Portable High-Power Laser Radiometer

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High Power CW Laser Applications

1. Military (ABL, anti-missle systems, …)
2. Medical (Surgery, …)
3. Remote Sensing (LIDAR, …)
4. Industrial (Cutting, Welding, Marking, Drilling, Peening, Sintering, …)


LaWS

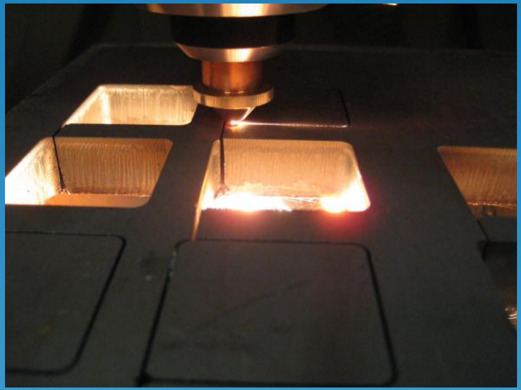

TLS

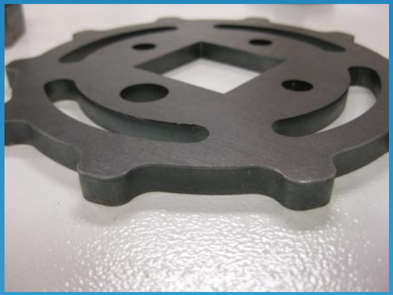
ABL

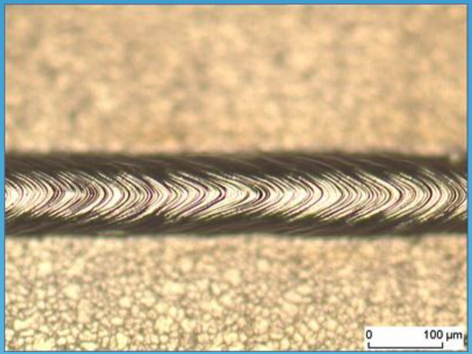
Navy Shipboard Lasers for Surface, Air, and Missile Defense: Background and Issues for Congress, Congressional Research Service, 7-5700, www.crs.gov, R41526

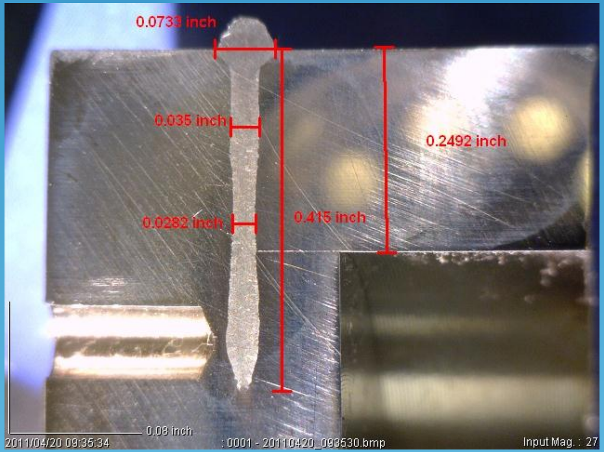
Laser Welding and Cutting is BIG

Requires lots of power (1kW – 15 kW)





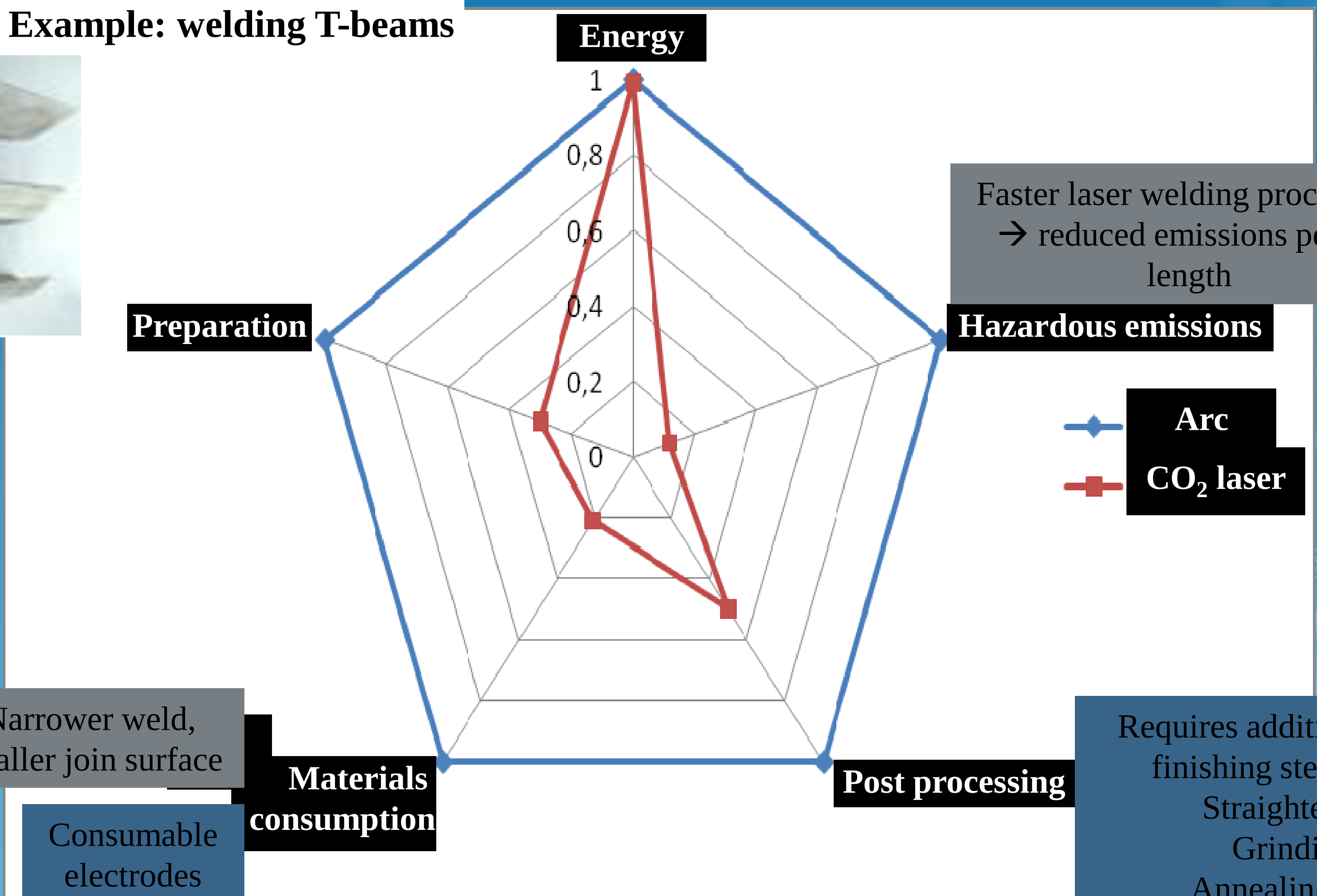




Laser welding is better

significant economic and environmental advantages

Example: welding T-beams



Faster laser welding process → reduced emissions per length

Narrower weld, smaller join surface

Consumable electrodes

Requires additional finishing steps
Straightening
Grinding
Annealing (2x)

S. Kaierle, M. Dahmen, O. Gudukkurt, “Eco-efficiency of Laser Welding Applications,” Invited Paper, SPIE Eco-Photonics 2011, Strasbourg, France.
W.M. Steen and J. Mazumder, (2010) Laser Material Processing. Springer, London, Section 4.1.

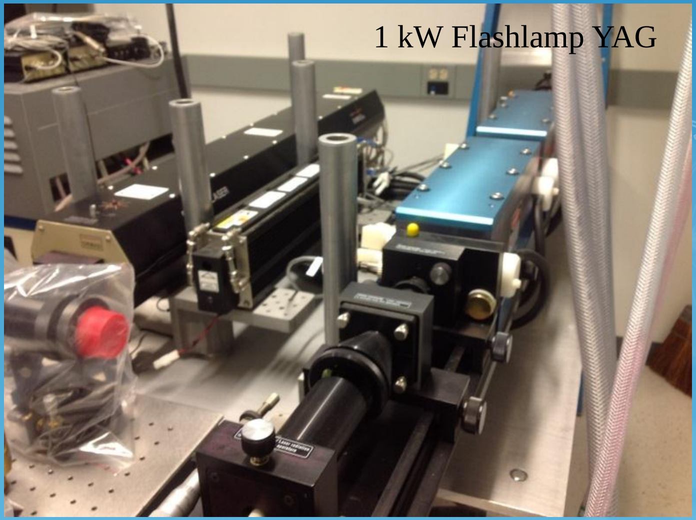
Evolution of High Power Lasers

Traditional high power lasers are:

- Less efficient (more input power and cooling)
- Higher maintenance (lamps, gasses, etc.)
- Cheaper! (for now)

Newer diode-pumped high power lasers are:

- Higher efficiency
- Lower maintenance
- Essentially turn key
- More expensive (but getting cheaper)



What do you need to know about your laser output beam

- Total power or energy.
- Beam profile.
- Temporal profile.
- Coherence properties.
- Spectrum.

All of these properties are important for any application.

Lets talk about the power and energy.

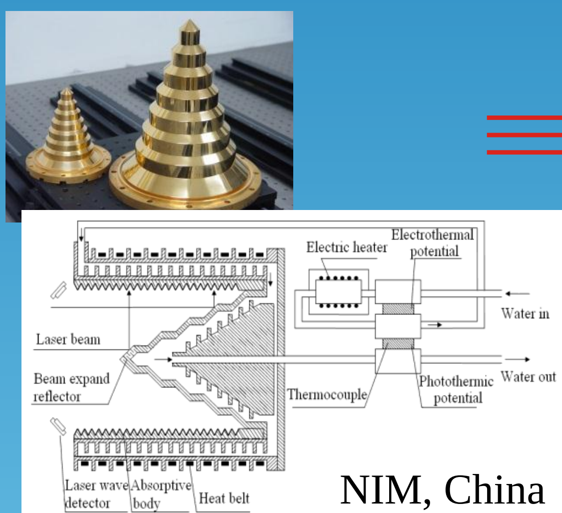
Laser Power → HEAT

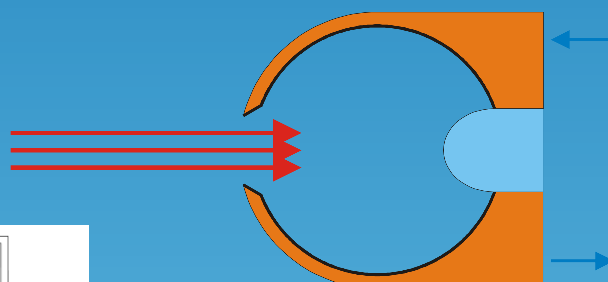
At 100 kW, tough part is converting the laser power to heat without damage to the radiometer.
Some traditional techniques for absorbing laser radiation are:

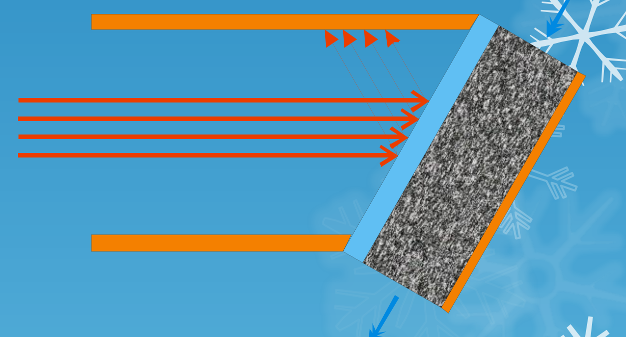
- High damage threshold black coatings.
- High power attenuation (first surface reflection for example).
- Use optics to expand the beam size before absorption by a surface.
- Absorb the laser power in a volume of material instead of at a surface.

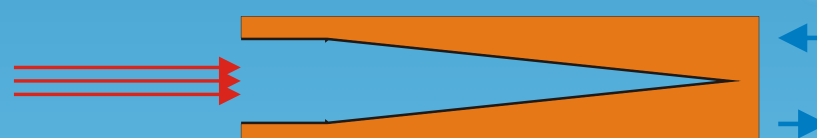
Possible Designs

- High damage coating first surface absorber.
- Sphere with fixed reflector.
- Long cone.
- Rotating reflector.
- Volume absorber (foams, liquids).



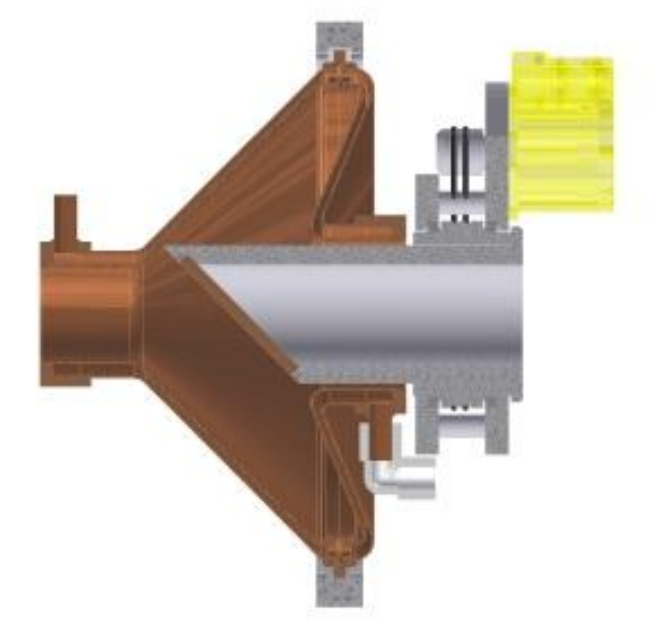




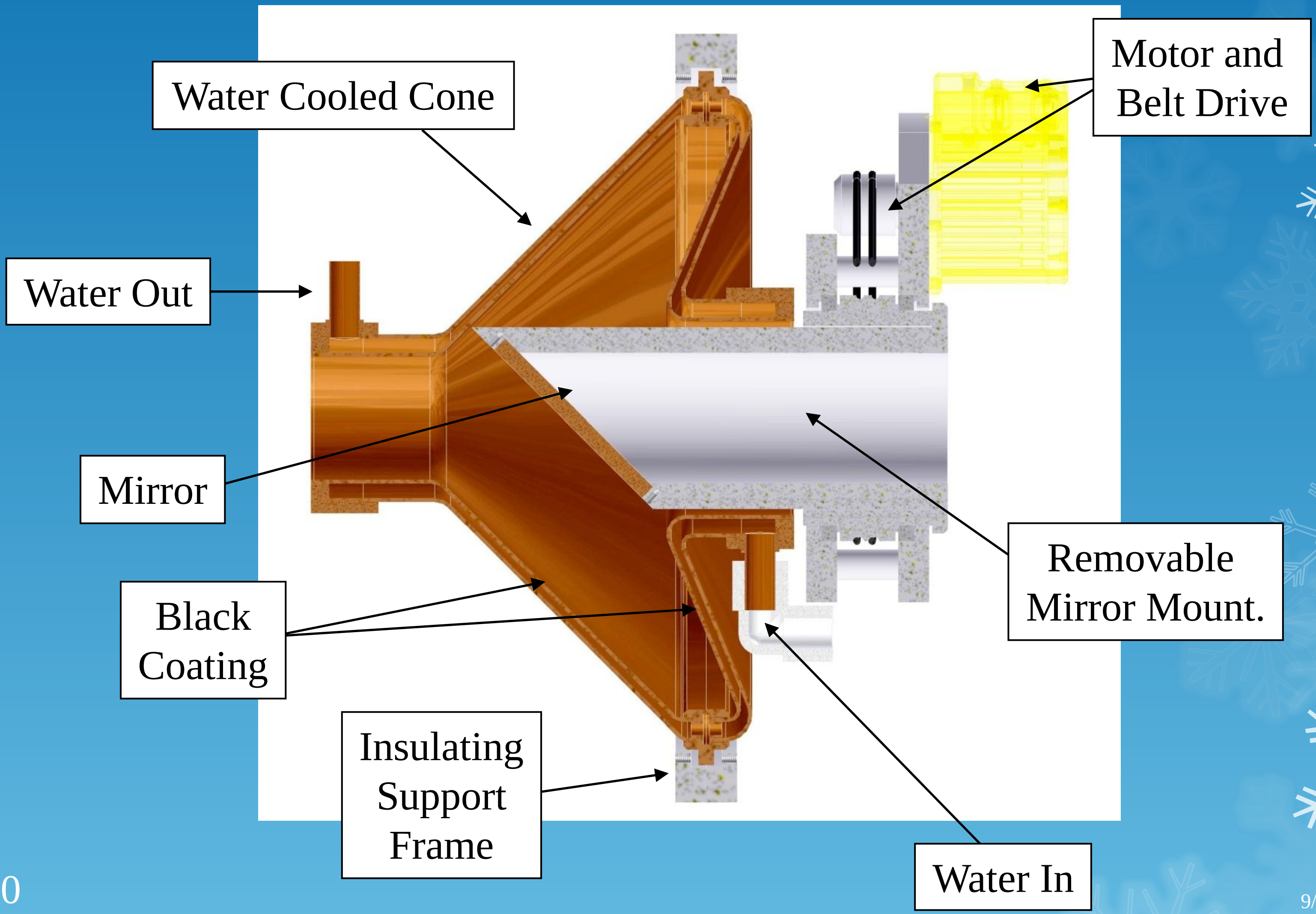


Receiver Design: Rotating Mirror Radiometer

- Rotating mirror to reduced laser dwell time on the coating.
- High reflectance removable mirror specific to one wavelength to reduce mirror absorption.
- Absorbing surfaces at an oblique angle further reducing power density at the coating.
- Reduced diffuse scatter due to deep cavity.
- Water cooling to measure absorbed power.



Key Components

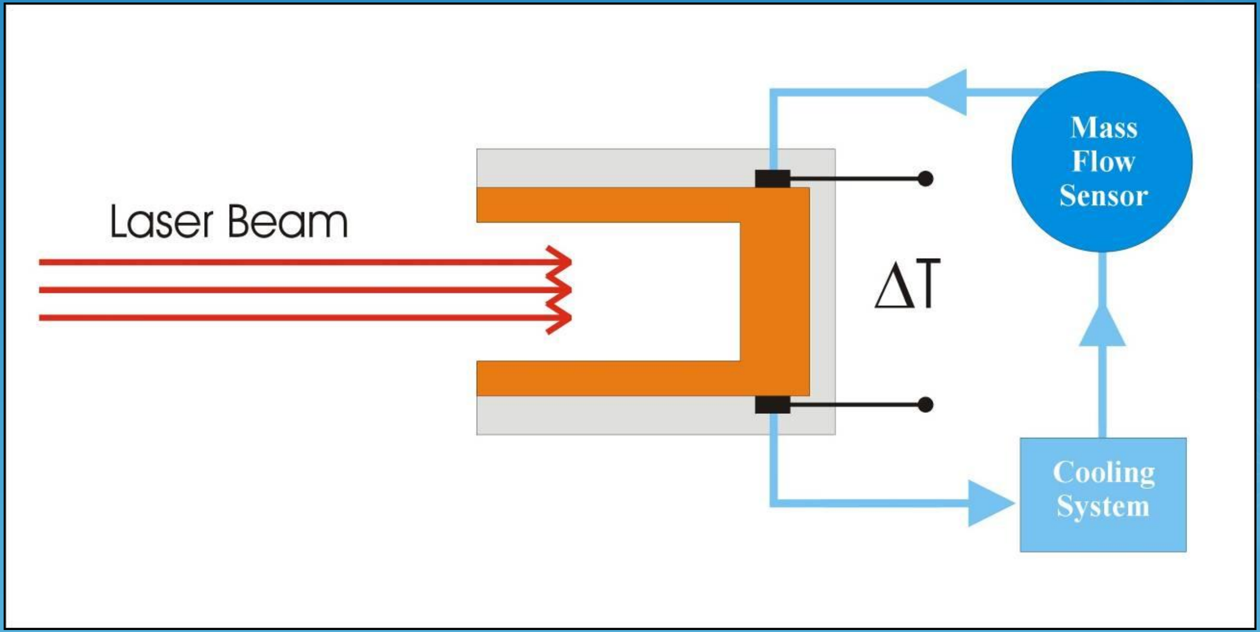


Advantages of Flowing Water Calorimeter

- Scalable to very high laser power by increasing flow rate of cooling water.
- Shippable due to the ability to separate the system components.
- Can be traceable through electrical calibrations performed offline with separate equipment that would stay at the primary lab.
- This “Heat Balance Calorimeter” can be run as a calorimeter (Joules) or as a power meter (Watts) with a time constant on the order of minutes. No “cool down” required.

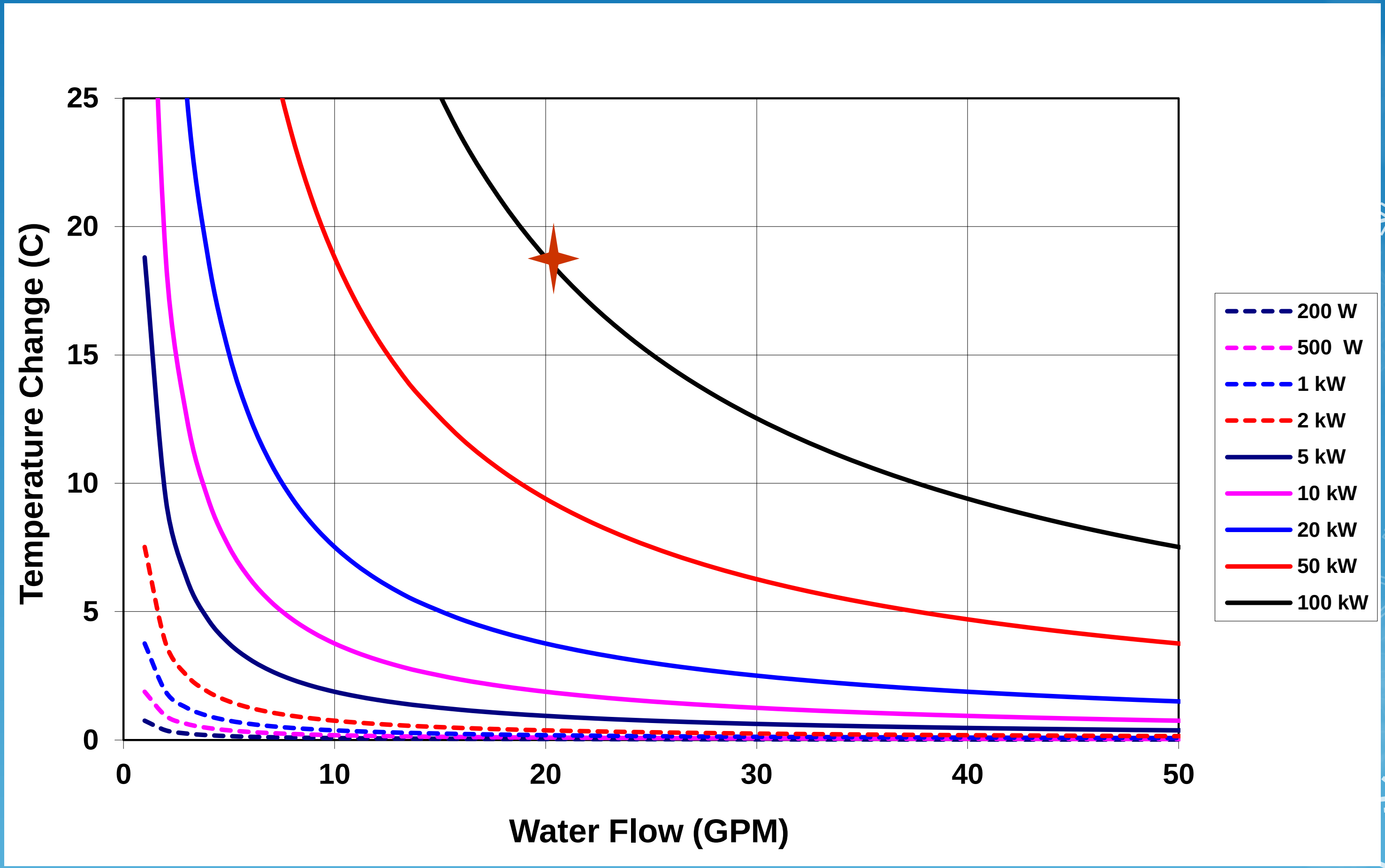
Laser Power Measurement Concept "Heat Balance Calorimeter"

$$P = \rho_m \cdot \Delta T \cdot C_p$$



Rule of Thumb: 70W power at 1 L/min results in 1 °C change in water temperature

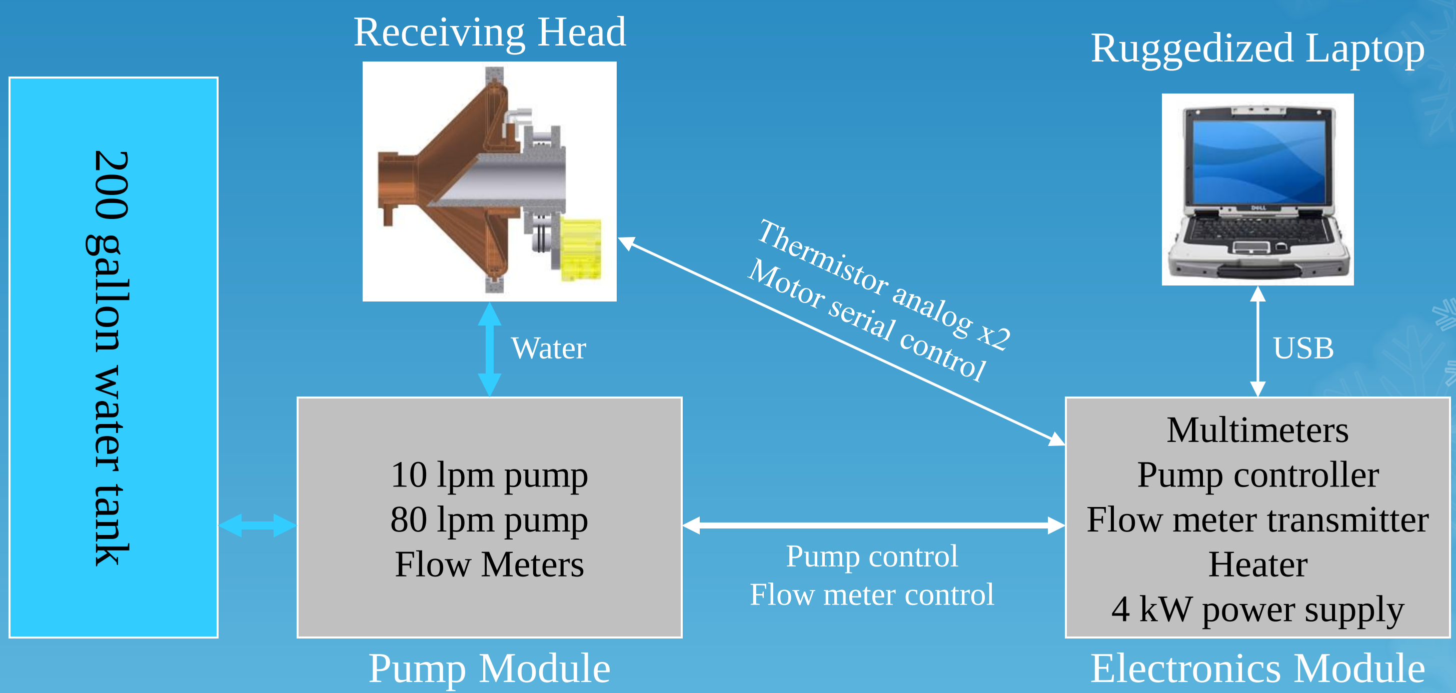
Temperature Rise vs Water Flow Rate



100kW = 18° C @ 21 GPM (80 LPM)

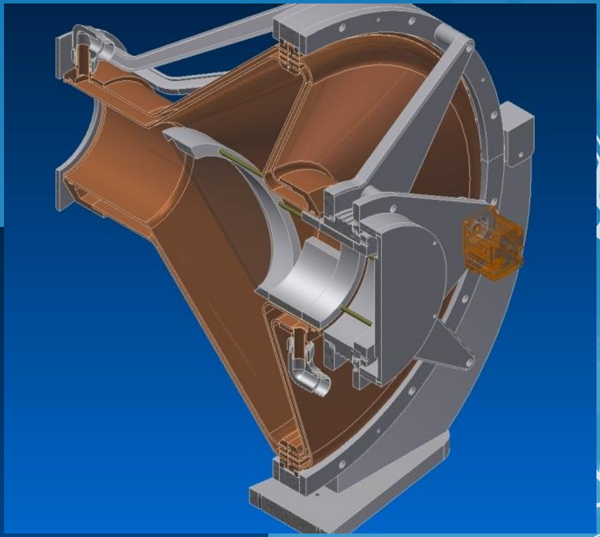
Portable Measurement System

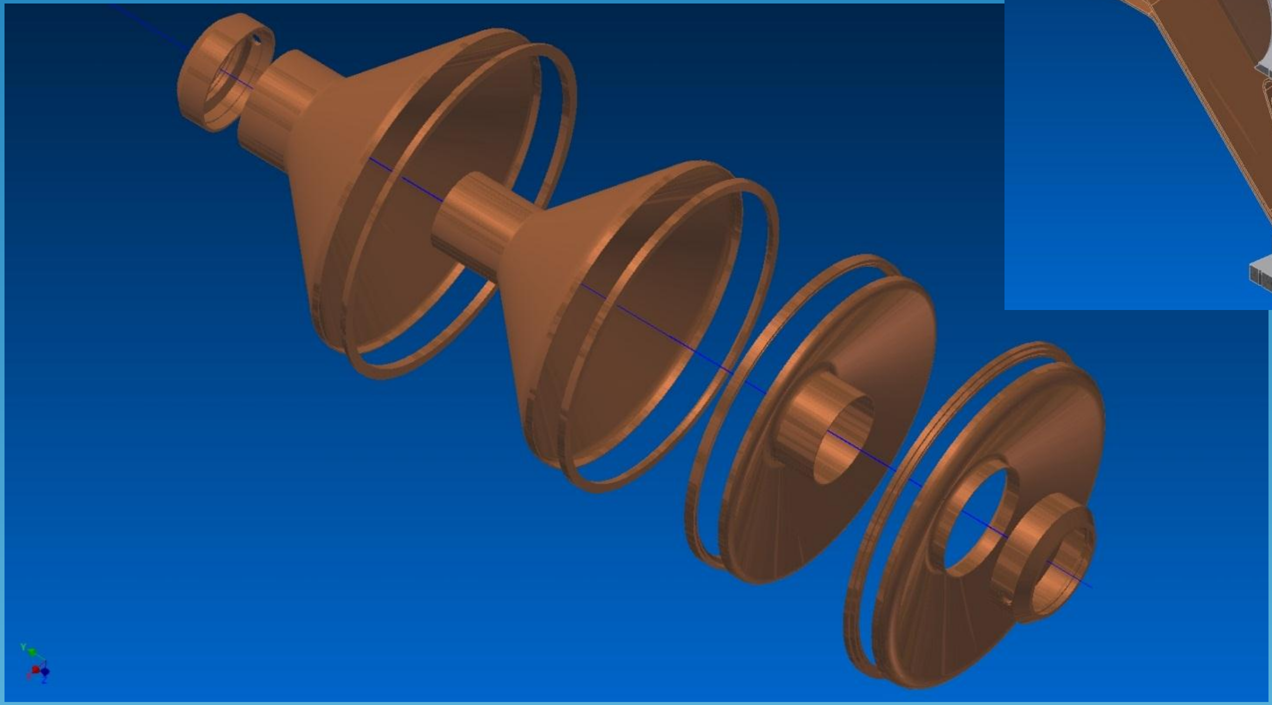
- Measurement system consists of a pump module, electronics module, receiving head, water tank, and laptop computer.
- Each section is separately shippable to the laser site.



Photos

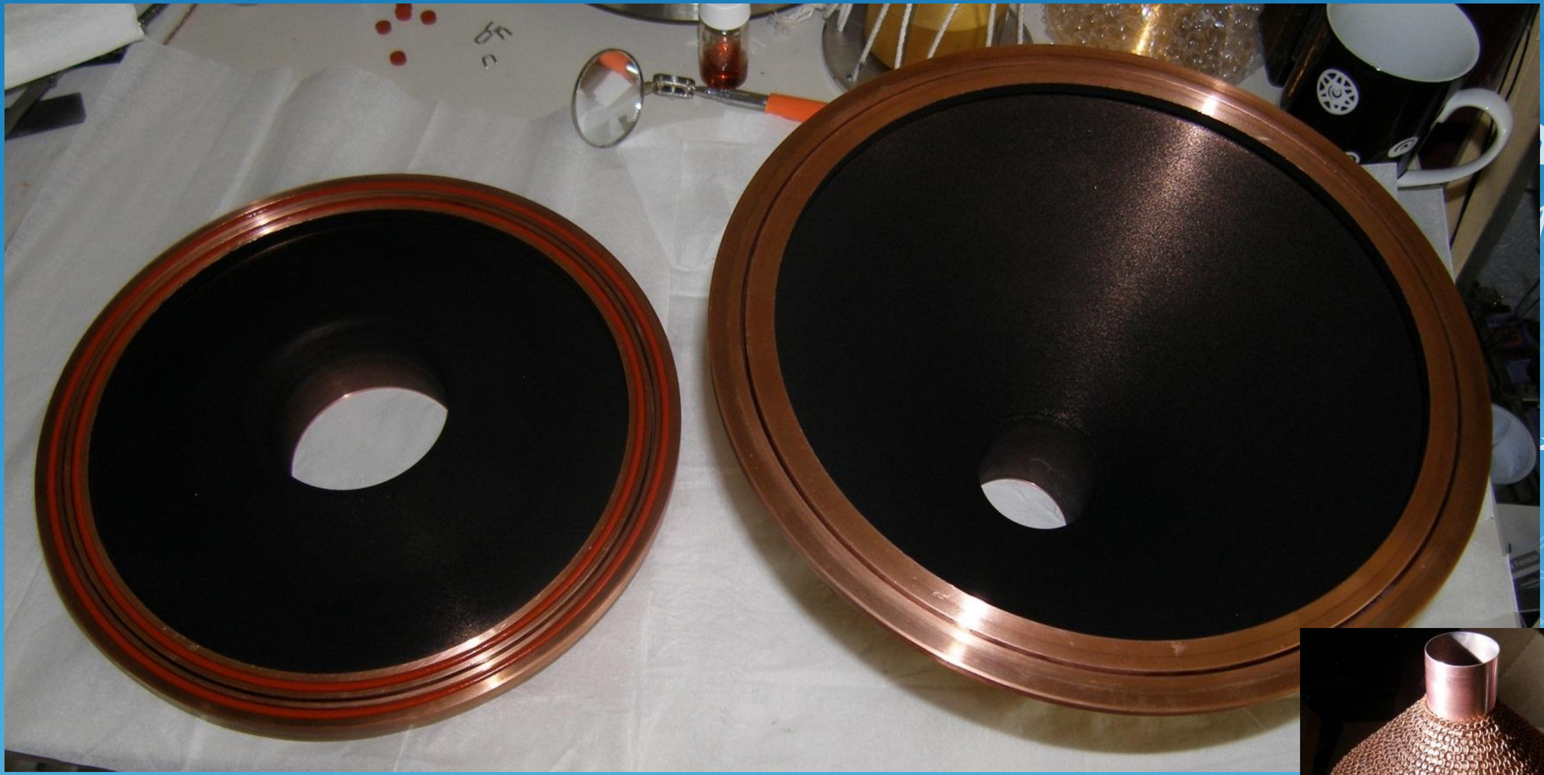
100 kW laser receiver head.





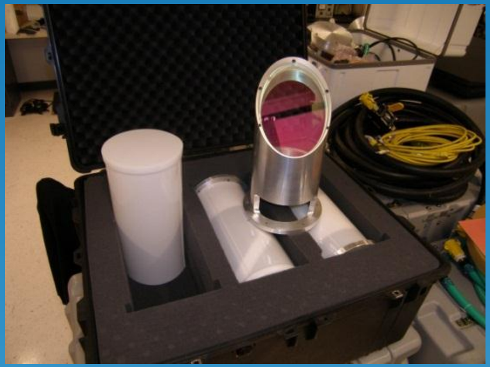
Exploded view of copper cones and fittings.

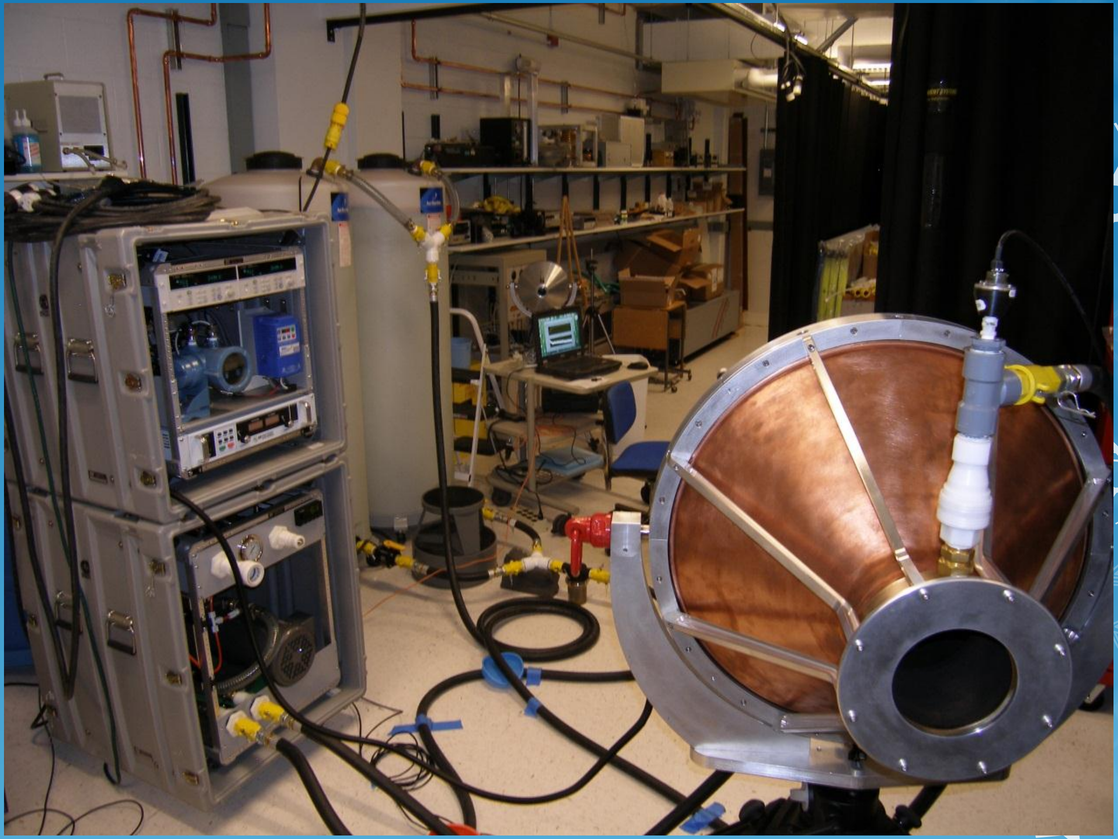
Photos



New Paint Job and Diffuser

Photos





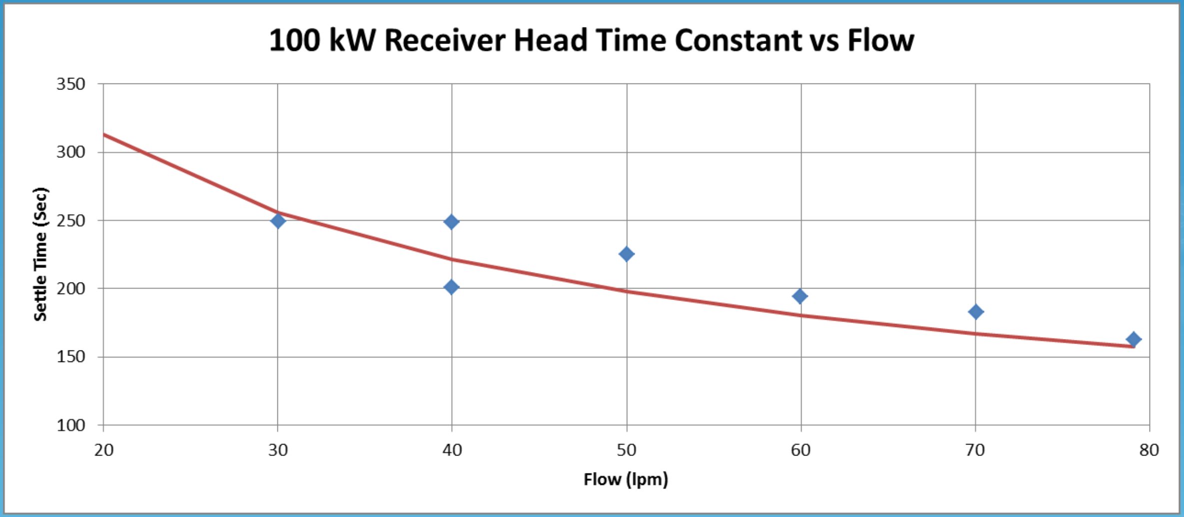
100kW laser receiver head, thermistor, and mirrors.

Time Constants

The system time constants are flow dependent. These are the time constants at maximum flow for each device.

- 100 kW Receiver 23 sec @ 80 lpm
- 10 kW Receiver 8 sec @ 10 lpm

For calculating settling time we use 7 x TC. So the 100 kW Receiver has a settling time of ~ 160 sec @ 80 lpm.



Core-Shell Composite of SiCN and Multiwalled Carbon Nanotubes from Toluene Dispersion

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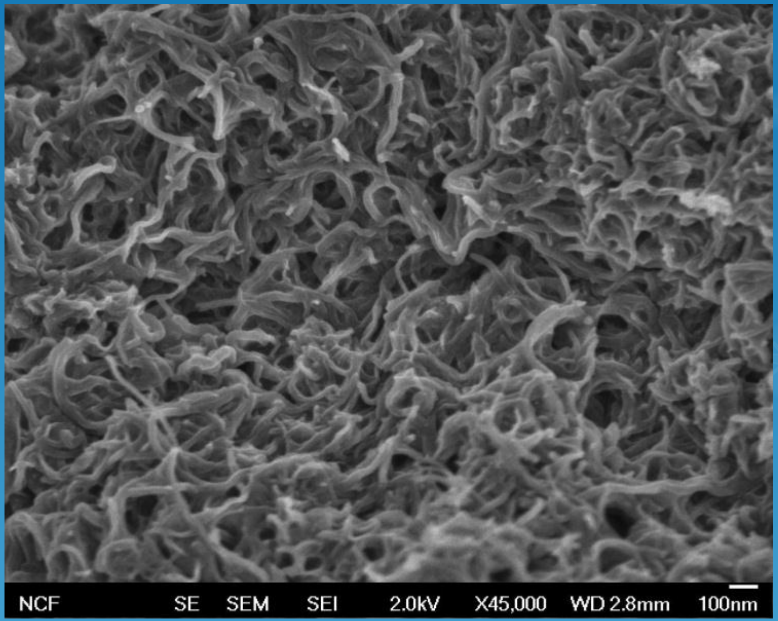
Abstract: We describe a novel route to form a shell-core material based on a polymer-derived ceramic of silicon carbonitride (SiCN) and multiwall carbon nanotubes (MWCNTs). The composite of SiCN surrounding MWCNT material (SiCN/MWCNT) distinguishes itself from MWCNTs because of a higher oxidation temperature as demonstrated by thermogravimetric analysis (716 °C vs. 580 °C). Raman scattering from 488 nm laser light distinguishes the core-shell composite from either MWCNTs or the SiCN alone. In addition, we document the coating process, images from scanning electron and transmission electron microscopy and measurement results that demonstrate the nature of the composite.

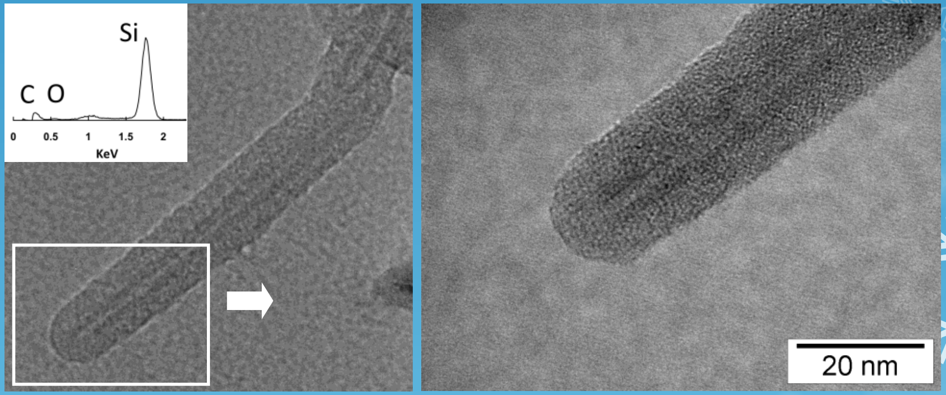
Journal of Materials Science Letters, 45, pp. 4251 – 4254, May 21, 2010

Polymer-Derived Ceramic Composite

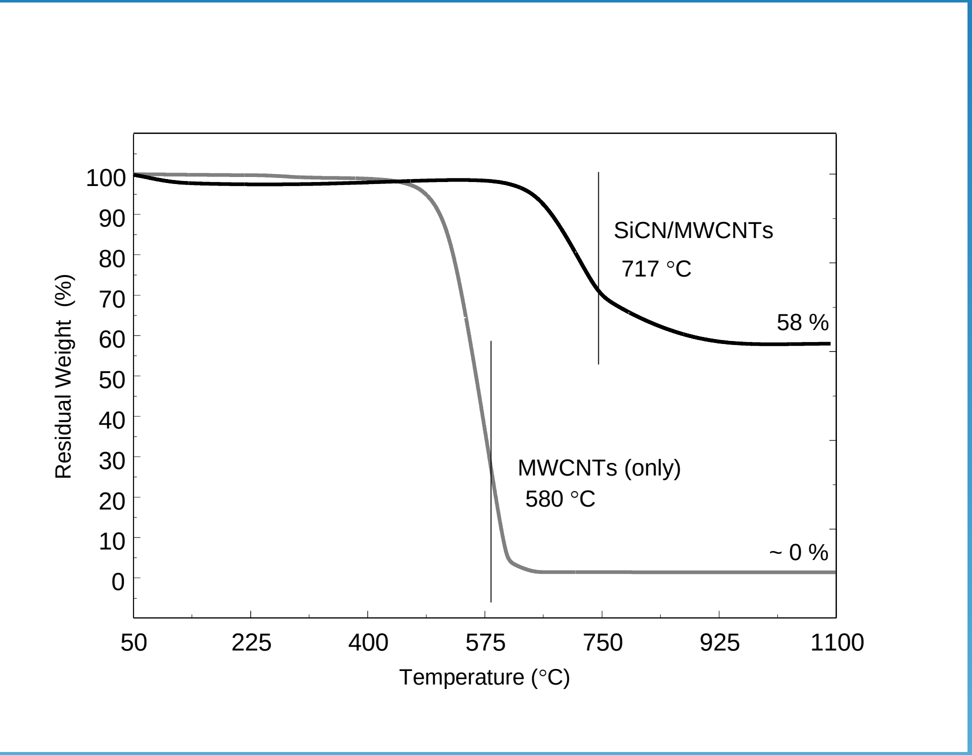
SEM image of SiCN/MWCNT material prepared at 1100 °C.



TEM images of a MWCNT coated with SiCN for specimen processed at a high-point temperature of 1100 °C. A thick ceramic coating (5-7 nm) covers the NT. Inset shows the TEM-X-ray energy dispersion spectrum (EDS) from the specimen.



Polymer-Derived Ceramic Composite



TGA of SiCN/MWCNT sample prepared at 1100 °C. The oxidation temperature at 717 is significantly higher than that of the MWCNTs alone (at 580 °C).

Carbon Nanotube Coatings

- Multiwalled carbon nanotubes (MWCNT) sprayed on copper have > 10 kW/cm^2 at 1064 nm! Easy to rub off. Not as good at 10.6 μm.
- Potassium silicate ("water glass") makes a good physical binder without changing the damage threshold.
- Ceramics make good high temperature coatings but are not black enough.
- Polymer-derived ceramics/MWCNT composites offer promise for high temperature, high thermal conductivity, high absorption materials.
- These composite cannot be applied directly to copper, but we can grind them to a powder and mix with the Potassium silicate binder!!!.

Carbon Nanotube/Silicate Coatings

Black Optical Coating for High-Power Laser Measurements from Carbon Nanotubes and Silicate

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Abstract: We describe a coating based on multiwall carbon nanotubes (MWCNTs) suspended in a potassium silicate solution. The coating has a high absorbance (0.96 at 1064 nm wavelength) and a laser damage threshold that is comparable to ceramic coatings presently used for commercial thermopiles for high power laser measurements. In addition to potassium silicate-based coating we discuss sodium silicate, lithium silicate and a commercially available ceramic coating. We document the dispersion process and a matrix of experiments that show the laser damage threshold at 1064 nm is greater than 10 kW/cm^2.

OCIS codes: 040.0040, 160.4236, 160.1890, 310.1210, 310.3915, 120.3940.

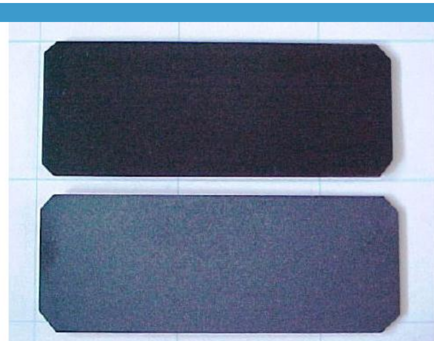


Figure 1. A photograph of copper coupons coated with MWCNT and sodium silicate. The lower coupon has been baked at 300° C and shows efflorescence. The brightness of the image has been modified to enhance the distinction.

Hard coating, not soft like gold black or bare CNT!!

Table 1. Damage threshold (P_t) and absorbance (α) at 1064 nm wavelength.

Material	α (average)	P_t
MWCNT-Sodium Silicate	0.91	10 kW/cm^2
MWCNT-Potassium Silicate	0.96	15 kW/cm^2
Ceramic	0.91	12 kW/cm^2

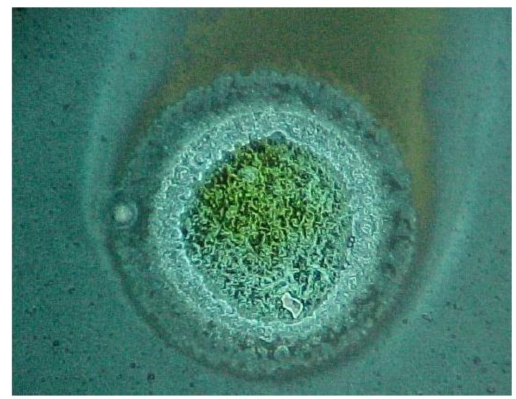


Figure 2. A photographic image of a laser-induced damage area. The diameter of the damaged area, indicated by the outermost ring, is approximately 2 mm. The translucent nature of the center suggests that the carbon is depleted and the frozen silicate remains. The brightness and contrast are modifed to enhance the visibility of the black coating that surrounds the damaged area.

Key Measurement Issues
(lessons learned)

- Input temperature must remain constant during a measurement. The heat capacity of the 100 kW receiver (~ 50 kJ/K) will absorb (or release) heat energy and result in a systematic error in the laser measurement.
- We maintain a thermocline in the 2 x 100 gallon water tanks to keep the receiver input temperature constant during measurements. The water tanks are stirred in between measurements.
- Time constants are reduced by minimizing thermal mass *downstream* from the heat absorption.
- A major source of error would be heat leaking to the environment. The receiver is thermally insulated from the aluminum support frame and mirror assembly.
- Convection losses are minimized by using high flow rate with good flow mixing to minimize surface temperatures.

Uncertainty Estimate

Source	Type B	Type A	
		Sr	N
Cavity Absorption	0.10%		
Electrical power	0.10%		
Lead Heating	0.10%		
T_{in} stability	0.15%		
Convection loss	0.15%		
Electrical Measurements		0.50%	3
Optical Measurements		0.68%	3
Combined Uncertainty	K=2	1.04%	

Summary of the sources of uncertainty and the total uncertainty for measurements of laser power and energy using the FWOPM

Barry N. Taylor and Chris E. Kuyatt; Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results. NIST Technical Note 1297: p.8 1994 Edition.

END

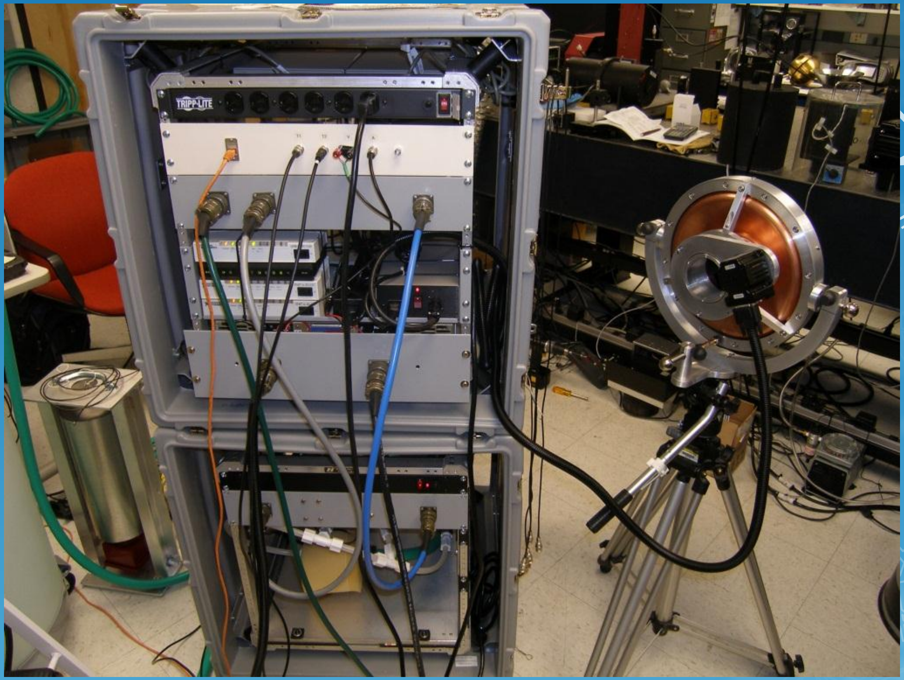
Polymer-Derived Ceramic Composite

- A dispersion of toluene and MWCNTs is mixed with a horn sonicator.
- Polyureasilazane (KDT Ceraset) is manually stirred into the dispersion, then further mixed in a bath sonicator, and then allowed to air dry.
- The residual solid is collected and placed in a zirconia crucible and baked in a nitrogen environment at ambient pressure.
- The temperature profile consisted of a two-hour ramp to 400 ° C, soaking at 400 ° C which polymerizes the Ceraset.
- This is followed by a four hour ramp to 1100 ° C, and a four-hour soak at the high temperature which converts the polymer to an amorphous SiCN based high temperature ceramic.
- The resulting material is a hard, black, crystalline material consisting of MWCNTs with an amorphous ceramic shell.
- This material is milled (crushed) and sifted with a 60 μm pore size stainless steel screen.
- This powder is mixed with water and Potassium silicate (water glass), and then sprayed with an air brush.

Photos

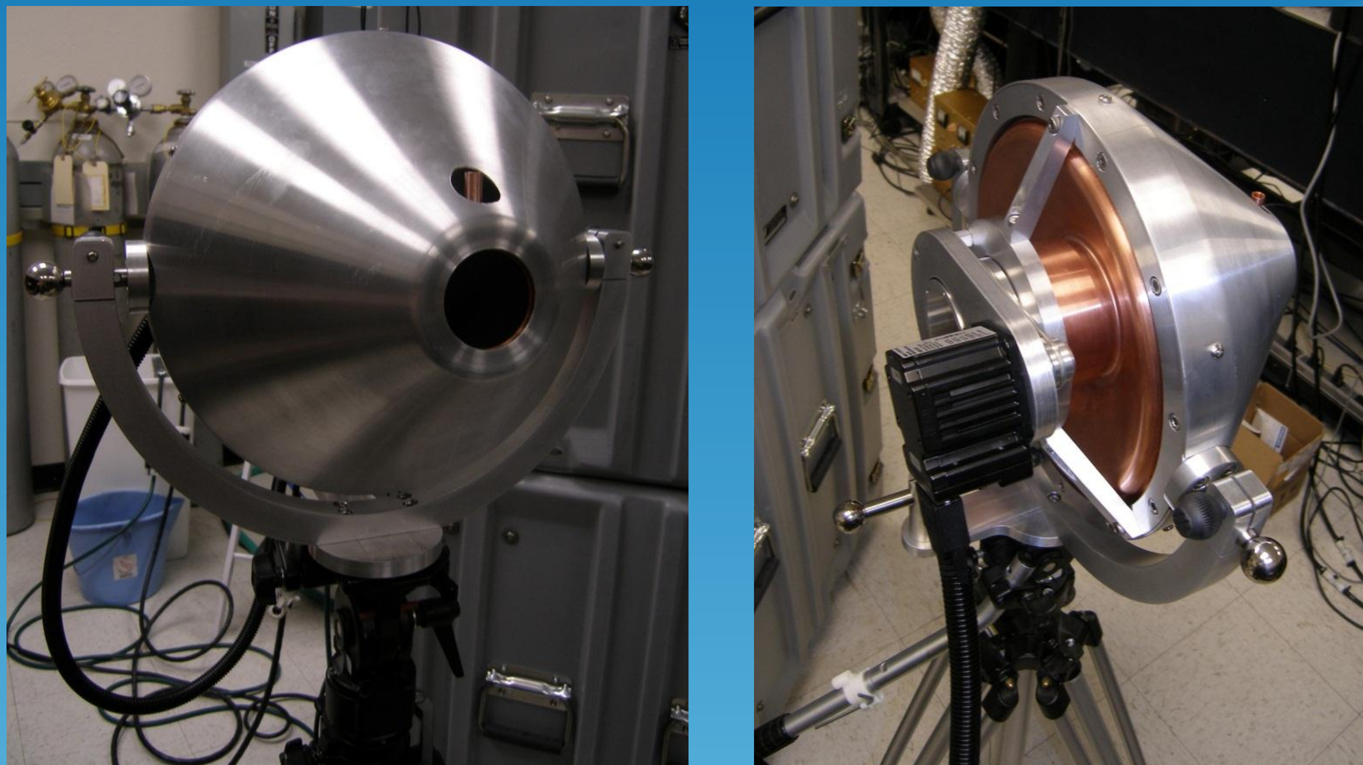
High Temperature Tube Furnace, Ball Mill, and Hood for Spray Coatings

Photos



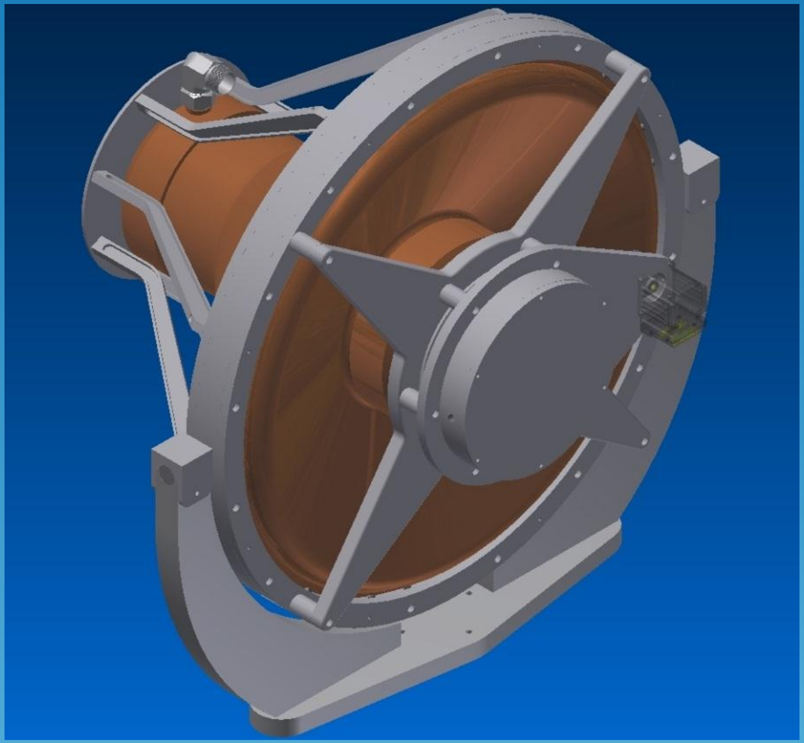
Electronics Rack, Pump Rack, and 100 gallon tank

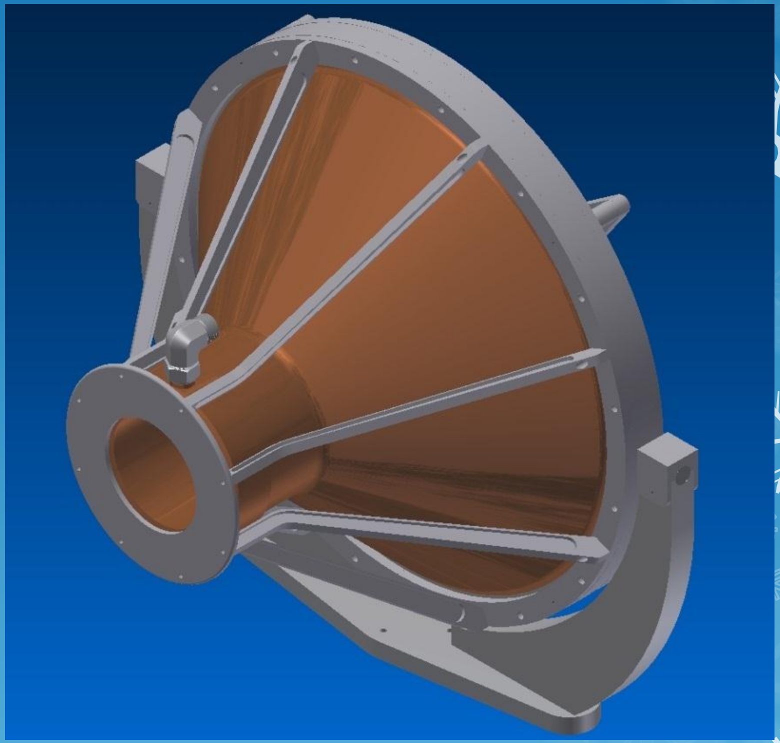
Photos



Final version of the 10 kW laser receiver head.

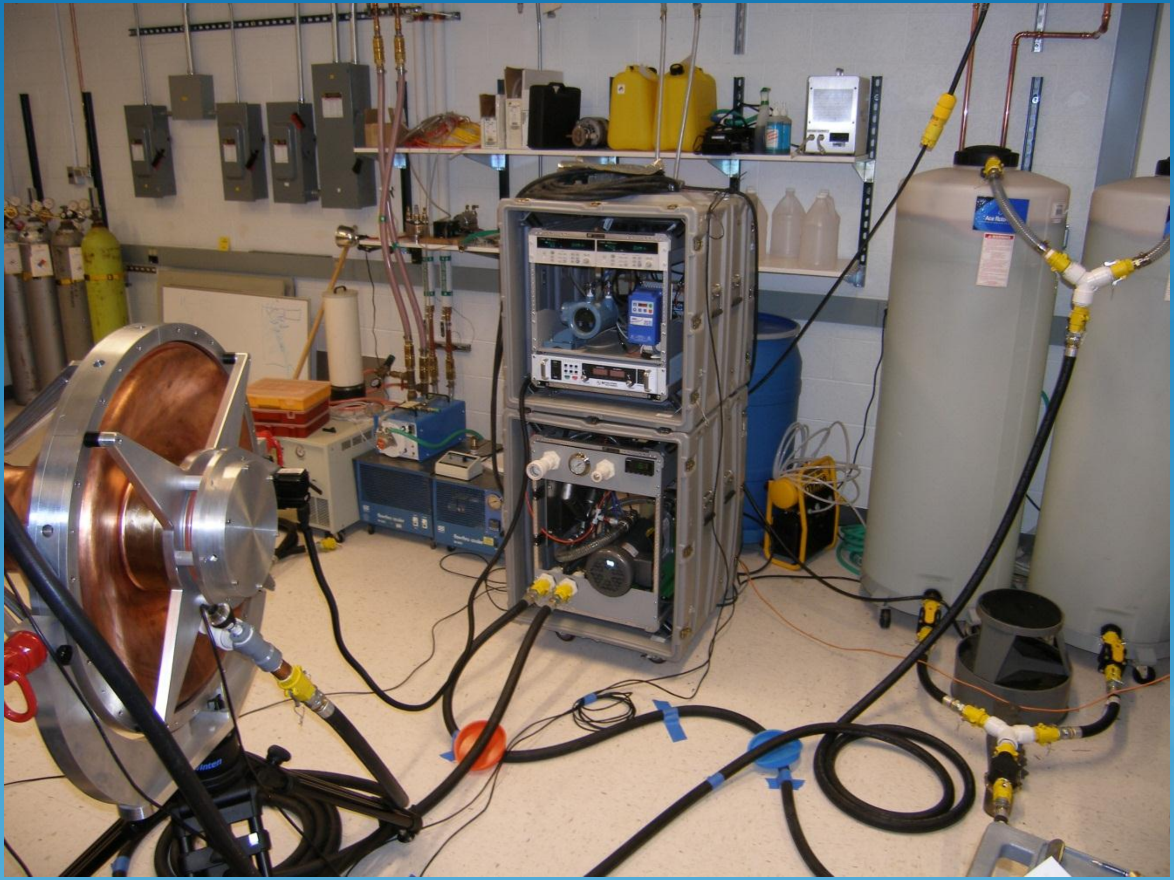
Photos





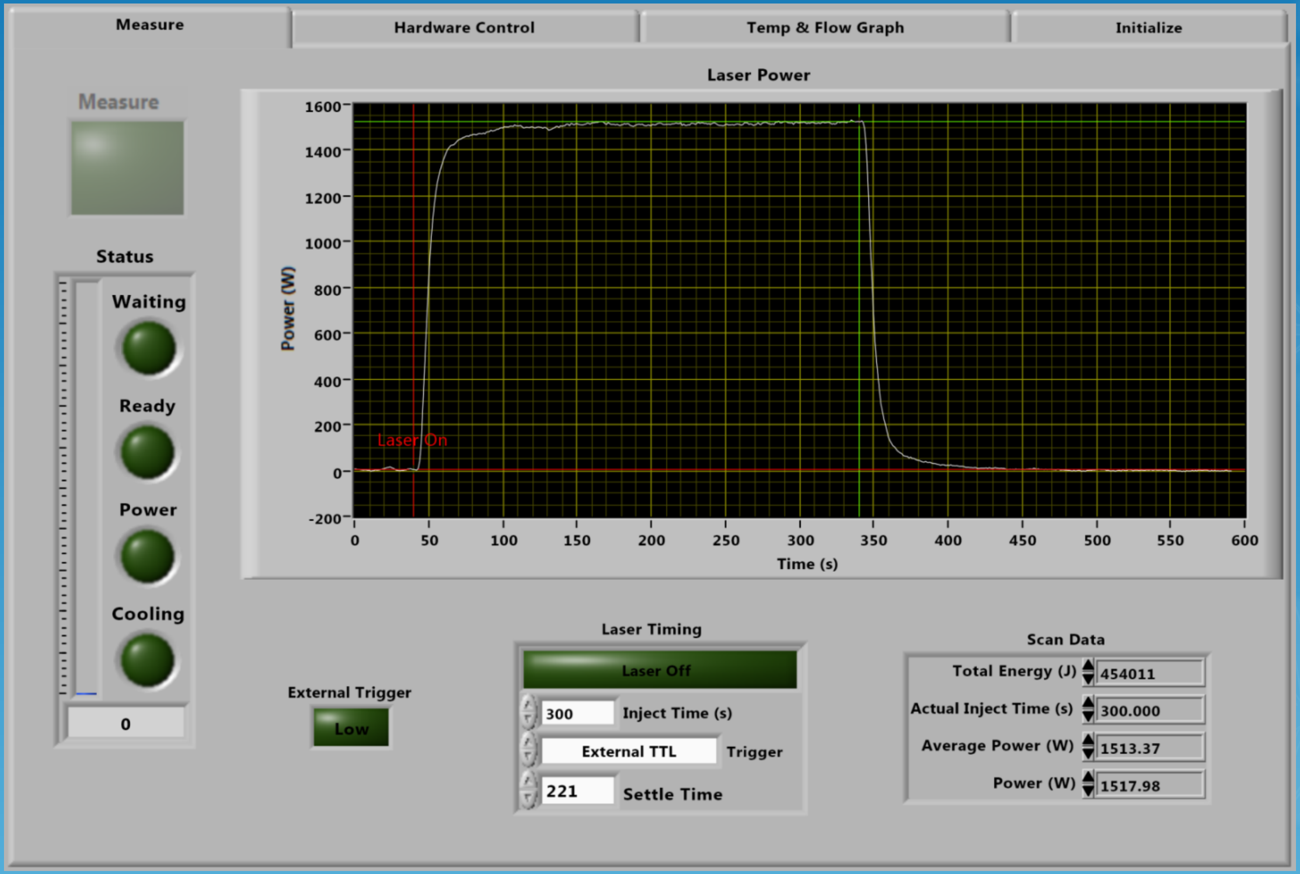
100kW laser receiver head.

Photos



Double tank arrangement for 200 gallon supply.
Shown is a calibration being done in the NIST K-Series Lab.

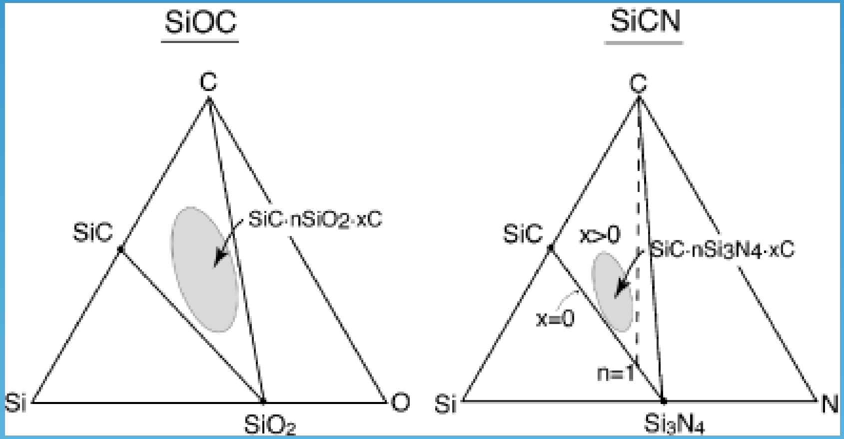
Measurement Program



300 sec injection @ 1500 W

Polymer-Derived Ceramic Composites

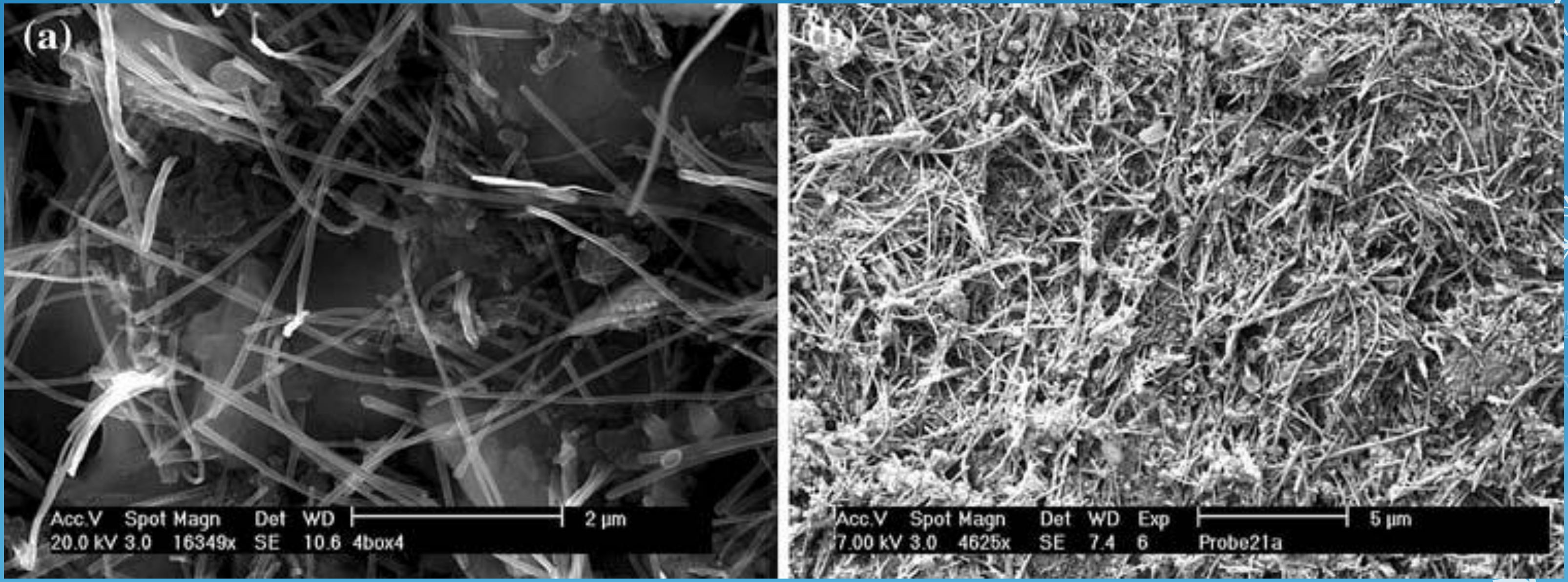
- Polymer-derived ceramics (Black Glass) start with an polysilazane liquid precursor that can be mixed with MWCNTs and then polymerized with heat at 200° C.
- The polymer is then converted to a crystalline ceramic materials (SiCNO system) by further heating to > 1000° C.
- We have tested a sprayed coating of a powdered ceramic/graphene mixture (from Virginia Tech) and verified > 10 kW/cm² at 10.6 μm.
- We are now trying to duplicate the process to obtain larger quantities of the ceramic/carbon composite to use in a sprayed coating with the Potassium silicate binder.



Polymer-Derived Ceramic Composites

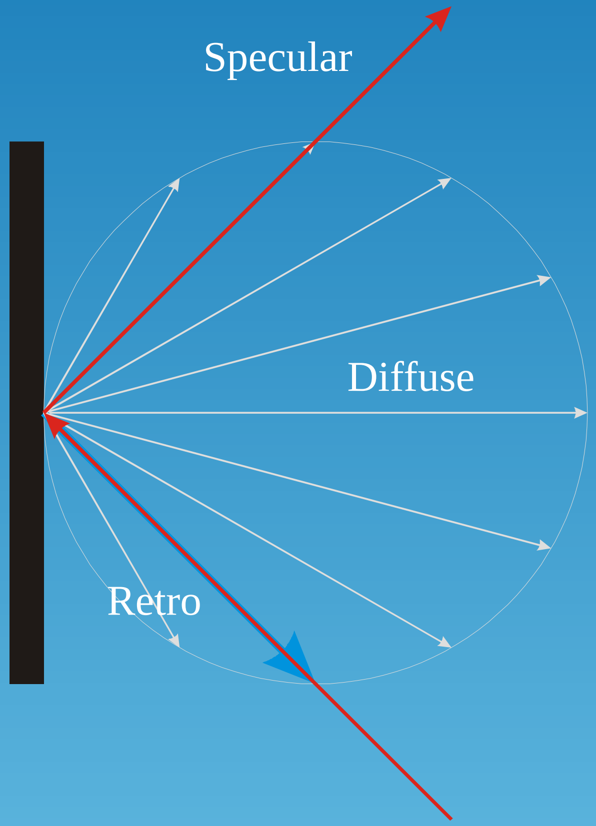
Dispersion assessment and studies on AC percolative conductivity in polymer derived Si–C–N/CNT ceramic nanocomposites

E. Ionescu, A. Francis, and R. Riedel.



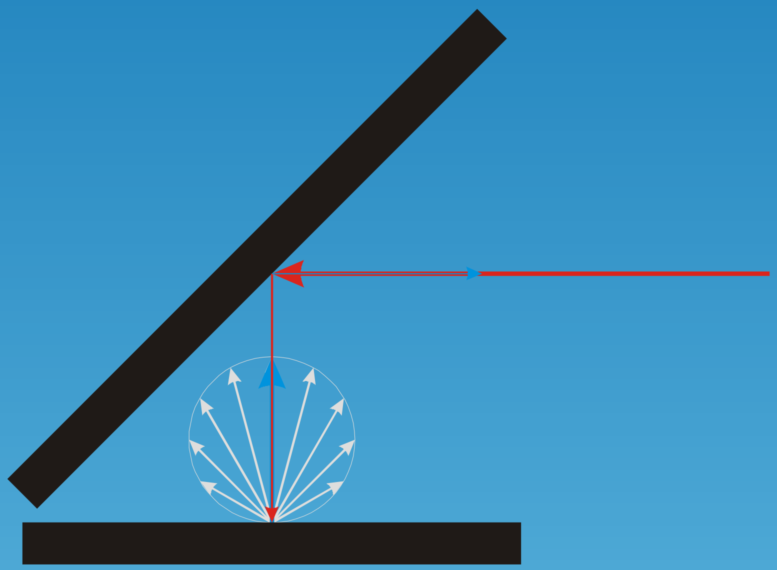
Scanning electron microscopy (SEM) images of the fracture surface of SiCN/ CNT composites containing 1 vol% (a) resp. 10 vol% (b) CNTs pyrolyzed at 1,100 C

Surface Reflectance



- Total reflectance is a combination of specular and diffuse components.
- To minimize the back reflection we need to reduce the diffuse reflectance.
- Make material blacker or make the surface shiny (more specular).

Reduced Back Reflection



- One strategy is to make first reflection specular and partially absorbing (~ 50 %).
- This attenuates the back reflection from the blackened second surface.
- Overall reduction in back reflection by a factor of ~ 4.