SAND2006-5802C

Meso Manufacturing of Innovative National Security Products

Technologies and Business Practices for Enterprise Transformation: Advanced Manufacturing Technologies II

NNSA Future Technologies Conference II

October 12, 2006

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Outline

- Origins of Miniaturization
- Value Proposition for Meso Manufacturing
- Meso Manufacturing Tools
  - Micro wire and die sinker EDM
  - Diamond machining
  - Micro stereolithography
  - Precision metrology
  - Ultra short pulse laser machining
- Case Study
- The Future

The Origins of Miniaturization

- **Post-WWII**
  - Richard Feynman *There's Plenty of Room At The Bottom*
  - Gilbert (1961) *Miniaturization* chronicled the desire to reduce size, mass, and cost of portable communications, guidance systems, and computers.
  - Drexler (1986) *Engines of Creation* heralded Nanotechnology.
- **Post-9/11**
  - Portable micro electronics equals more capability to the war fighter.
  - Environmental sensing
  - NASA, Goldin: *Better, faster, cheaper*

http://www.civil.usyd.edu.au/wtc.shtml

www.history.nasa.gov

The increase in demand began nearly 50 years ago.

National Nuclear Security Administration

Sandia National Laboratories

Complement Microfabrication When the Design Calls For…

- **Miniature high aspect ratio 3-D forms**
  - Complex optics
  - Members for transmitting high forces and torques
- **Bulk materials that are not effectively**
  - Electrochemically, vapor, or sputter deposited
  - Patterned and selectively etched
- **Monolithic, 3-D, self-assembled, multi-functional "smart" structures**
- **In certain cases, lower cost (low volume) alternative manufacturing systems**

This is the value proposition for meso manufacturing.

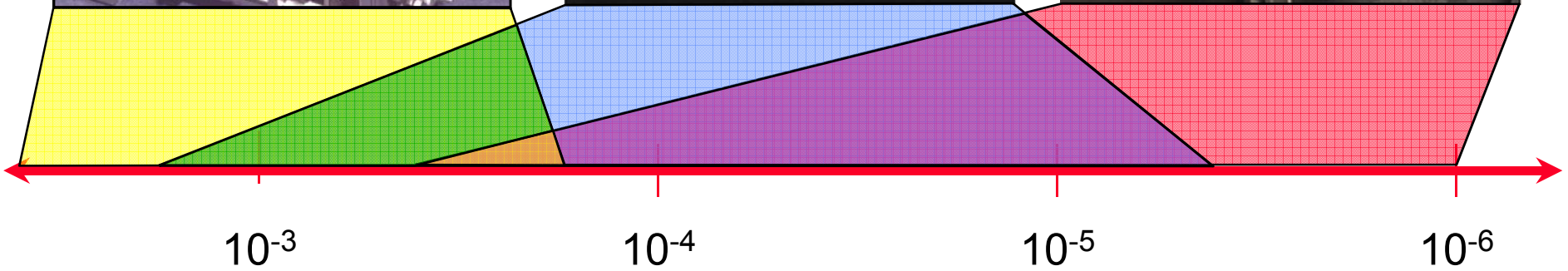
Meso *(Mesos)* "In the Middle"

Conventional Miniature Machining

***Meso Machining* & LIGA**

Surface and Bulk Micromachining

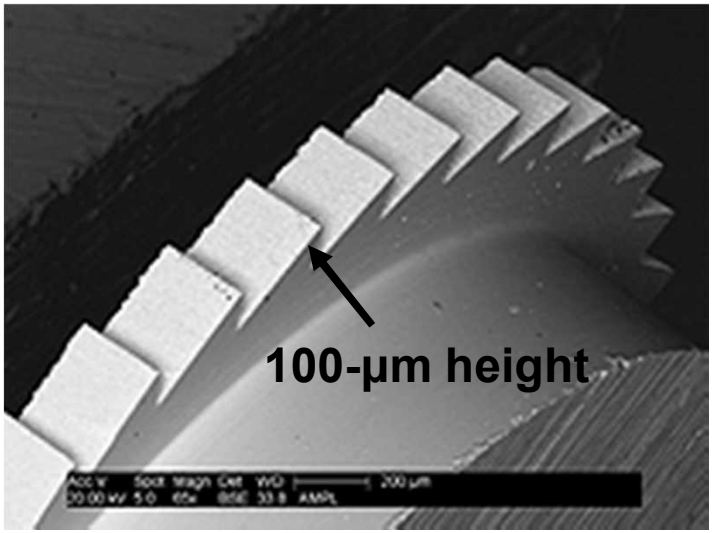
Meso Manufacturing implies a suite of meso machining technologies used in concert.

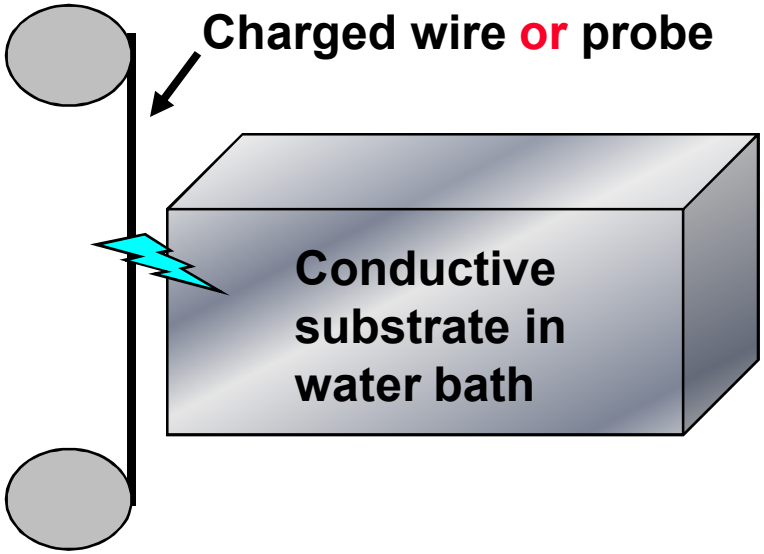


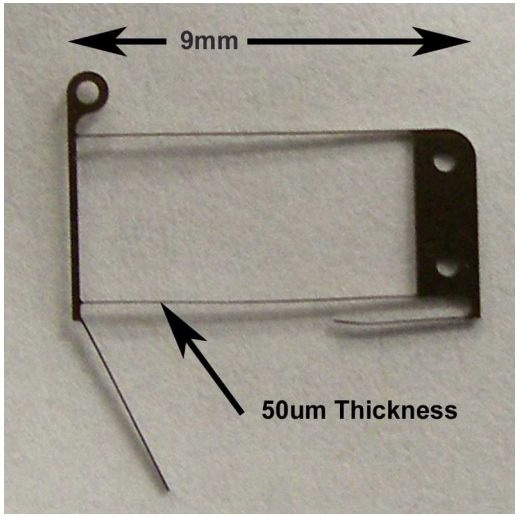
Critical dimensions (Meters)

Micro Electro Discharge Machining (µEDM)

- Computer-controlled pulsed spark erosion to machine high aspect ratio 2-D OR 3-D features
- Wire (milling, grinding) and die-sinker (drilling) configurations
- Virtually any conductive material
- Agiecut™ and Agie Vertex systems
  - Minimum feature (wire) size of 25 µm
  - Positioning system resolution of ± 1.5 µm.

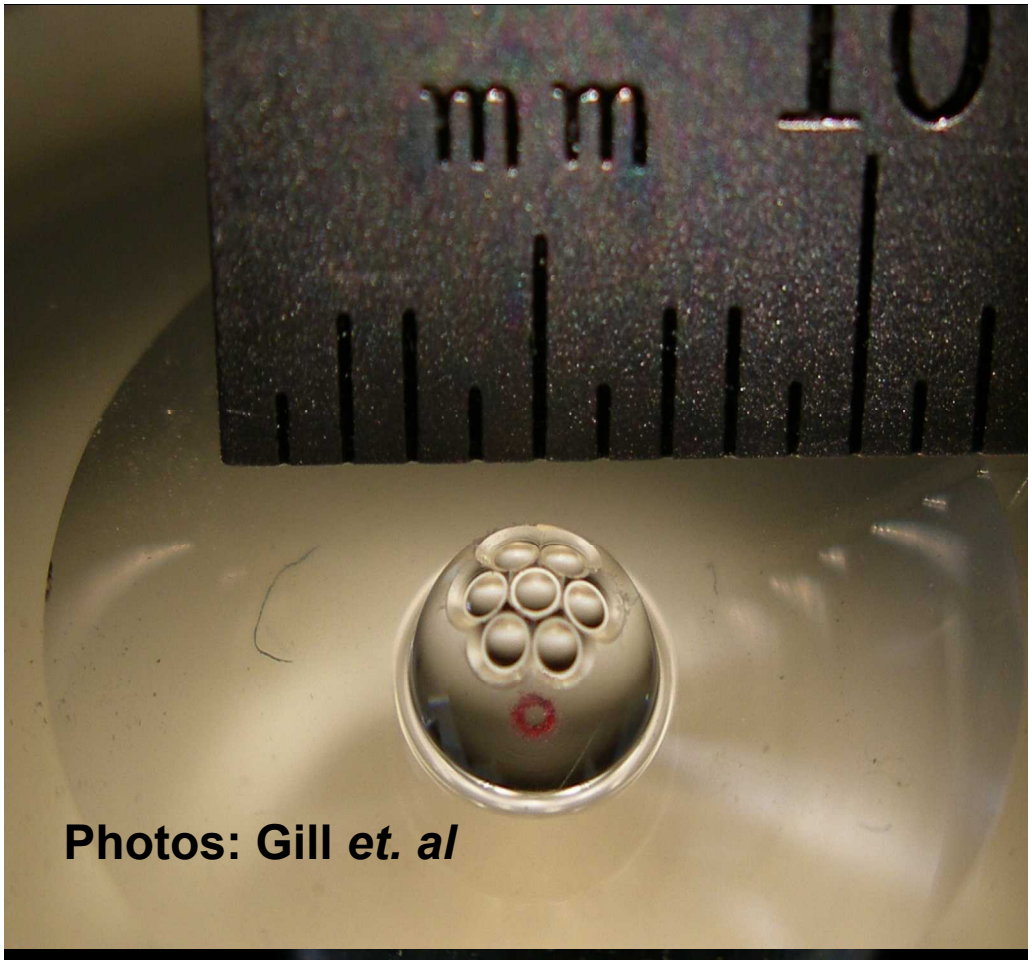






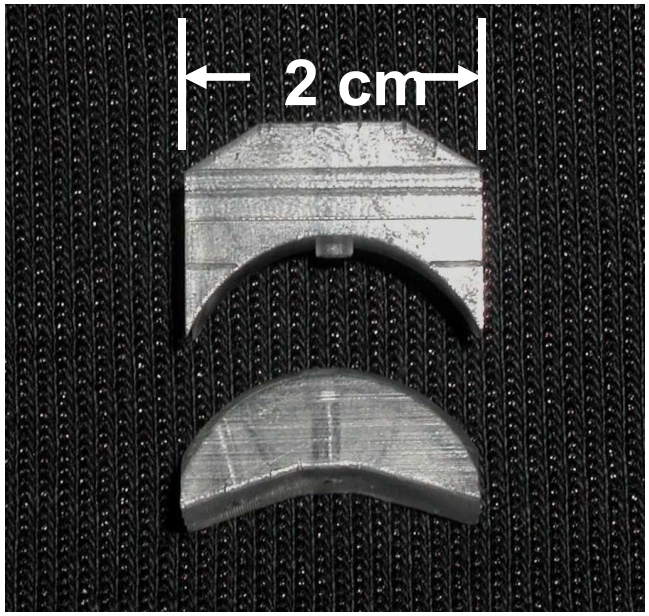
Diamond Machining

- **High precision enabled by:**
  - Ultra sharp diamond tool
  - High resolution positioning system
- **Moore Nanotechnology 350 FG**
  - Positioning accuracy of 250 nm
  - Form errors less than 100 nm RMS
  - Surface finish as low as 2 nm Ra (optical quality without polishing).
  - Additional axes provide milling, turning, and drilling capability.
- **Complex optics**
  - 600 µm-diam. convex lenslet array (acrylic)
  - Dragonfly Eye: convex aspherical lenslets aligned with internal optics, 1 µm radial alignment.

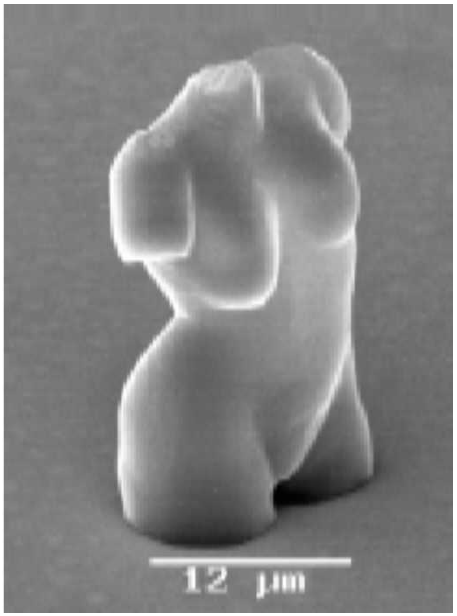


Photos: Gill *et. al*

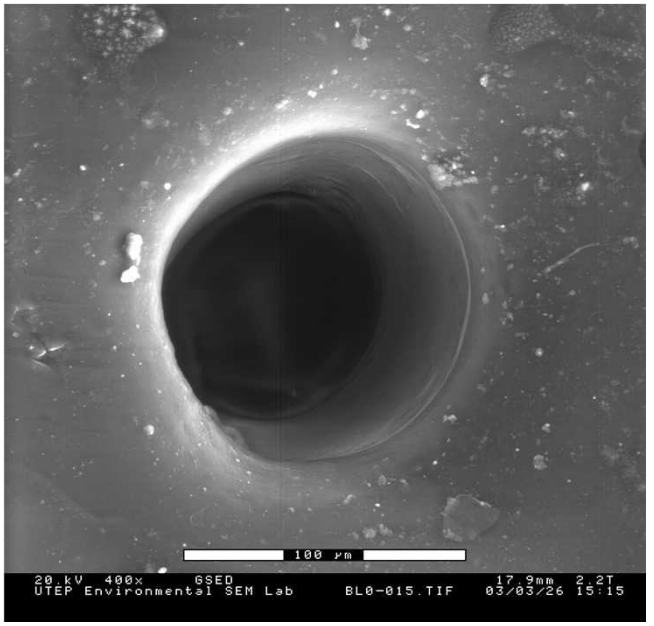
Micro Stereolithography (MSL) and 2-Photon Polymerization



Miniature retinal implant mold (UTEP)



µVenus (Chichkov et al., 2004)

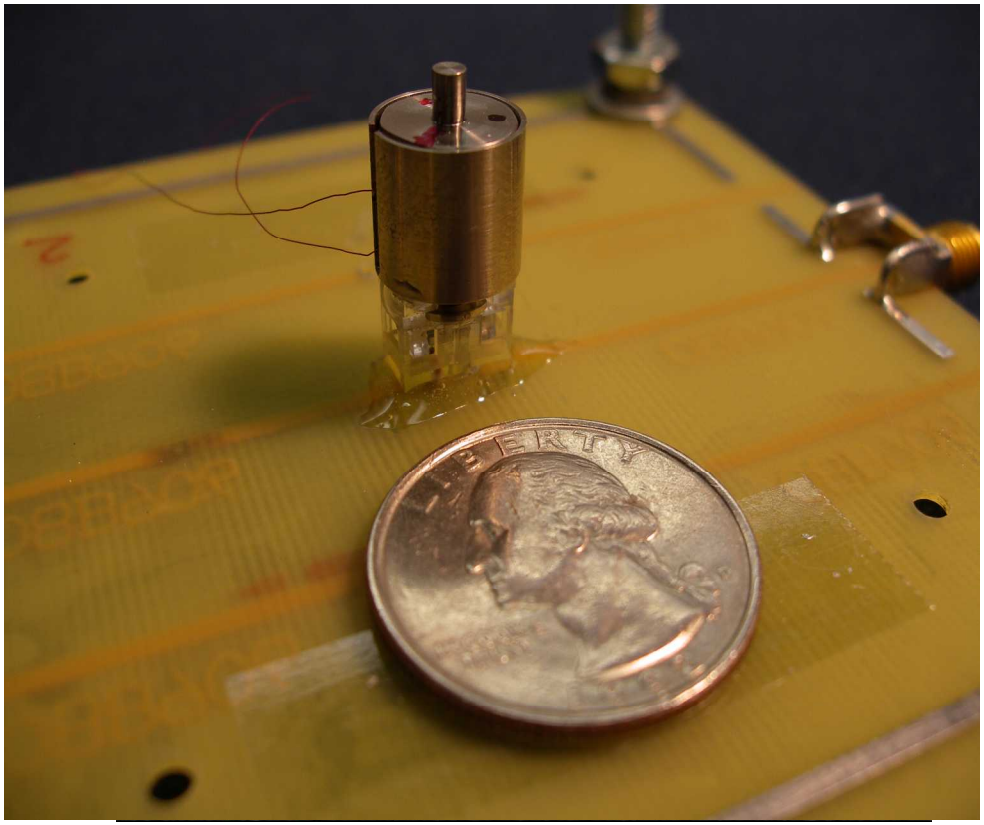


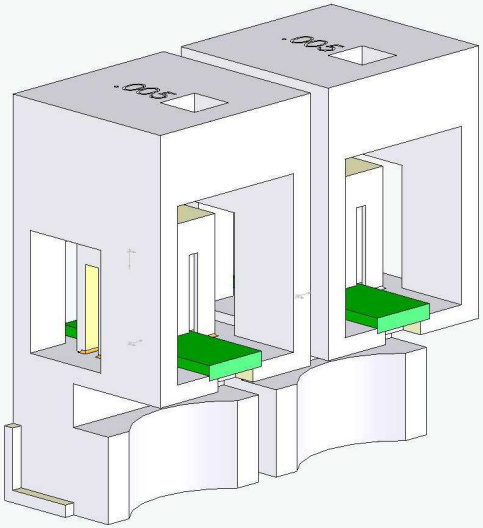
100 µm-dia. hole made by Viper™ MSLA (Wicker et al., 2004)

Layer additive commercial MSL process achieves 75 µm lateral resolution with 50 µm layer thickness (Sony Corp.).

mRF Relay: A Meso Manufactured Product

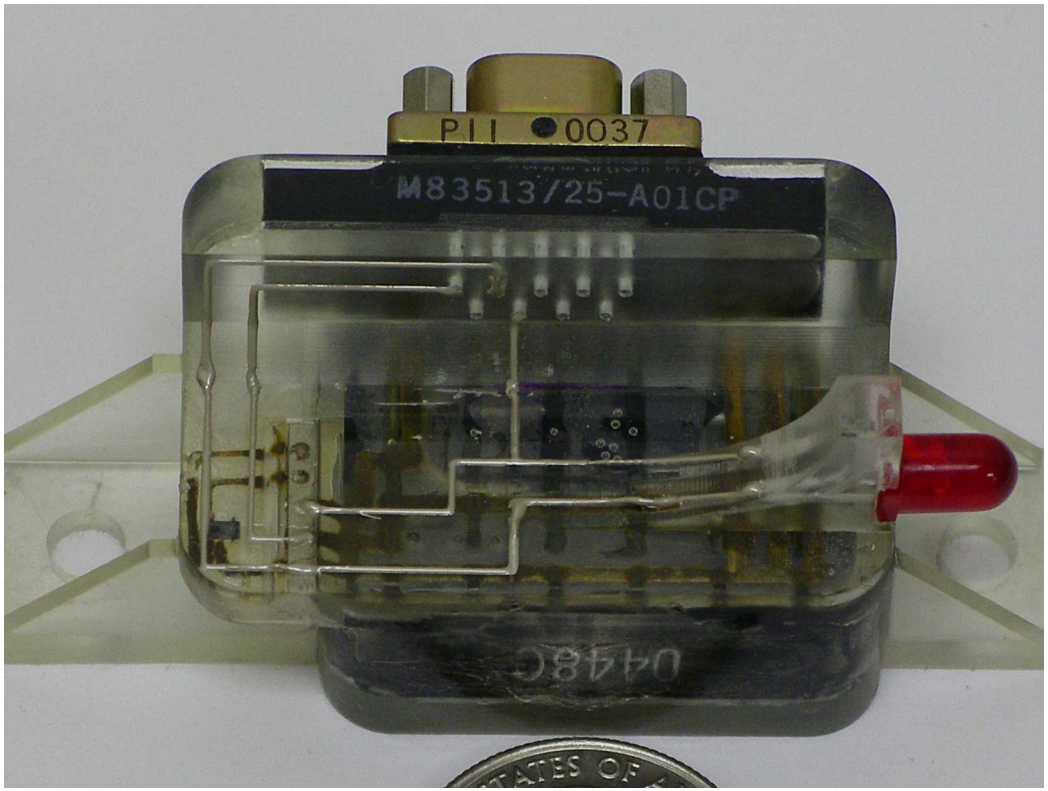
- Encapsulated high accuracy aluminum μEDM components
- Self-assembled flexure system (impractical to machine)
- Removable inserts to maintain small gaps
- Batch fabrication
- Telerobotic miniature assembly





Multi-functional Smart Structure

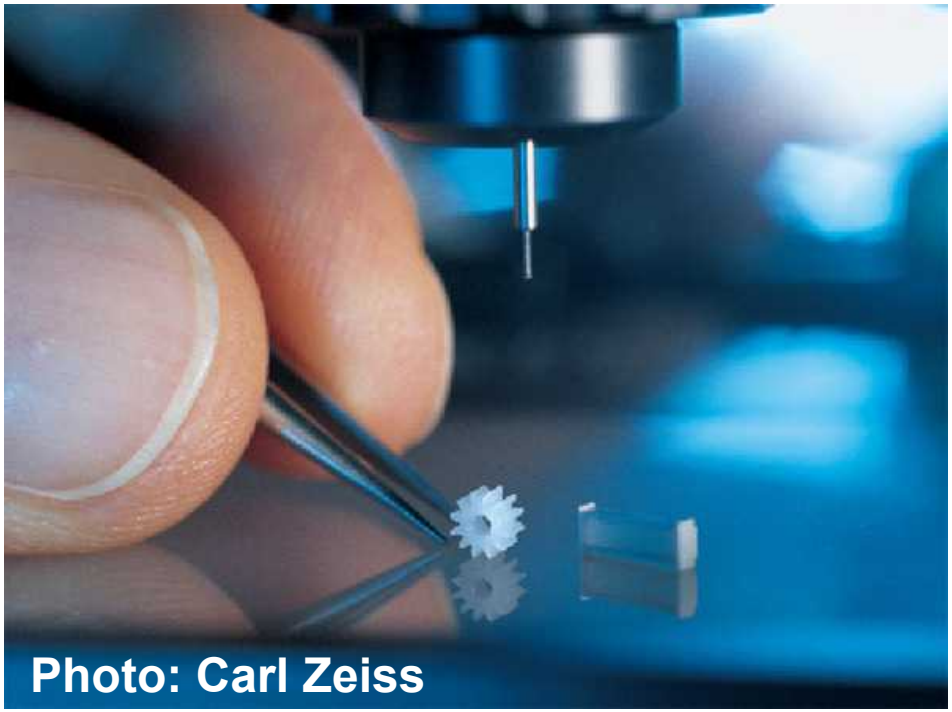
- **Conventional Design**
  - PWB stack interconnected with press-fit headers
  - 4-inch aluminum housing
  - INPUT: 28 VDC (upper Micro D connector) to DC-DC converter with series EMI filter (lower board)
  - OUTPUT: 5 VDC
- **SL Smart Structure**
  - Encapsulates components & circuitry, anchors to satellite bus
  - Solderless 3-D DW interconnect joins DW circuitry on 2 “Device Planes.”
  - LED output demo



Solderless, automated 3-D DW interconnect replaced press-fit headers.

Precision Metrology for Meso Manufacturing

- **Optical systems**
  - White light interferometry (Taylor-Hobson CCI)
  - 3-D surface texture, step height and micro-dimensional measurements
  - Limited vertical resolution (~100 mm)
- **Contact Coordinate Measurement Machines (CMM's) are still preferred**
- **Carl Zeiss F25 (ref: www.sme.org)**
  - Micro stylus tip diameters of 120 - 700 µm
  - Stiffness 0.5 µN/µm
  - 250 nm uncertainty
  - 7.5 nm resolution



A new generation of metrology instruments have been created to verify 3-D meso and micro parts.

Ultra Short Pulse Laser Machining

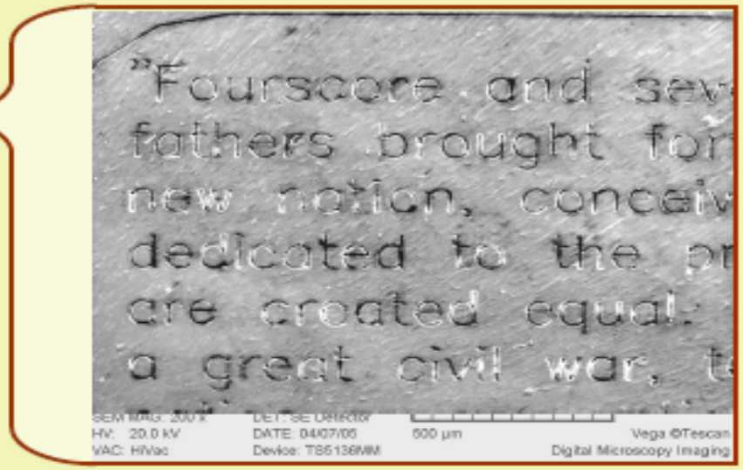
- **What does "ultra short" mean?**
  - Each "burst" is 120 femtoseconds.
  - 1 fs is to 1 second as 1 second is to 32 million years (Scientific American, 2000).
  - Non-ultra short pulses: 1 nanosecond
  - Made possible by chirped pulse amplification (CPA)
- **Advantages:**
  - "Bursts" of laser radiation (1 per ms) explosively remove (ablate) semiconductors, ceramics, polymers, and bio materials with little thermal damage.
  - Lower ablation thresholds
  - Micro spot size
  - Focus inside the bulk of transparent materials.
- **Laser**
  - Ti:sapphire, 1 mJ, 950 mW
  - Wavelength: 800 nm (IR)
  - Frequency: 1 kHz
- **Positioning System**
  - XY: 2-um accuracy
  - Z: 1-um accuracy

PENNSTATE

Electro-Optics Center

Photo: Penn State University EOC

The Gettysburg Address contains 267 words or 1189 characters, all of which are reduced to fit onto the penny enclosed in the case below, an area measuring less than 4mm (3/16 inch) by 6mm (1/4 inch). The height of each letter is 1/10 of a millimeter tall (four-thousandths of an inch), or the thickness of a piece of paper. The lines cut by the laser are 10 times thinner than the average human hair.

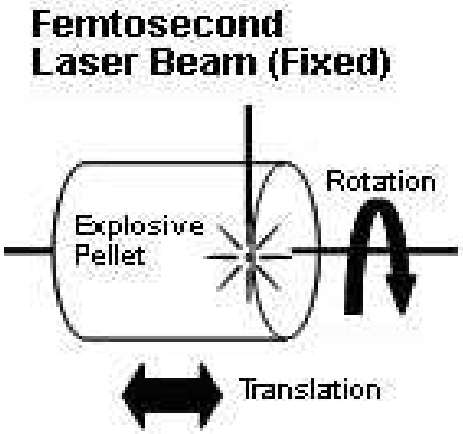


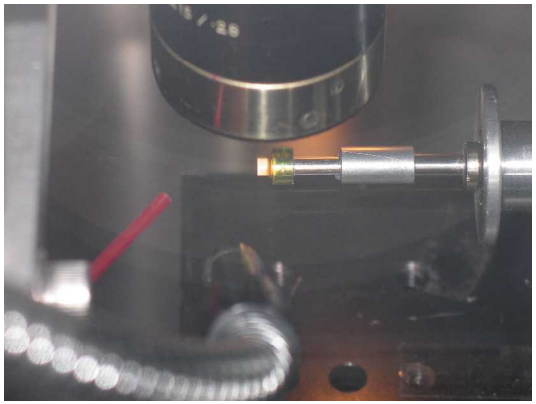
The writing on the penny was created using an ultrashort pulse laser system in conjunction with a micromachining workstation at the Penn State University Electro-Optics Center in Freeport, Pennsylvania.

Ultra short pulses ablate various materials with little or no heat transfer.

Case Study:
Ultra Short Pulse Meso Machining of Explosives

- **Micro/Meso Detonics Study Sample**
  - Create a micro column ~1 mm long, 100 – 500 μm diam.
  - Start with 1/8-inch diameter pressed pellet.
  - HNS, CL-20, RSI-007
- **Conventional machining is not an option**
  - Causes friction and heat transfer
  - Leads to combustion (deflagration) or detonation
- **Ultra short pulse laser meso machining**
  - Ablates energetic material without reaction.
  - Proven in LLNL studies (Roos *et al*., 2002)
- **Proposed solution: ultra short pulse laser lathe**
  - 100 – 200 mW (~15 J/cm^2)
  - ~ 400 rpm
  - Rough vacuum (~50 Torr)
  - 40 micrometers per pass.

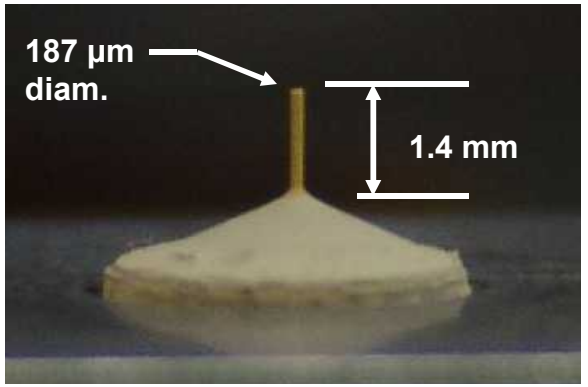


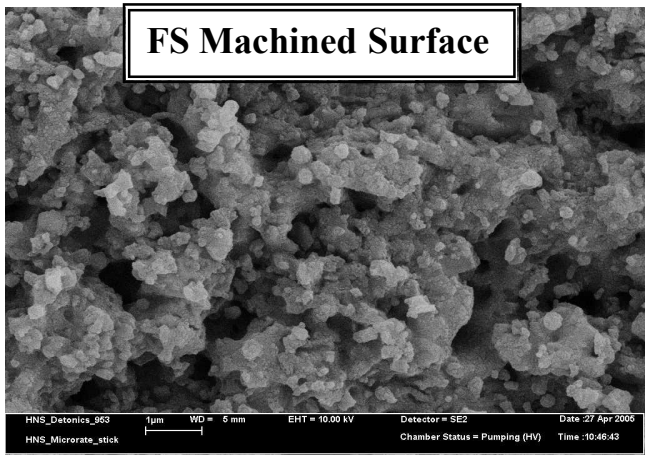


Ultra short pulse laser meso machining is currently the only method available.

Results

- Machined samples with diameters less than 200 µm without detonation or combustion.
- Surface finish most sensitive to translation (feed) rate (4 mm/min).
- SEM analysis of machined surface
  - Evidence of nanometer scale particles
  - May prove to be a means for creation of nano-energetic materials.
- Challenges
  - ~50% yield
  - Smaller spot sizes (high peak energy) cause localized combustion.
  - Improve throughput.

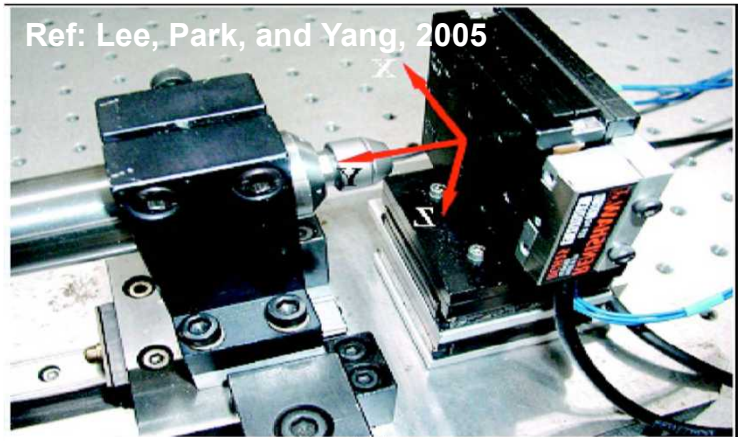




First demonstration of ultra short pulse laser lathe technique for explosives

The Future

- **Expanding markets for miniature/portable products**
  - RFID and health monitoring
  - Standoff detection
  - Meso/micro robots and mechatronics
- **Challenges**
  - EDM white layer characterization
  - Nanosecond pulse artifacts
  - Expanded material systems for SL and diamond machining
  - Verification and characterization of compliant meso structures
- **New directions in research**
  - To make meso parts, you need a true “meso machine.”
  - Ultra short pulse fiber lasers
    - Low cost, durability = expanded applications
    - Higher repetition rates preferred
  - High speed EDM
  - Low cost precision optics by encapsulation



Thank You!