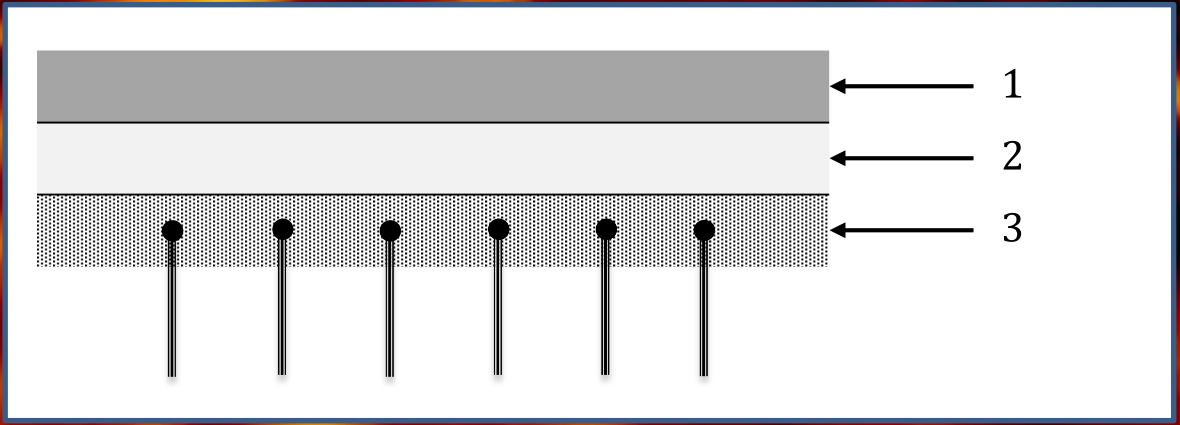
Architecture Based Counter Directed Energy Defensive System

- Biologically inspired, multifunctional, macroscopically heterogeneous approach to the design and fabrication of a parent structure
- Goal is to provide the parent structure with the capability to
  - (1) reflect the majority of an incoming directed energy insult,
  - (2) passively detect structural injury from penetrating energy (as in input signal for subsequent evasive maneuvering)
  - (3) protect the above system from environmental effect damage.

Architecture Based Counter Directed Energy Defensive System

– Concept Architecture :

1. Epidermis
2. Dermis
3. Modified Parent Structure with Nervous System



Architecture Based Counter Directed Energy Defensive System

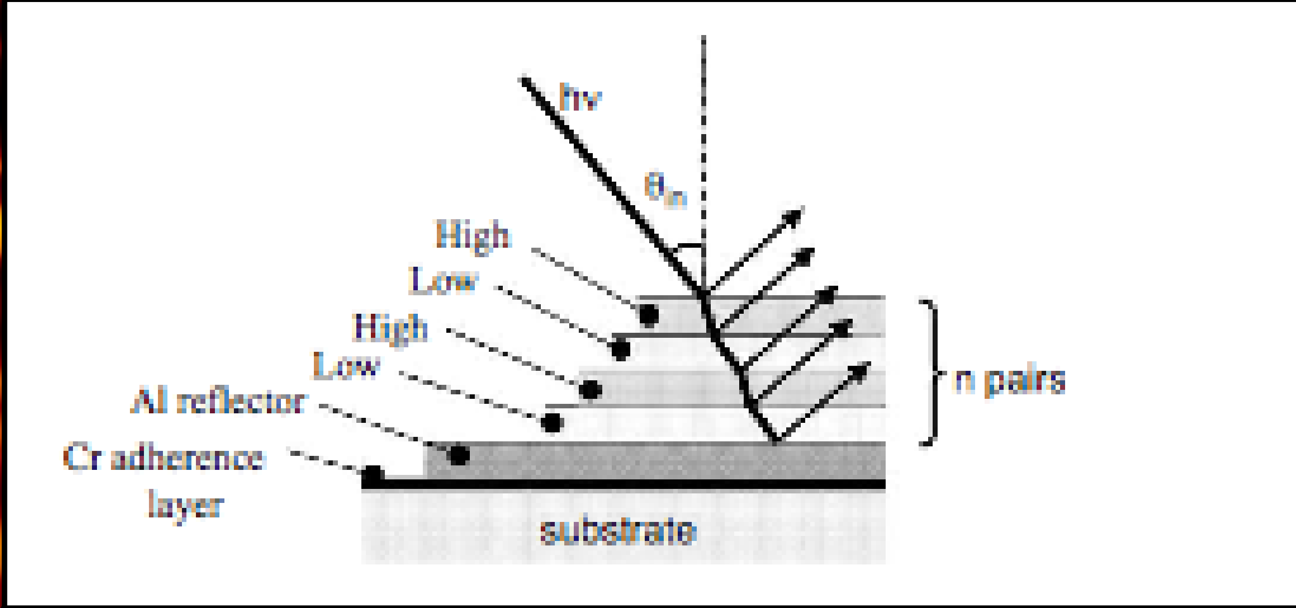
1) **Epidermis** - a (potentially sacrificial) layer that is either transparent to laser or is intended to disintegrate from incident laser energy. The role of this layer is to protect the modified parent structure from environmental effects. This layer can potentially include radar absorbing materials, cosmetic paint, etc.

Architecture Based Counter Directed Energy Defensive System

2) **Dermis - a** layer that is intended to reflect laser light wavelengths or to sense/collect/disperse incident laser energy.
   - An ideal monolithic layer material would have a plasmon frequency significantly higher than expected laser frequency ranges.
   - A Bragg mirror reflective layer strategy would consist of alternating layers of transparent materials with a high and low refractive indices.
     - Each layer of the Bragg mirror has a thickness equal to one quarter of the wavelength of the incident laser energy being defended against.
     - The internal mirrors used to generate and control laser light are designed and fabricated using this paradigm and report reflective coefficients in the 95% to 99% range.

Architecture Based Counter Directed Energy Defensive System

- **Bragg Mirror Functionality**
  - **Alternating high and low indices of refraction cause reflection at each material interface.**



From: "Metal Multi-dielectric mirror coatings for Cherenkov detectors", Braem, David, and Joram, Nuclear Instruments and Methods in Physics Research, 2005

<u>A</u>rchitecture <u>B</u>ased <u>C</u>ounter <u>D</u>irected <u>E</u>nergy Defensive System

3) **Modified Parent Structure with Nervous System:** The outer surface of the parent structure is intended to be instrumented with a distribution of thermal sensors to detect temperature change, strain gauges to detect deformation, or an optically/electrically conductive network to detect material discontinuities from damage. Candidates for this network include (but are not limited to) MEMS temperature sensors, optical fibers, strain gauges, etc. This distributed system of nerves would necessarily need to feed this information to a "central nervous system" in the form of a CPU to inform the operator of an attack or for use in a decision engine for autonomous evasive maneuvering.

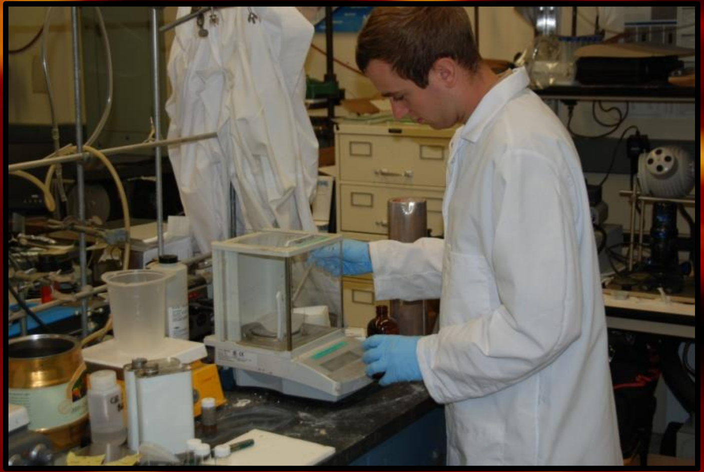
Literature Survey
Bragg Mirrors

- "Simple Analytical expressions for the reflectivity and penetration depth of a Bragg Mirror between arbitrary media" Optics Communications, Brovelli and Keller, 1995
- "Epitaxial Bragg mirrors for the mid-infrared and their applications." Progress in Quantum Electronics, Heiss, Schwarzl, et. al., 2001.
- "Fabrication of an integrable subwavelength ultrabroadband dielectric mirror", Applied Physics Letters, Chen, Huang, et. al., 2006.
- "Comparison of different strategies to realize highly reflective thing film coatings at 1064nm." Infrared Physics & Technology, Yang, Zhou, Jiang, 2008.

Program of Work

- **Dermis layer (Damage detection)**
  - Goal is to investigate embedded sensor technologies applicable to composite structures
  - Midn 1/C Moberg – internship at NRL (June 2010)

Various combinations of Cu and Al wires as well as thermocouples were embedded into a 2 ply S-glass/polyester composite panel
To investigate the potential for detection via a break in an electrical circuit.
The melting points of both metals are below that of the composite, failure of the wiring occurred prior to burn through.
The wires also served to indicate the temperature in the composite at a given time. The loss in continuity coincides with the melting temperature of the metal acting as a type of localized thermocouple.



Future Work – Fall 2010

Midn 1/C Moberg – Bowman Scholar

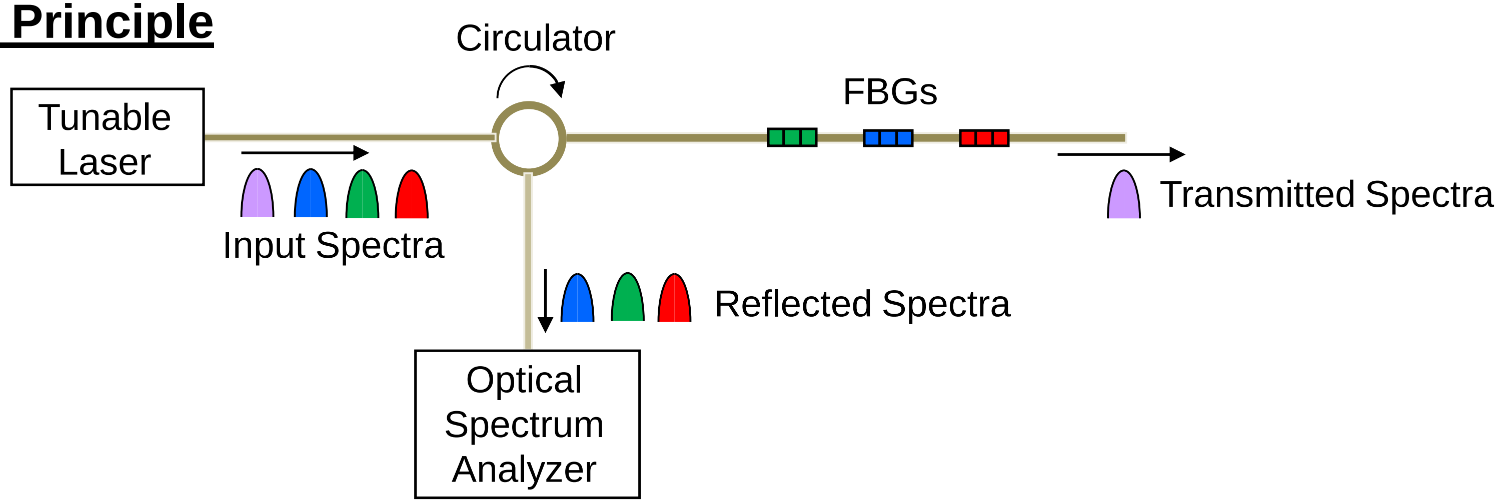
- Carbon fiber conductive nature as a means to detect damage
  - Carbon fiber strands are moderately conductive
  - As such, the resistance of the fibers in a panel act in a manner akin to that of many resistors in parallel
  - The resistance can be monitored, and the change in resistance can be used to indicate damage
    - Resistance is altered by loss of the fiber “resistors”
    - Further, the resistance is changed by fluctuation in temperature
  - Problems may arise with Aluminum and Carbon Fiber due to electro- chemical corrosion
  - Further testing will determine the practicality of this approach

Program of Work

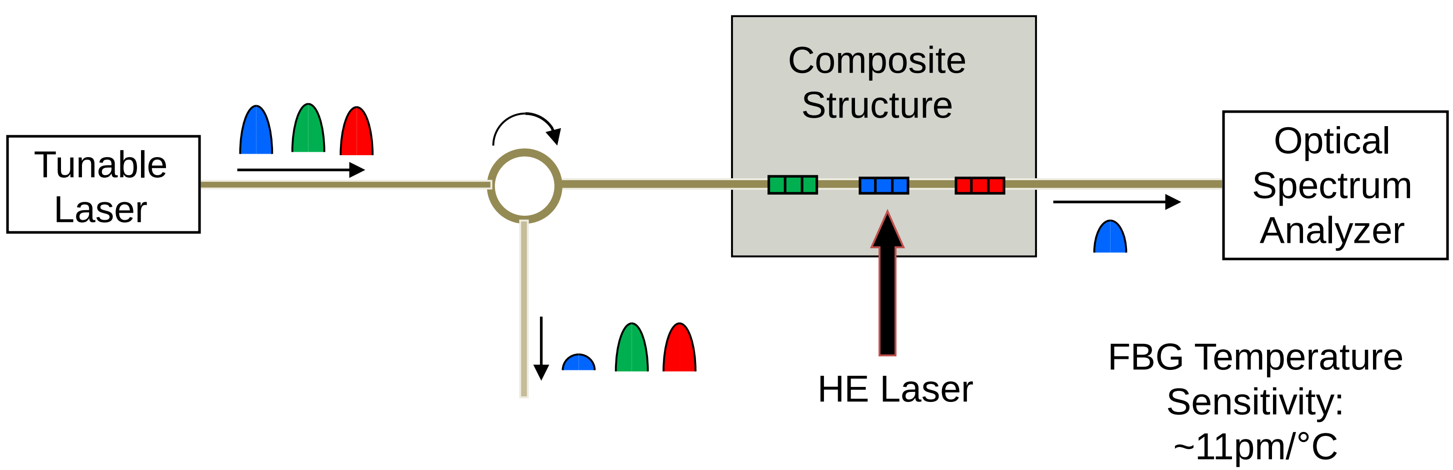
- **Dermis layer (Damage detection)**
  - Test commercially available fiber optic based thermal sensors to learn how current technology works.
    - Obtain a fiber optic thermal sensor and interrogate/test it using lasers
  - Embed a fiber Bragg grating in a composite structure and test the device under varying temperature conditions.
    - For optical testing, the grating should be reflective around 1550 nm to be compatible with existing lasers
  - *Begin to explore ideas for a fiber optic network architecture that would communicate the sensor data through the overall vehicle/parent structure.*

Laser Detection Using Integrated Fiber Optic Temperature Sensors

Fundamental Principle



Experiment



Initial Experiments with Fiber Optics Temperature Sensors

FBG Sensor Specifications

Center wavelengths: 1540, 1545, 1550 nm

Reflectivity: >60%

Maximum temperature: 300 °C (Fiber coating: Polyimide)

FBG Spacing: 50 mm FBG Length: 10 mm

Interrogation

High Power DE Laser, Tunable Laser, Circulator, and Optical Spectrum Analyzer

Possible Future Experiments

FBG Sensor Specifications – multiple channels

Center wavelengths: many

Maximum temperature: >300 °C

FBG Spacing: <5 cm

Reflectivity: TBD

Fiber coating: Polyimide

FBG Length: TBD

Interrogation Options

1) Tunable Laser or Broadband Source
2) Circulator or High Power DE Laser (Wind Tunnel)
3) Arrayed Waveguide Grating
4) Oscilloscope and Optical Spectrum Analyzer
5) DAQ for temperature (real time analysis) and location (high resolution)

Alternative Sensing Techniques

Distributed sensing (Brillouin or Raman scattering) – poorer spatial resolution (?)

D-Core Fiber gratings – high temperature sensing (> 1000 °C, ms response times, BYU)

Program of Work

- **Dermis layer (Reflectivity/protection)**
  - Create a theoretical model that predicts the performance of a multiple layer coating with thickness and material variations.
    - Determine appropriate software to model multiple layers
    - Indentify monolithic laser reflective materials.
    - Identify candidate multi-layer laser reflective architecture
  - Manufacture proposed coatings
    - Identify potential manufacturing processes
    - Identify groups already proficient in the fabrication of Bragg mirrors
    - Fabricate test and control specimens
  - Design an experimental set-up and procedure to test the predicted coating parameters and determine the efficacy of the manufactured coatings
    - Identify test parameters
    - Determine required experimental test fixtures
    - Determine required experimental software

Future Work – Spring 2011

Midn 1/C Medford – Bowman Scholar

- Goal is to characterize the trend of strength-loss as exposure to a laser of a given irradiance increases – from initial damage to complete burn through.

Future Work – Spring 2011
Midn 1/C Medford – Bowman Scholar

- Methodology
  - Fabricate 6-ply cross-ply laminates E-glass/Polyester
  - Cut into tensile test coupons (10” x 1”)
  - Coupons damaged via HEL and examined via ultrasonics or other NDE
  - Specimens tensile tested for residual strength