RESONETICS

THE LEADER IN LASER MICRO MANUFACTURING FOR LIFE SCIENCES

Overview

Who is Resonetics?

Mission

Resonetics will be the leader in laser micro manufacturing for the life sciences industry by providing innovative solutions and unrivaled customer service.

- Expertise in polymers, metals, glass and ceramic
- Unparalleled innovation with engineering resources
- State-of-the-art facilities and equipment
- Locations: Boston, Dayton, San Diego, Costa Rica, Minneapolis

Values

Creativity | Urgency | Quality | Integrity |Respect

Who Do We Help?

Who is Resonetics?

- 270 employees including 50 engineers and 5 Ph.D.'s
- 5 state-of-the-art facilities with 113,000 sq. ft.
- 75 laser workstations with 13 ultrafast lasers
- Lightspeed ADL™ prototyping & process development capabilities in Nashua, Kettering, and Plymouth facilities
  - 18 laser workstations
  - 21 engineers and technicians
- Clean room manufacturing in all 5 sites
- 90% of revenues in the life sciences industry
- 89% of revenues are contract manufacturing (11% systems/spares/service)
- Produce >16 million parts per year

Locations

Contract Manufacturing

Lightspeed ADL

Systems Group

55,000 Sq. Ft.

Contract Manufacturing

20,000 Sq. Ft.

Contract Manufacturing

Lightspeed ADL

20,000 Sq. Ft.

Contract Manufacturing

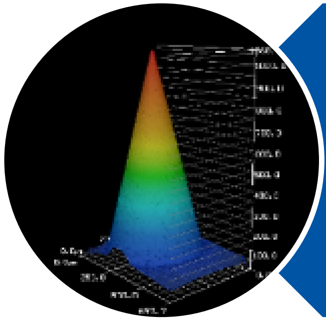
Lightspeed ADL

9,000 Sq. Ft.

Contract Manufacturing

9,000 Sq. Ft.

Business Model



Advanced Technology Group

Next Generation Laser Micro Manufacturing Technology

LightspeedADL™

Application Development Lab

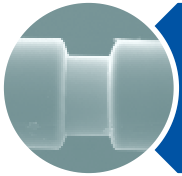
Quick Turn Prototypes

Contract Manufacturing

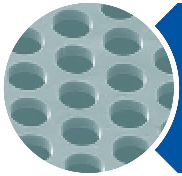
Volume Production

Custom Laser Systems

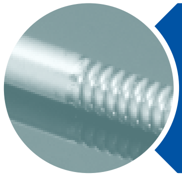
Technologies



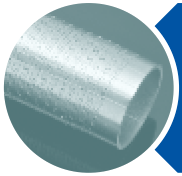
Ablating



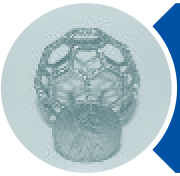
Drilling



Welding

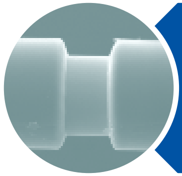


Cutting



Additive

Technologies



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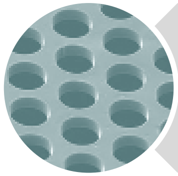
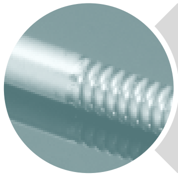
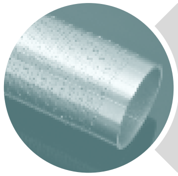


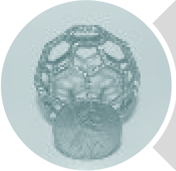
Drilling



Welding



Cutting

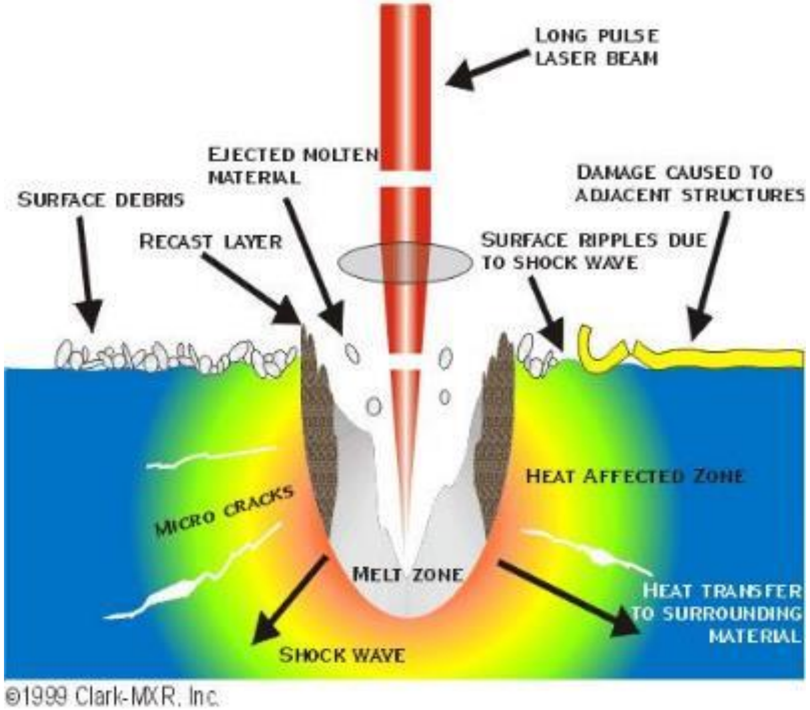


Additive

Pulse Duration – Long vs. Short Pulse

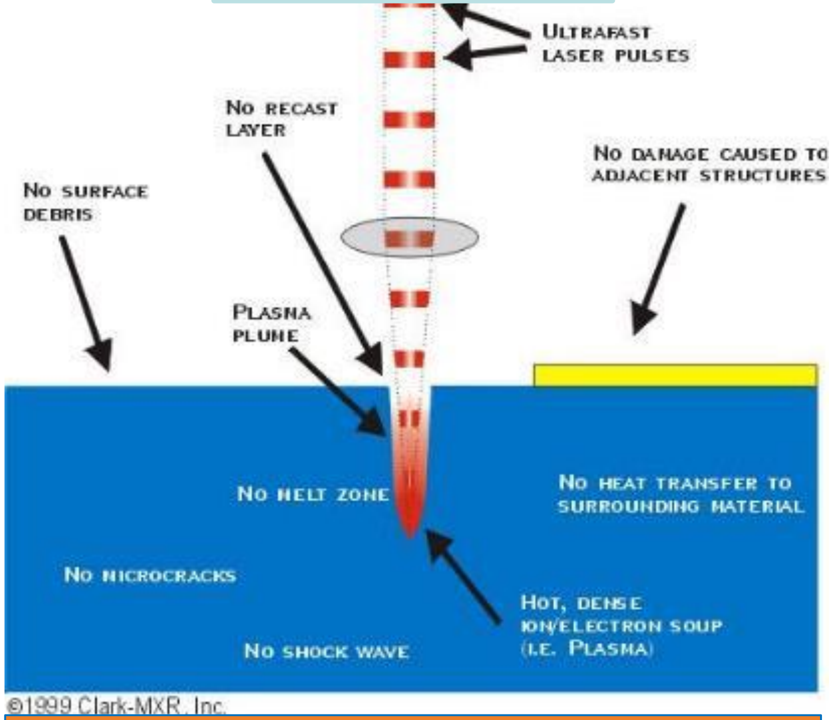
Long pulse

Nanosecond



Short pulse

Pico/Femtosecond

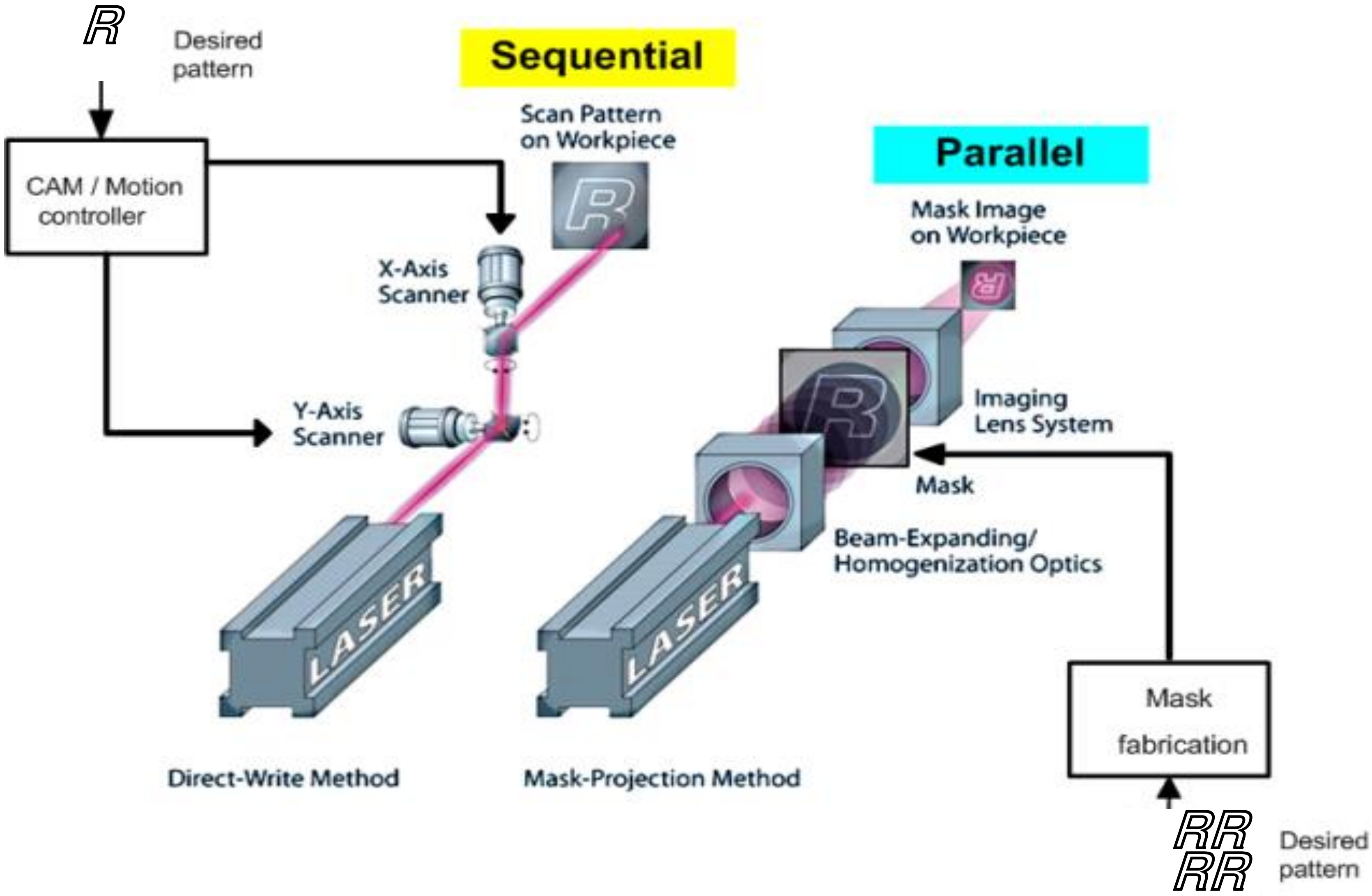


+ multi-photon absorption

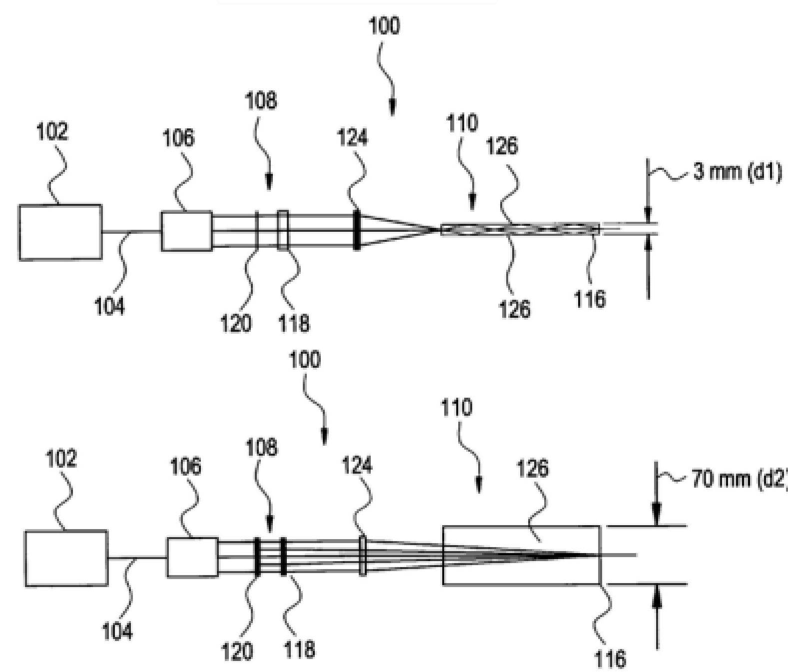
→ all materials

→ sub-resolution

Direct Write and Mask Projection



Braided Catheter



(12) **United States Patent**
Broude et al.

(10) **Patent No.:** **US 7,210,820 B2**
(45) **Date of Patent:** **May 1, 2007**

(54) **METHODS AND APPARATUSES FOR HOMOGENIZING LIGHT**

(75) Inventors: **Sergey V. Broude**, Newton Centre, MA (US); **David S. Holbrook**, Lexington, MA (US); **Pascal Miller**, North Chelmsford, MA (US)

(73) Assignee: **Resonetics, Inc.**, Nashua, NH (US)

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,744,615 A		5/1988	Wilczynski et al.	350/96.1
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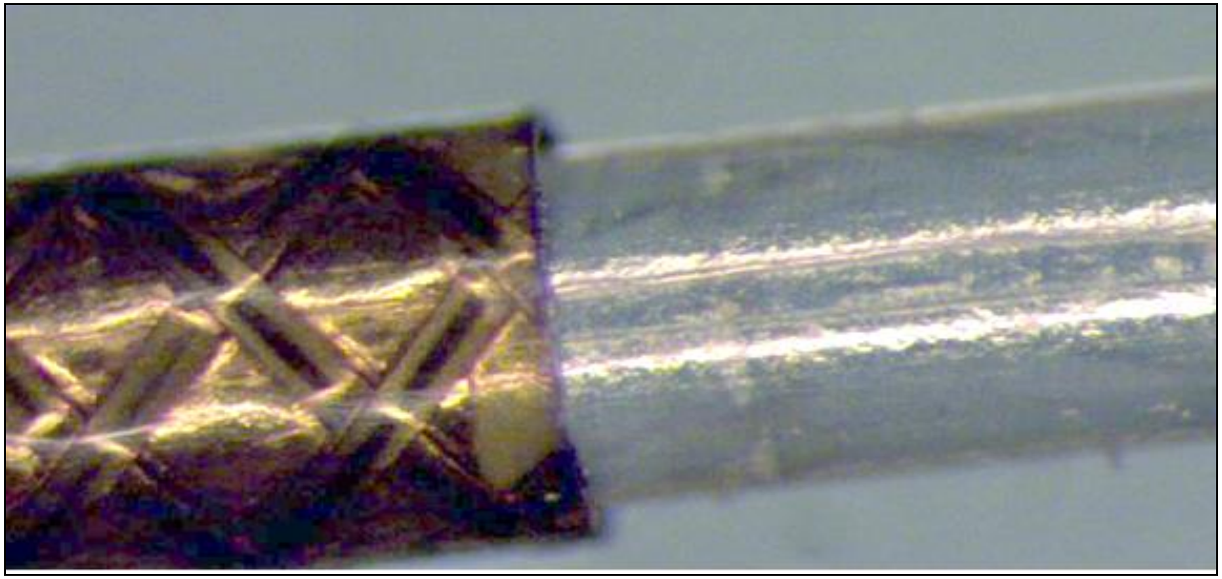
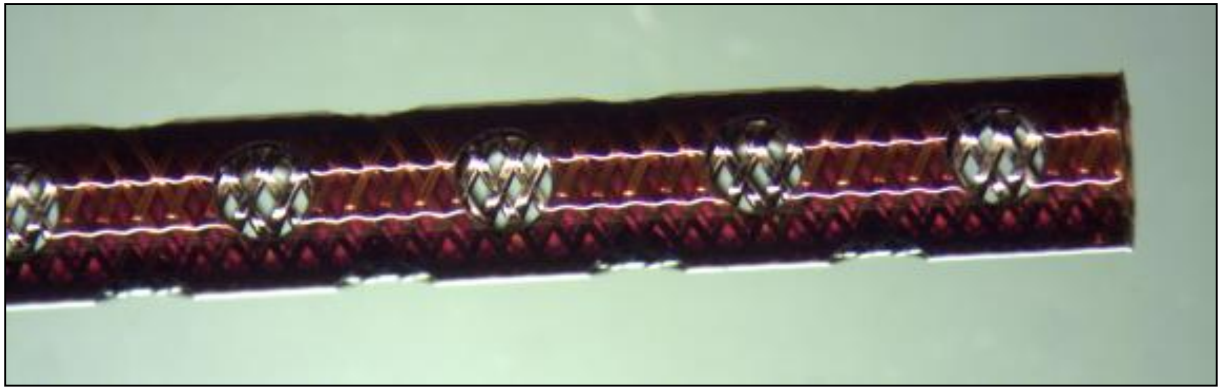
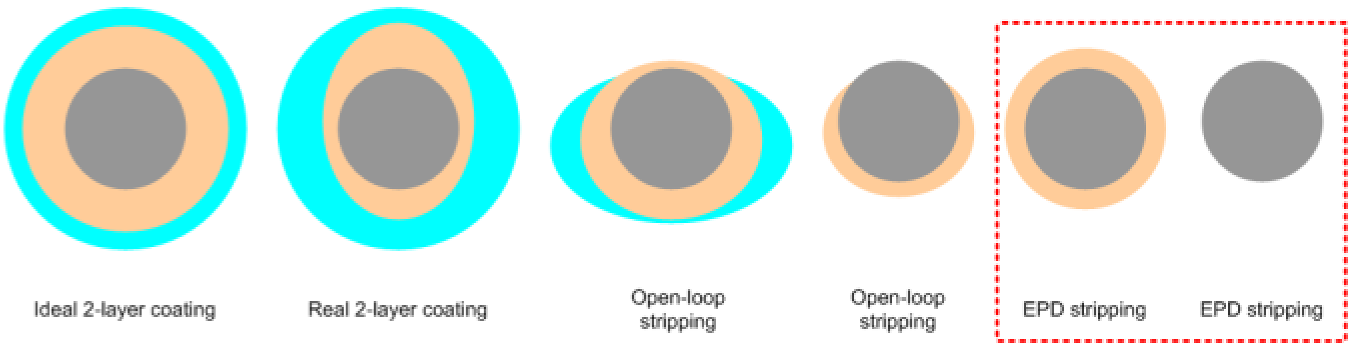
5,721,416 A		2/1998	Burghardt et al.	219/121.73
5,946,138 A	*	8/1999	Mizouchi	362/259
6,002,101 A	*	12/1999	Yamazaki et al.	359/622

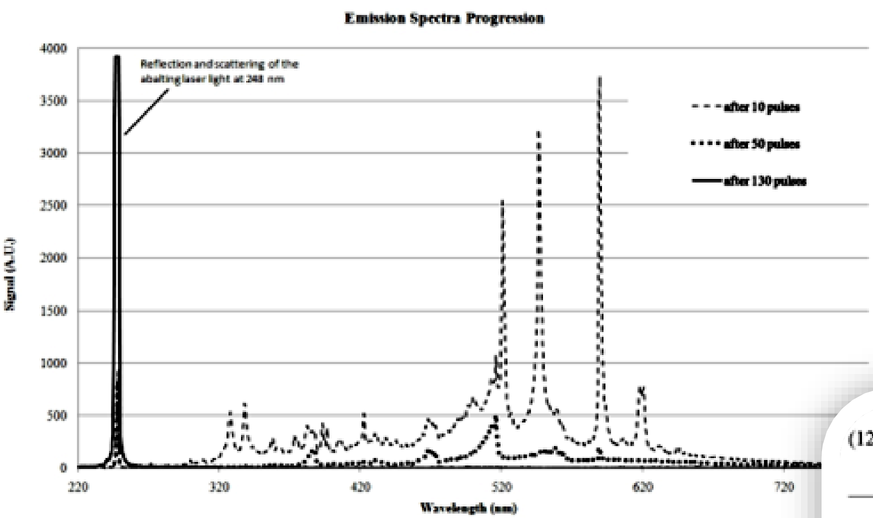
Braided Catheter

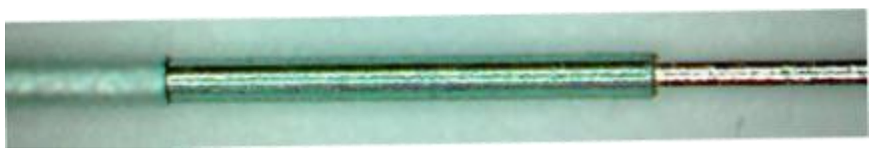


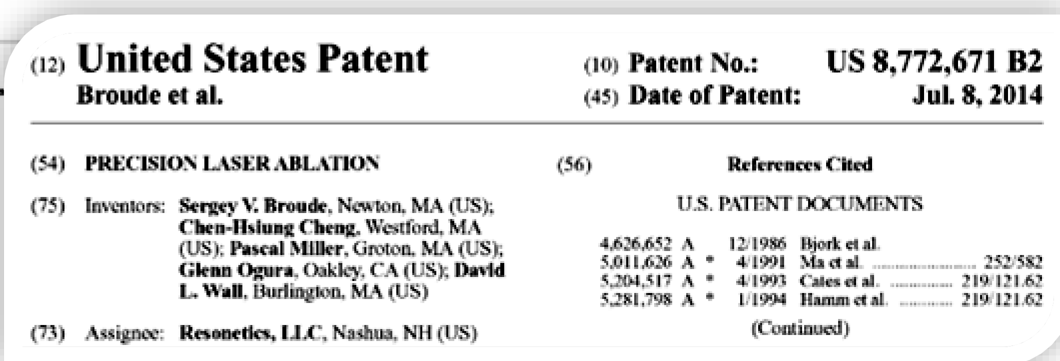


Wire Stripping – Assure End-Point Detection™









(12) **United States Patent**
Broude et al.

(10) **Patent No.: US 8,772,671 B2**
(45) **Date of Patent: Jul. 8, 2014**

(54) **PRECISION LASER ABLATION**

(75) Inventors: **Sergey V. Broude**, Newton, MA (US); **Chen-Hsiung Cheng**, Westford, MA (US); **Pascal Miller**, Groton, MA (US); **Glenn Ogura**, Oakley, CA (US); **David L. Wall**, Burlington, MA (US)

(73) Assignee: **Resonetics, LLC**, Nashua, NH (US)

(56) **References Cited**

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5,011,626 A	*	4/1991	Ma et al.	252/582
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5,281,798 A	*	1/1994	Hamm et al.	219/121.62

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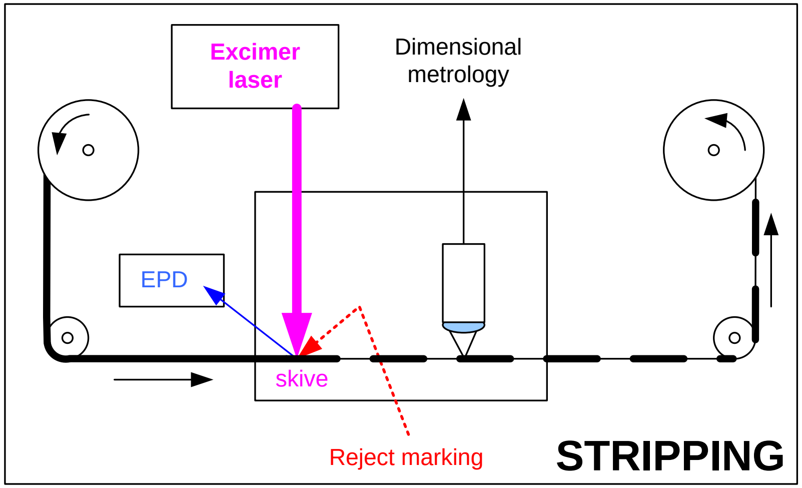
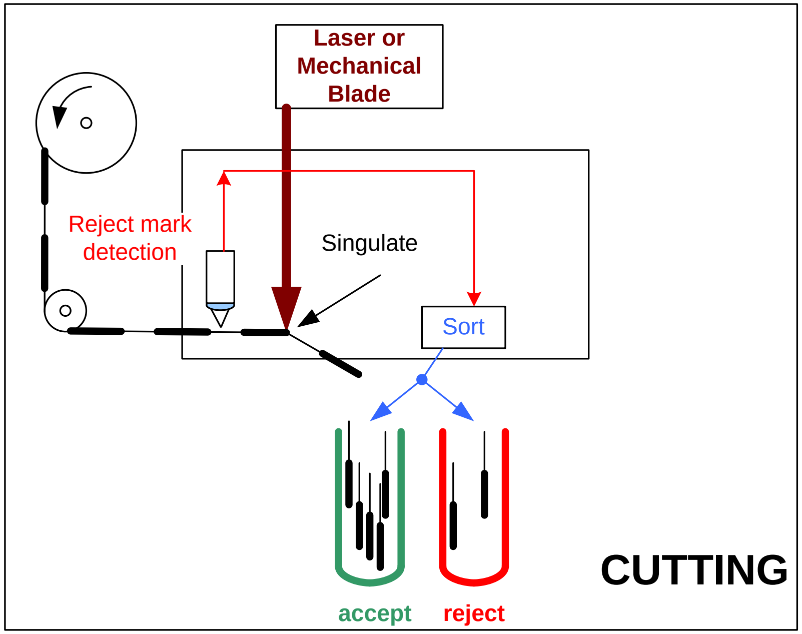
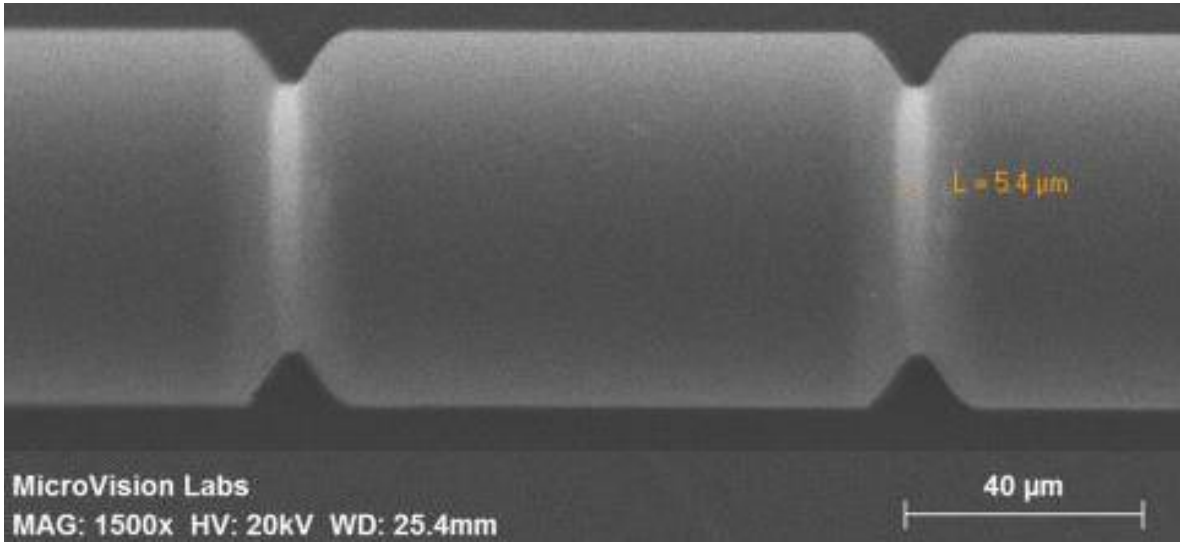
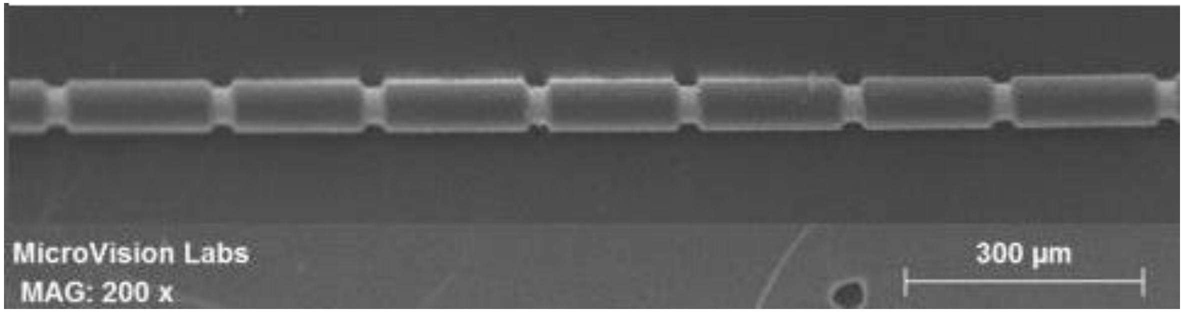
Reel-to-Reel Wire Stripping System

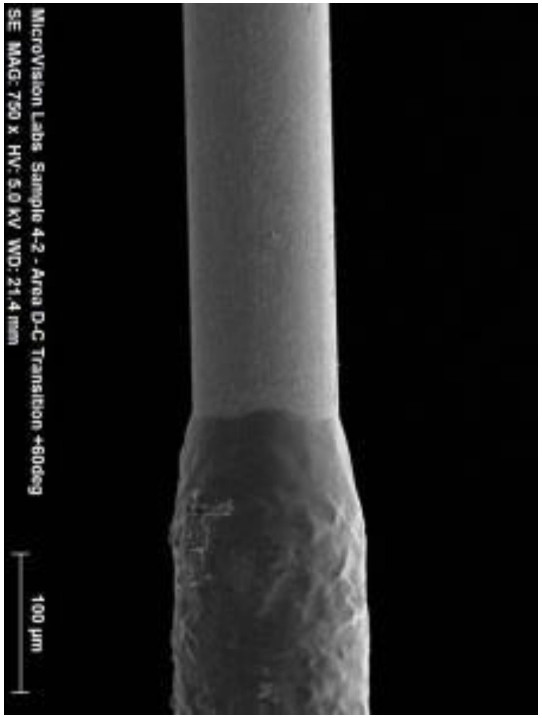




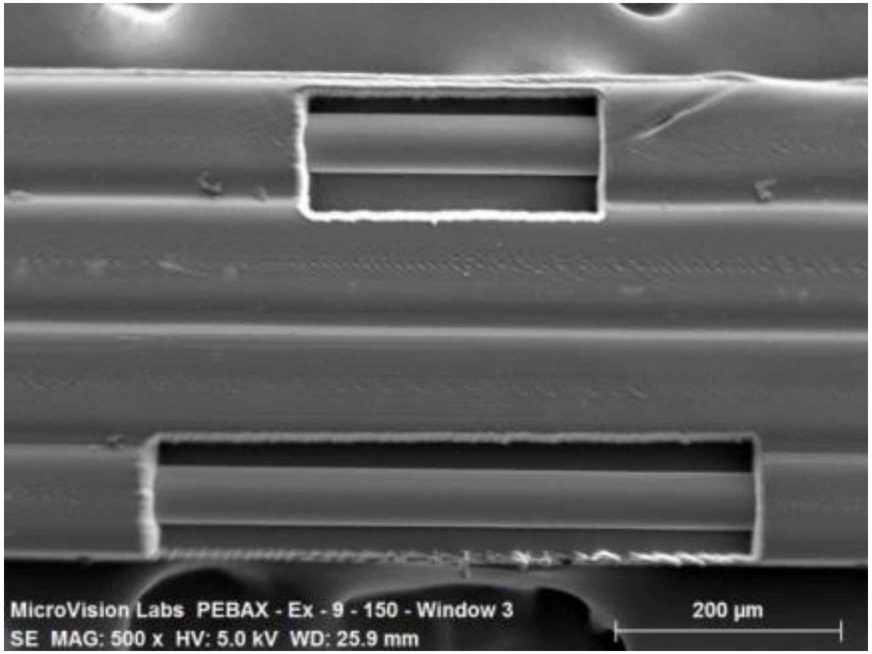
Wire-Stripping – High Resolution

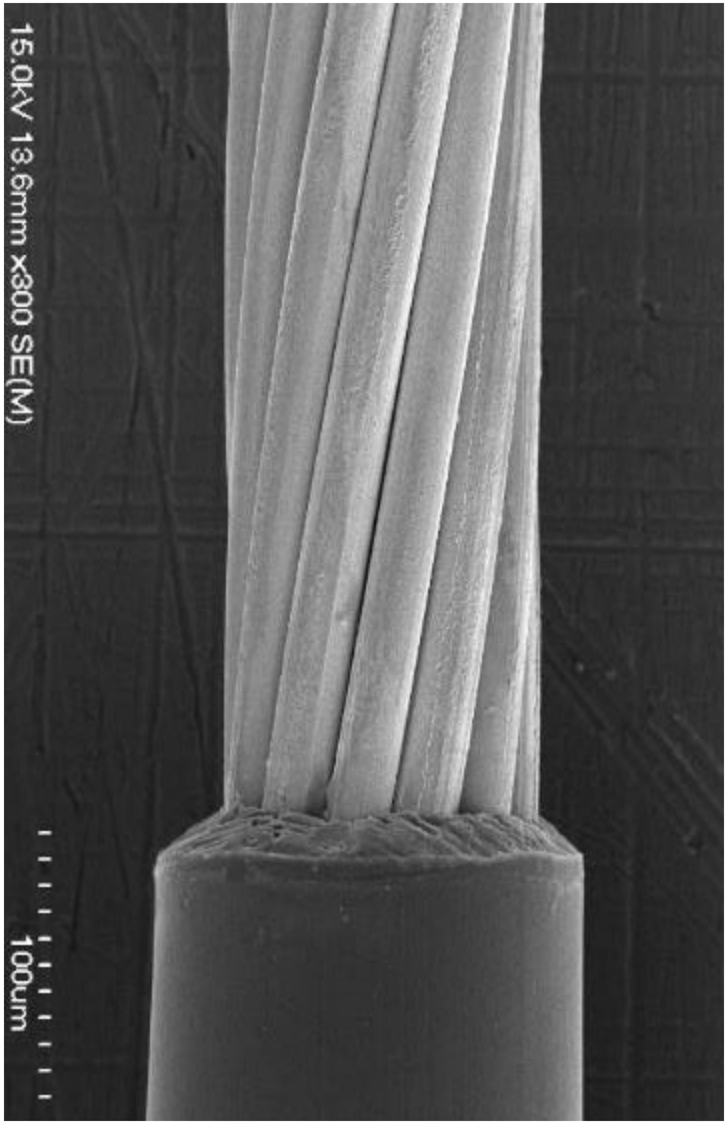




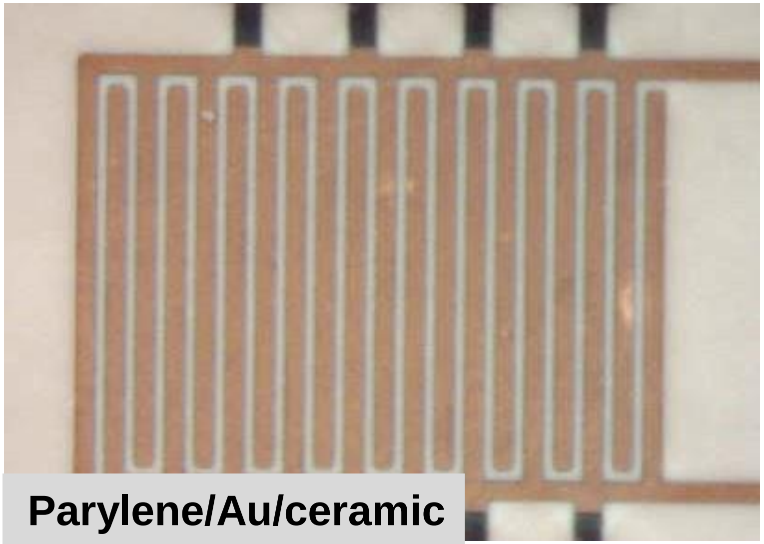


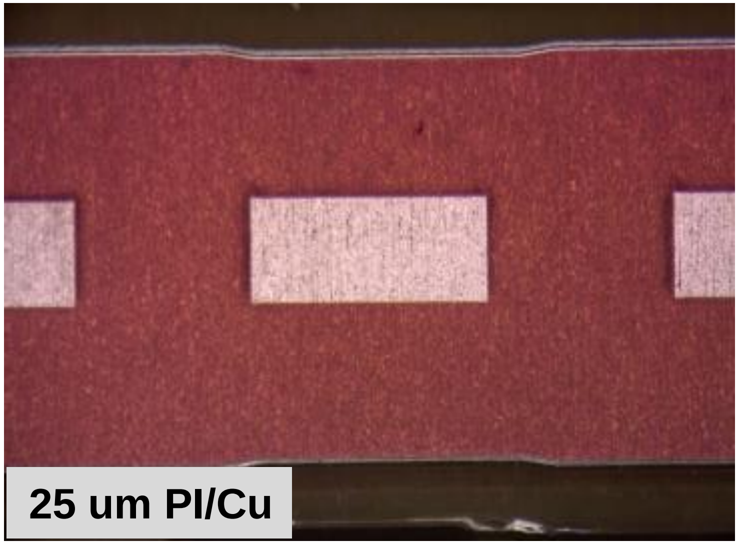
Wire Stripping – Examples

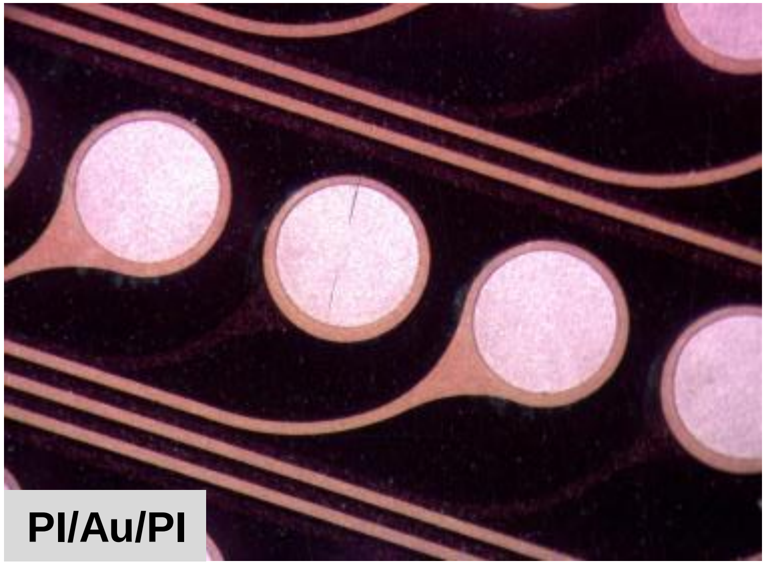


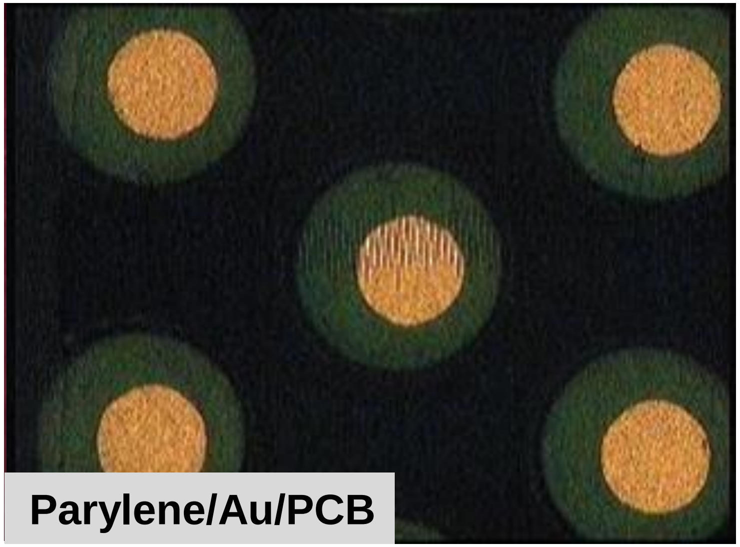


Electrode Exposure

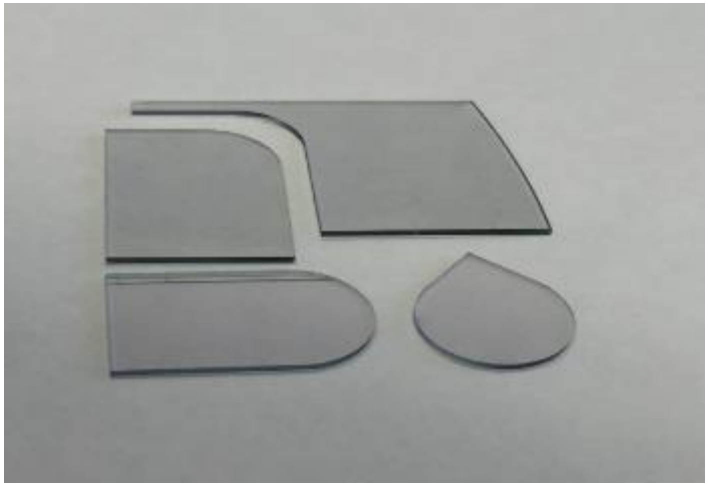


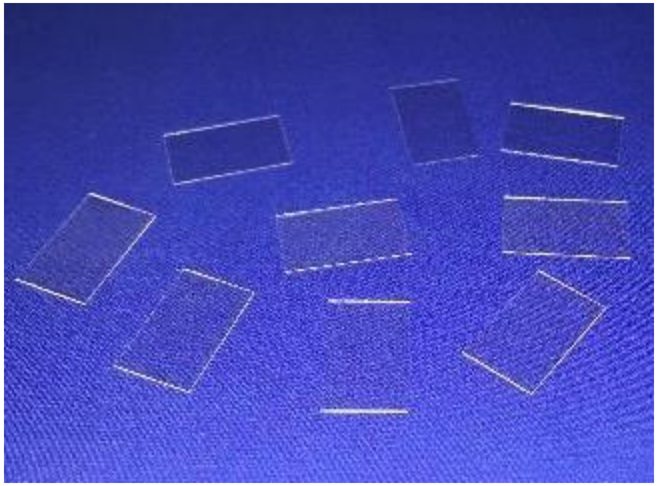


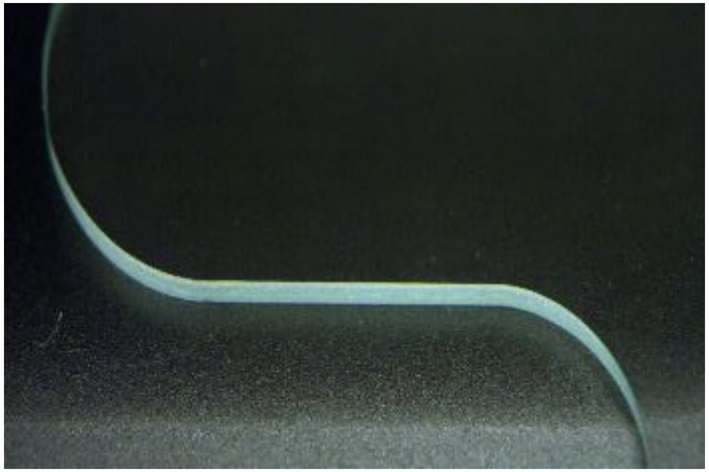


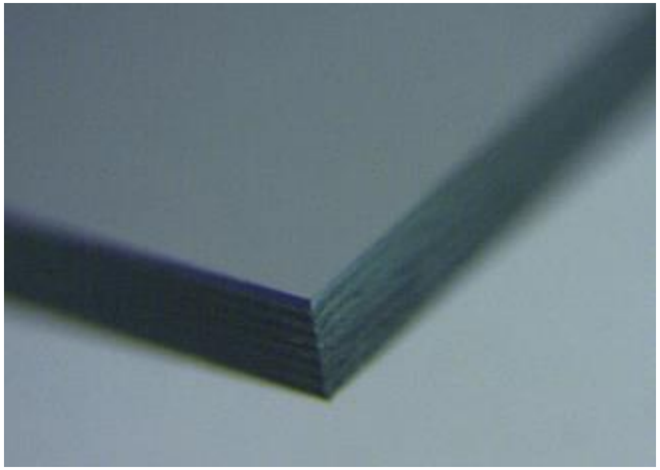


Zero-Kerf Glass Cutting





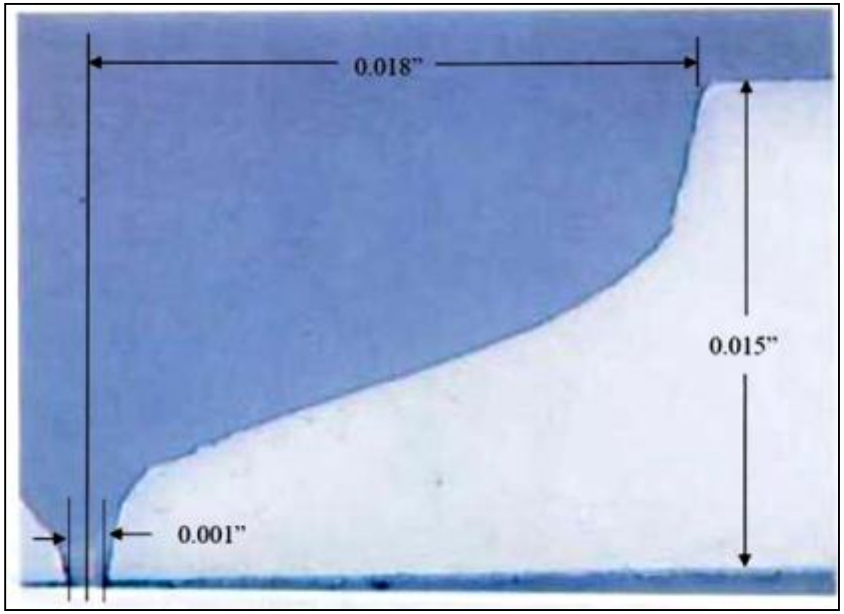


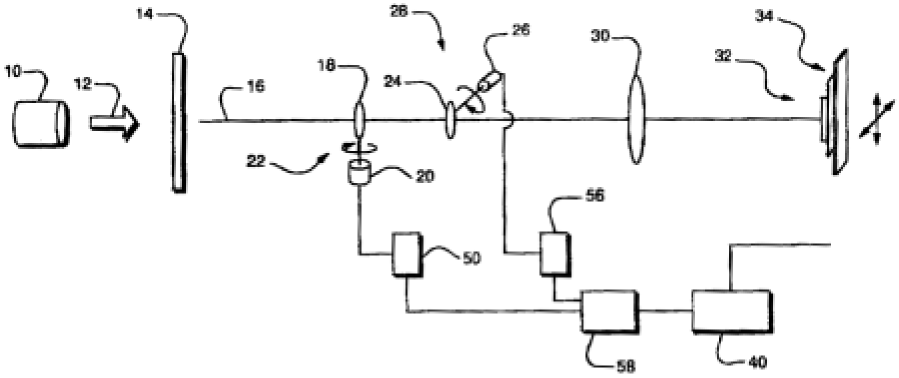


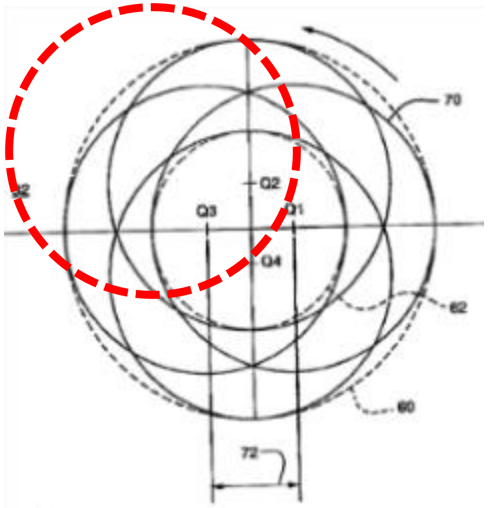
Application:

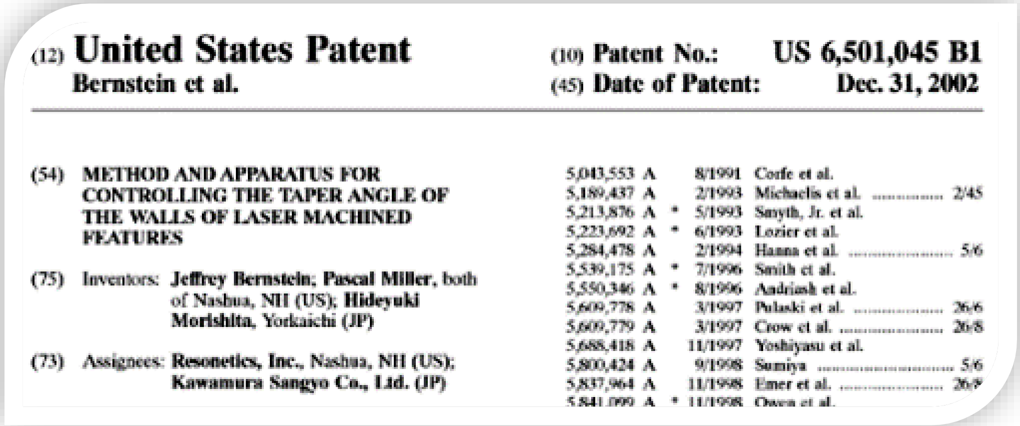
3D Ablation

Image Trepanning for Taper Control









(12) **United States Patent**
Bernstein et al.

(10) **Patent No.:** **US 6,501,045 B1**
(45) **Date of Patent:** **Dec. 31, 2002**

(54) **METHOD AND APPARATUS FOR CONTROLLING THE TAPER ANGLE OF THE WALLS OF LASER MACHINED FEATURES**

(75) Inventors: **Jeffrey Bernstein; Pascal Miller**, both of Nashua, NH (US); **Hideyuki Morishita**, Yorkaichi (JP)

(73) Assignees: **Resonetics, Inc.**, Nashua, NH (US); **Kawamura Sangyo Co., Ltd.** (JP)

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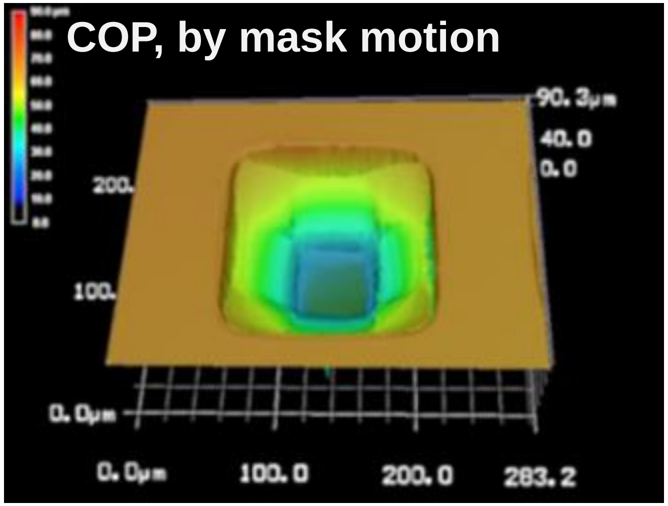
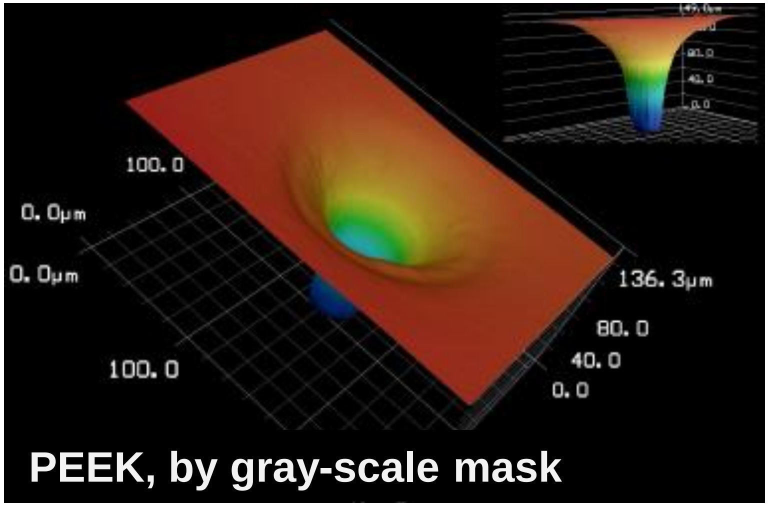
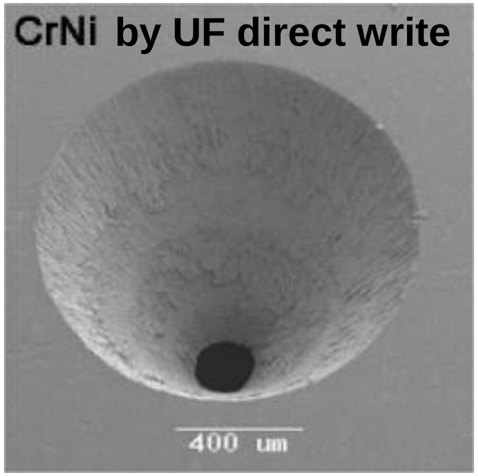
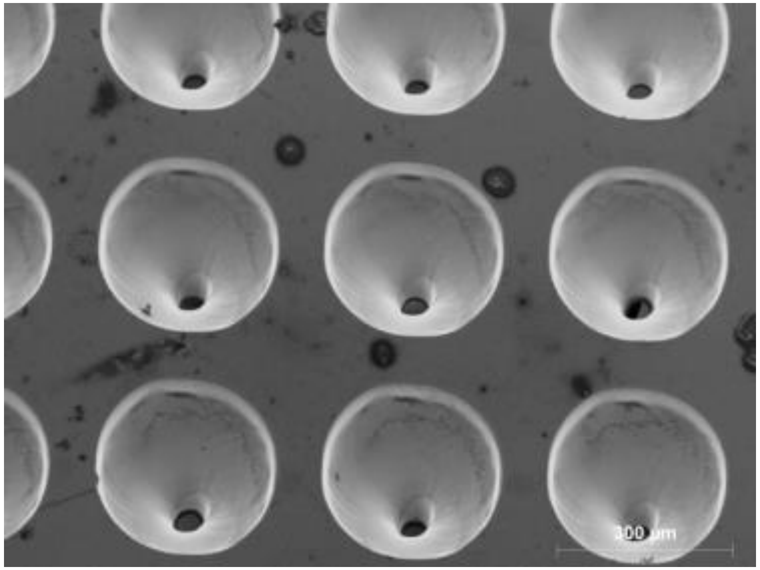
5,841,099	A	*	11/1998	Owen et al.	

Tailored Profiles

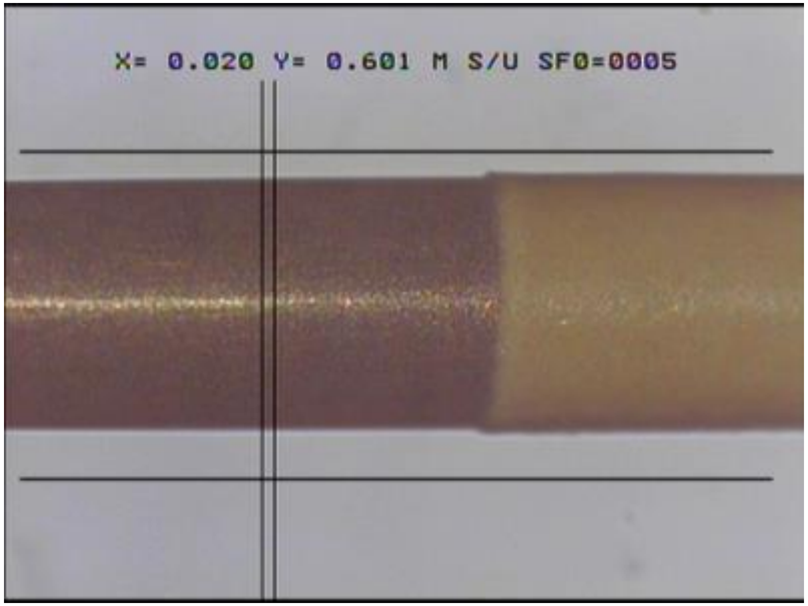


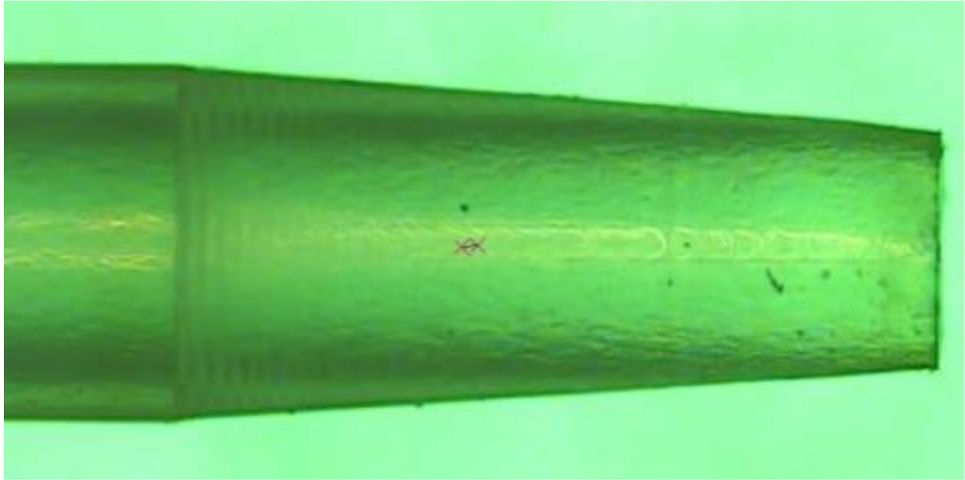


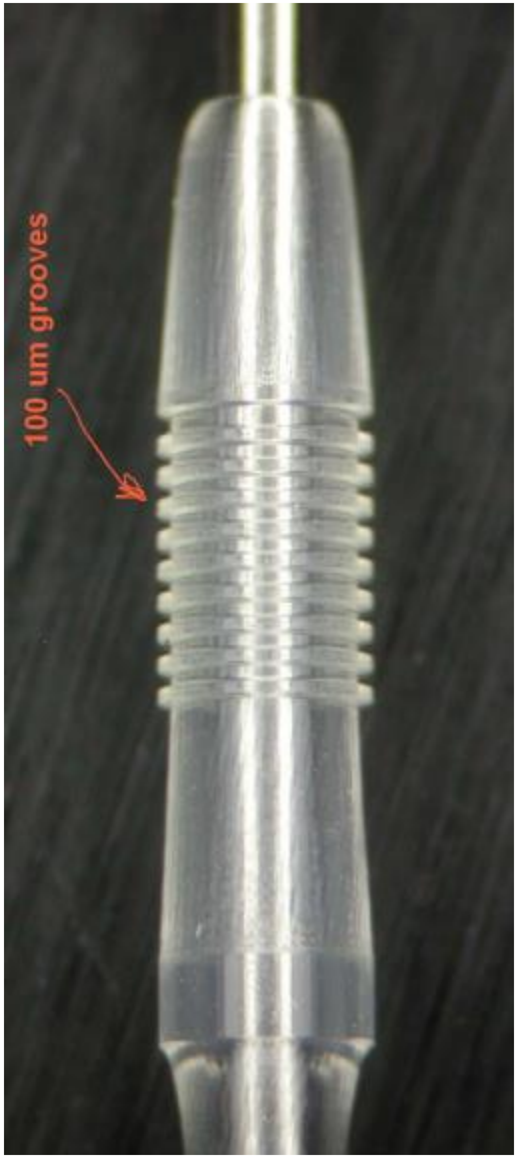




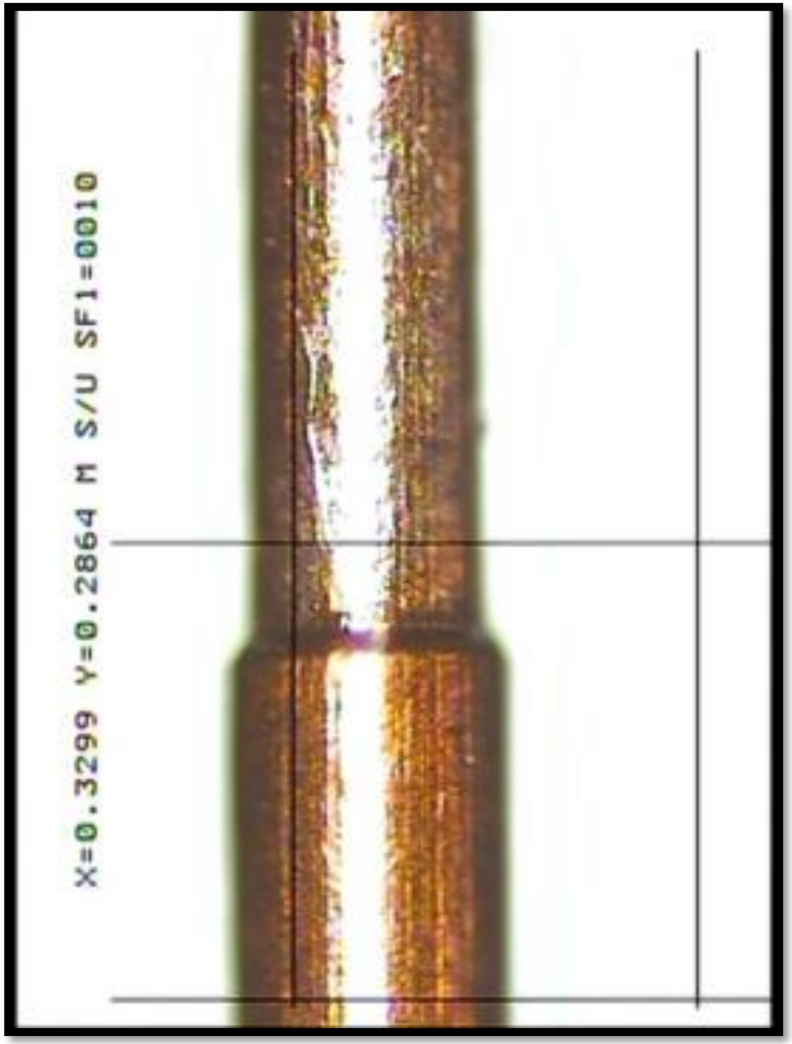
Tube Lathe – Polyimide, Pebax



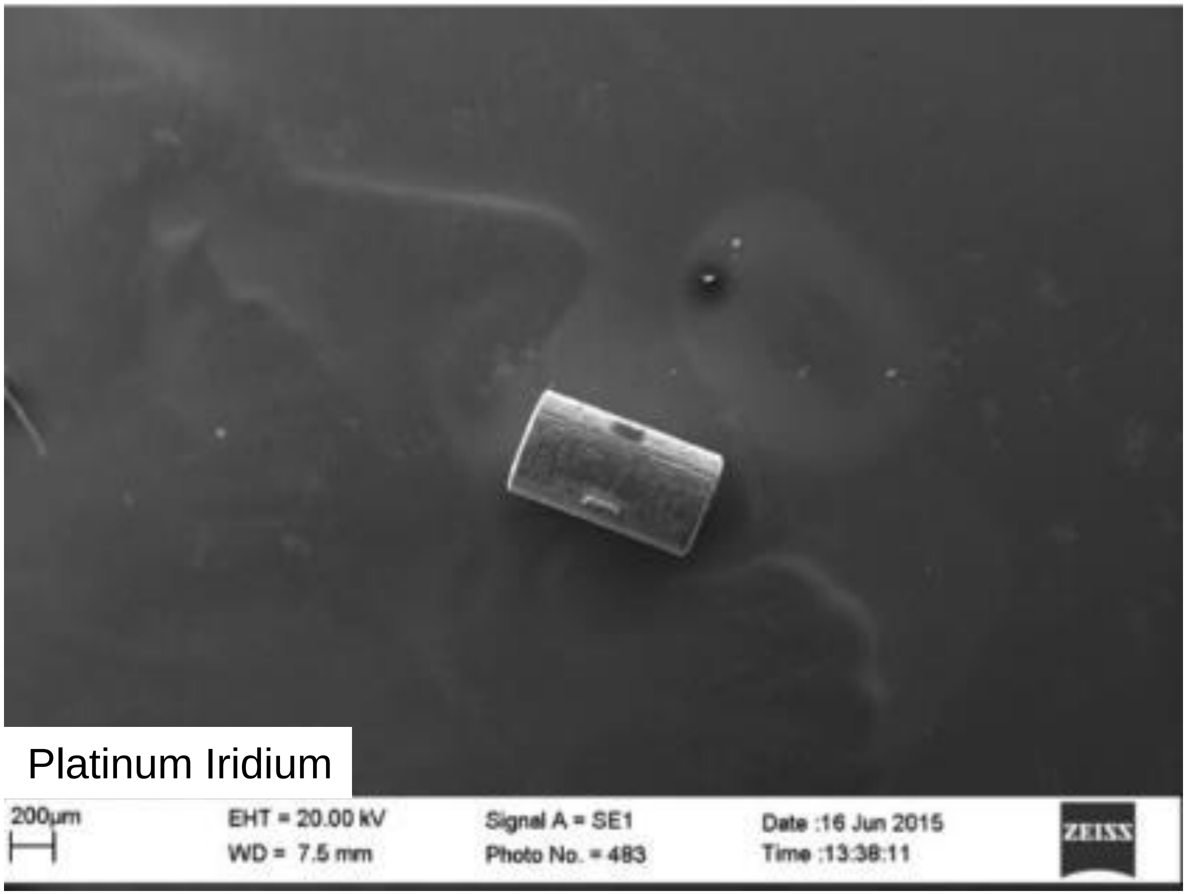


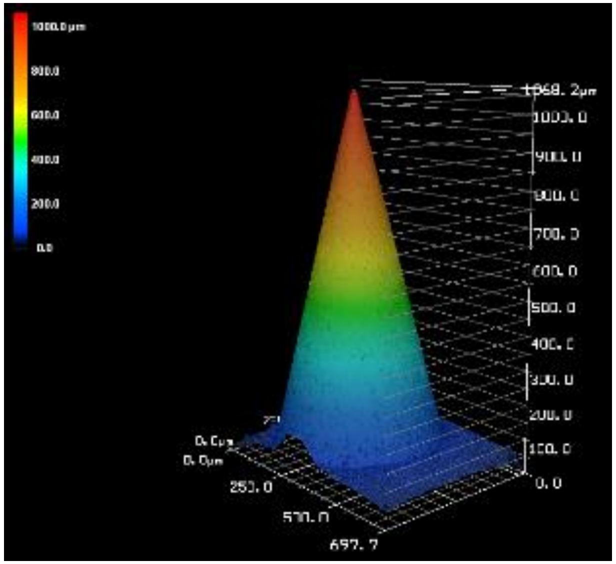


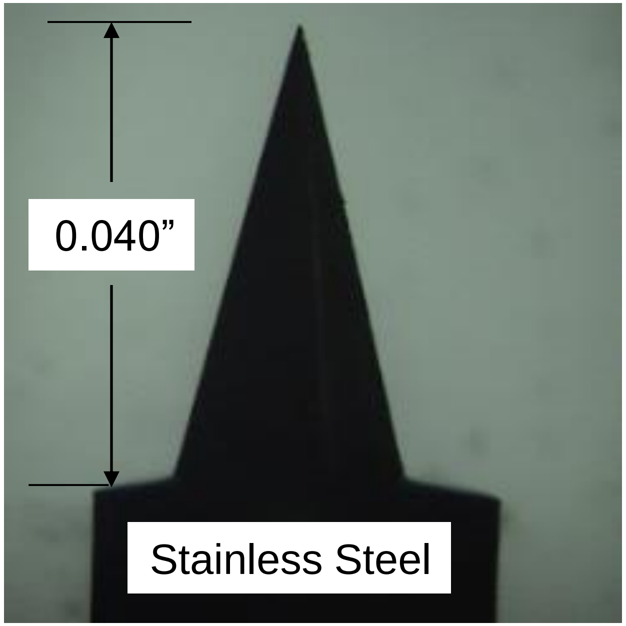
Tube Lathe – Polyimide



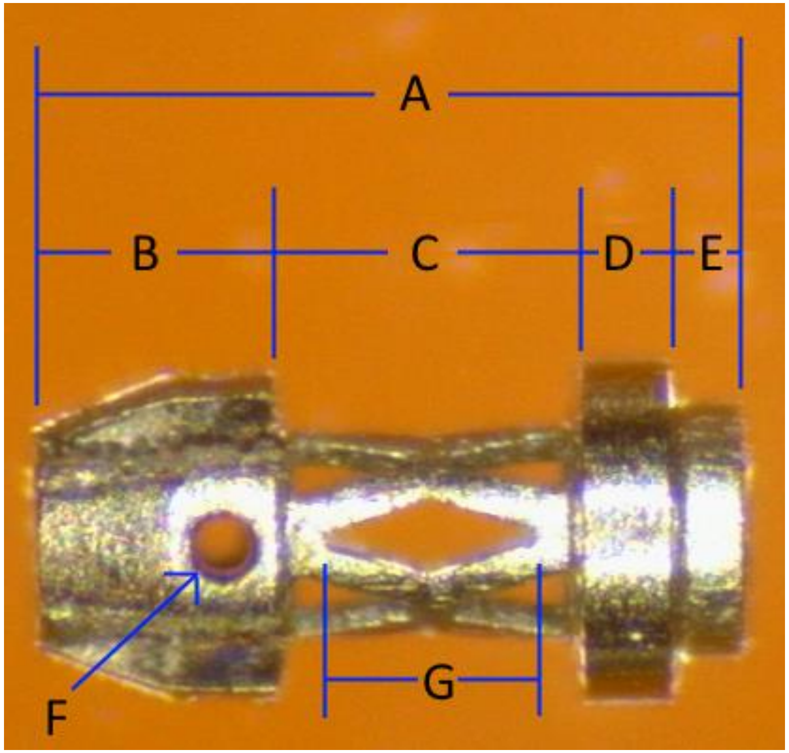
Metals: Platinum, Nitinol, Stainless Steel

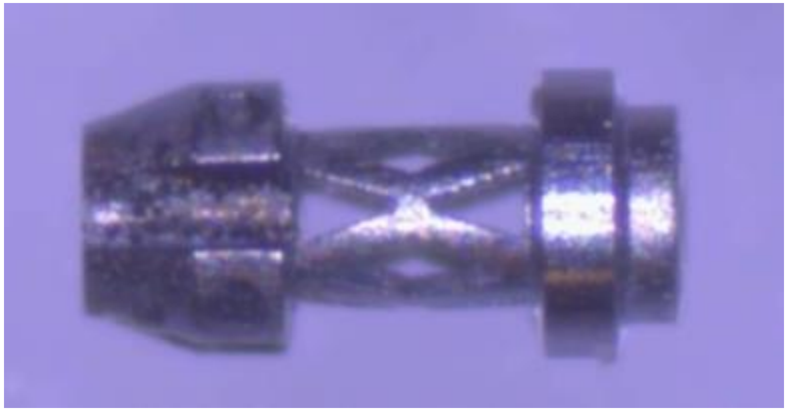




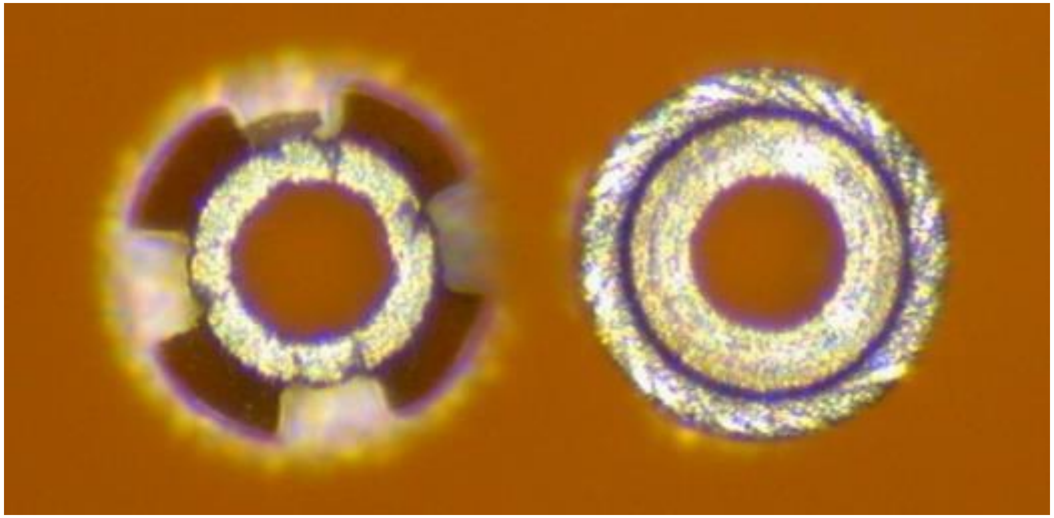


Nitinol 3D Micromachining/Ablation





- Nitinol Hypotube
- ID 0.0054” (0.137mm) / OD 0.0135”(0.343mm)
- Dim A = 0.68mm
- Dim B = 0.23mm
- Dim C = 0.29mm
- Dim D = 0.095mm
- Dim E = 0.065mm
- Dim G = 0.20mm
- ∅ C = 0.2mm
- ∅ D = 0.343mm
- ∅ E = 0.254mm
- ∅ F = 0.06mm
- Tip Taper = 20°

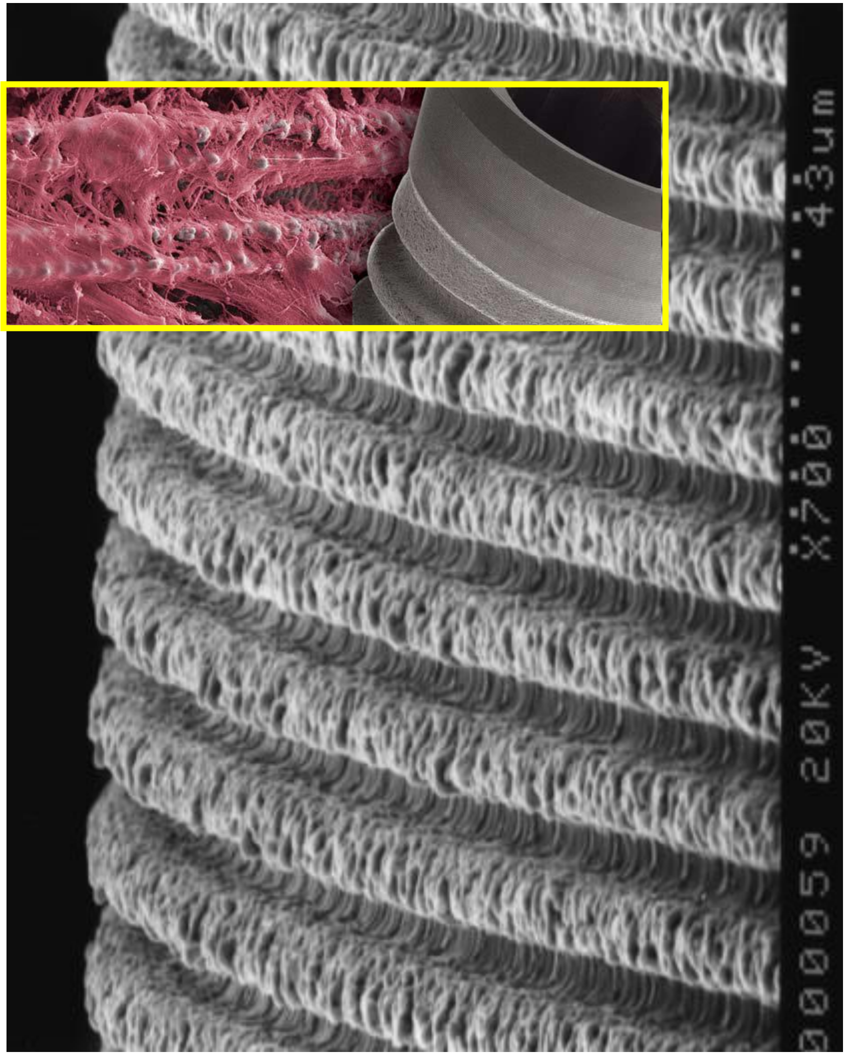


On a Dime for Scale

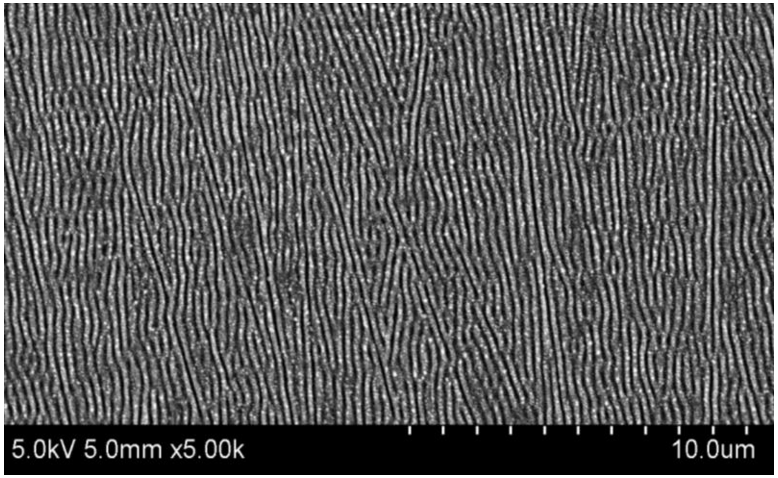
Application:

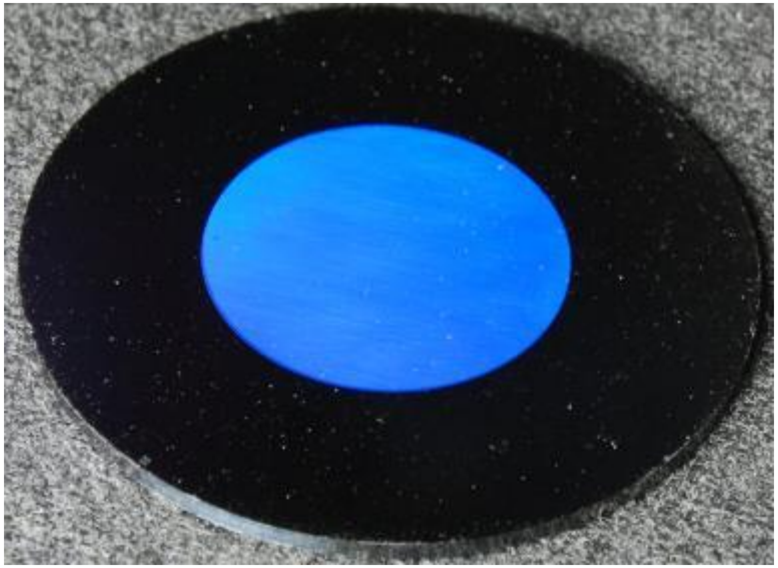
Surface Texture

Surface Texturing – Micron to Nano Scale



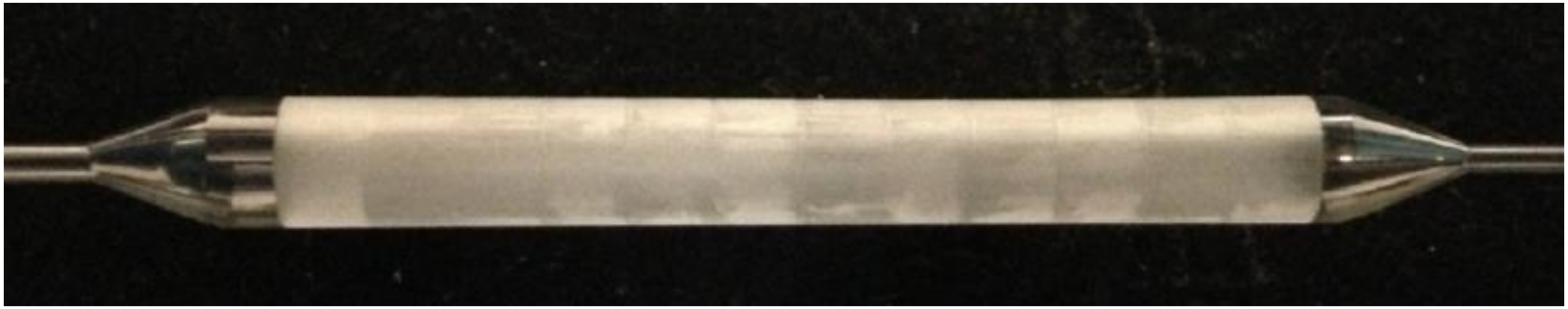
Titanium

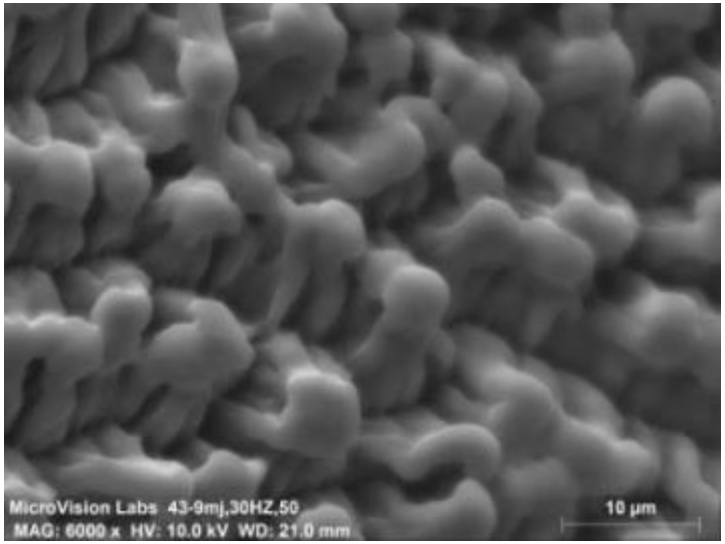


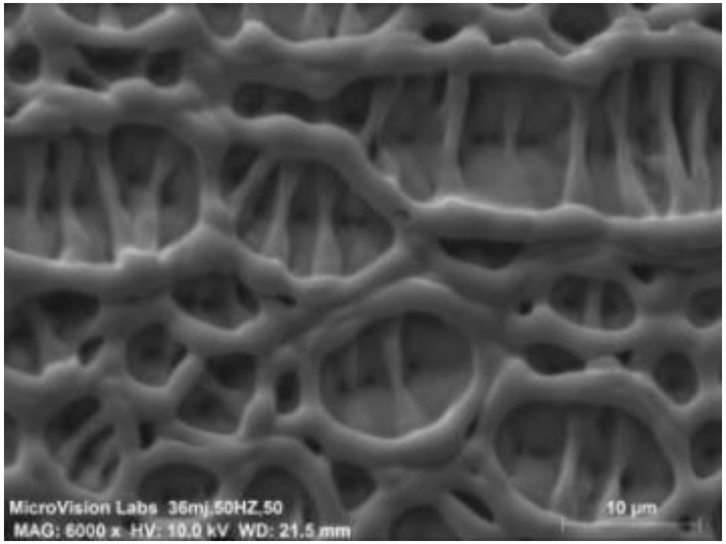


Silicon Carbide

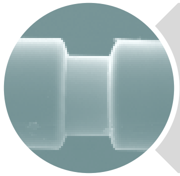
(Balloon) Surface Texturing



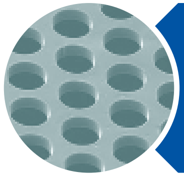




Technologies



Ablating



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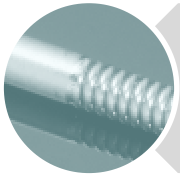
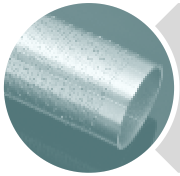
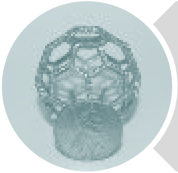


Welding

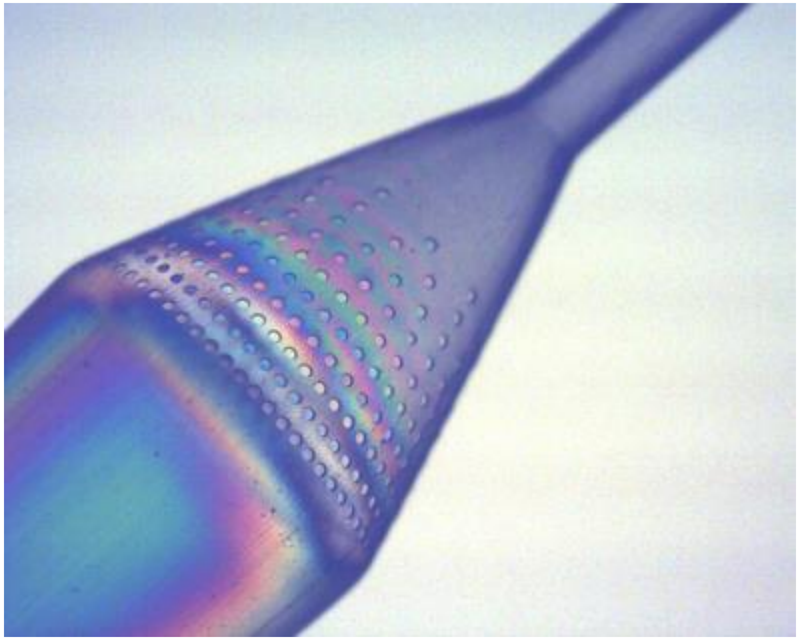


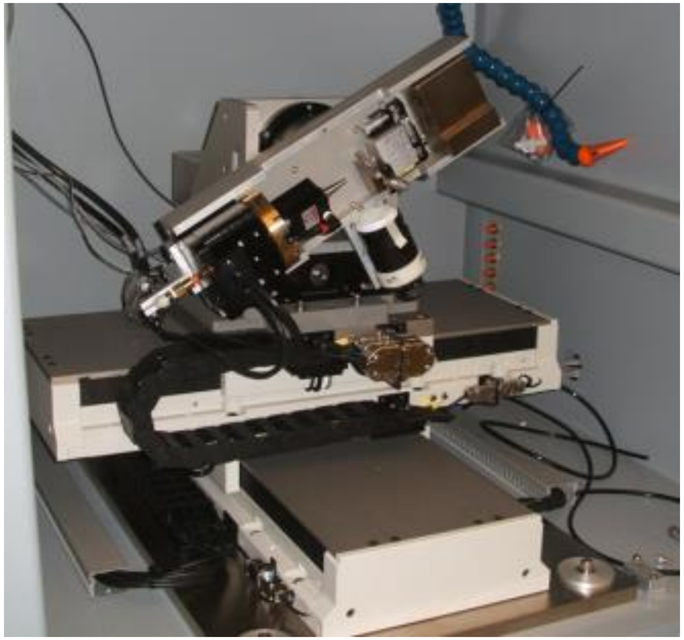
Cutting

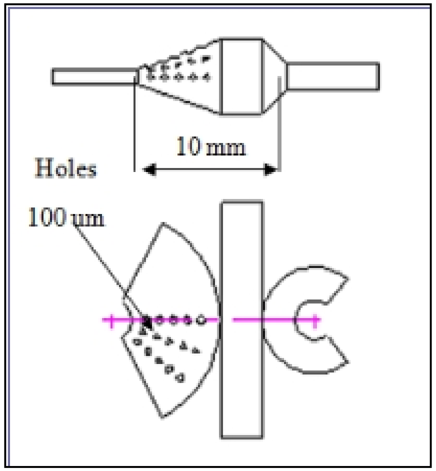


Additive

Mask Projection Hole Drilling: Filters







(12) **United States Patent**
Broude et al.

(10) **Patent No.: US 7,812,280 B2**
(45) **Date of Patent: Oct. 12, 2010**

(54) **METHOD AND APPARATUS FOR LASER MICROMACHINING A CONICAL SURFACE**

(75) Inventors: **Sergey V. Broude**, Newton Center, MA (US); **Rong Gu**, Hudson, NH (US); **David S. Holbrook**, Lexington, MA (US); **Kenneth T. McDaniel**, Merrimack, NH (US); **Pascal Miller**, Groton, MA (US); **David L. Wall**, Burlington, MA (US)

(73) Assignee: **Resonetics, Inc.**, Nashua, NH (US)

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FOREIGN PATENT DOCUMENTS

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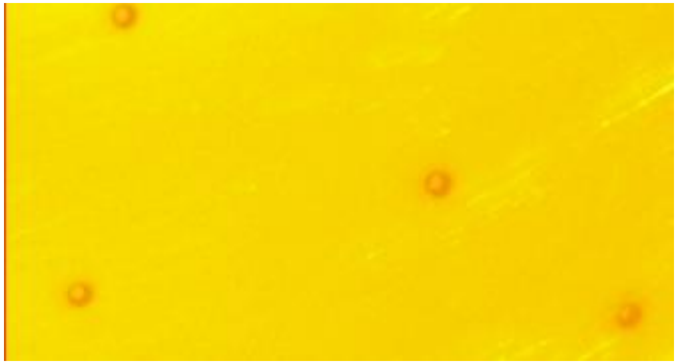
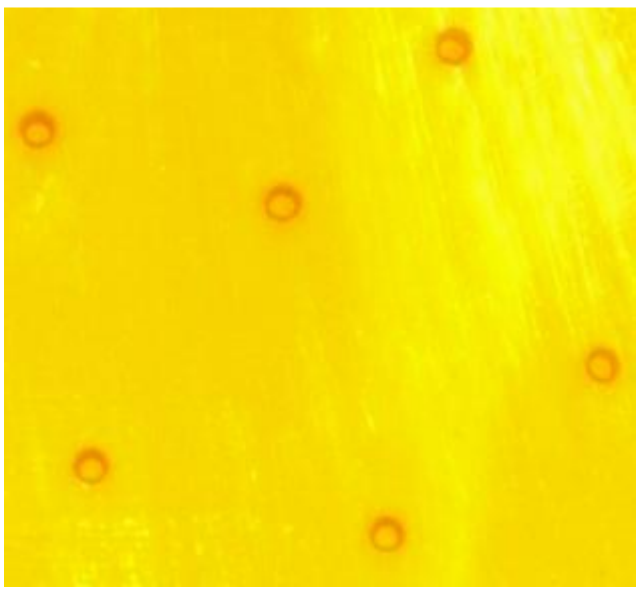
JP	2001096389	4/2001

OTHER PUBLICATIONS

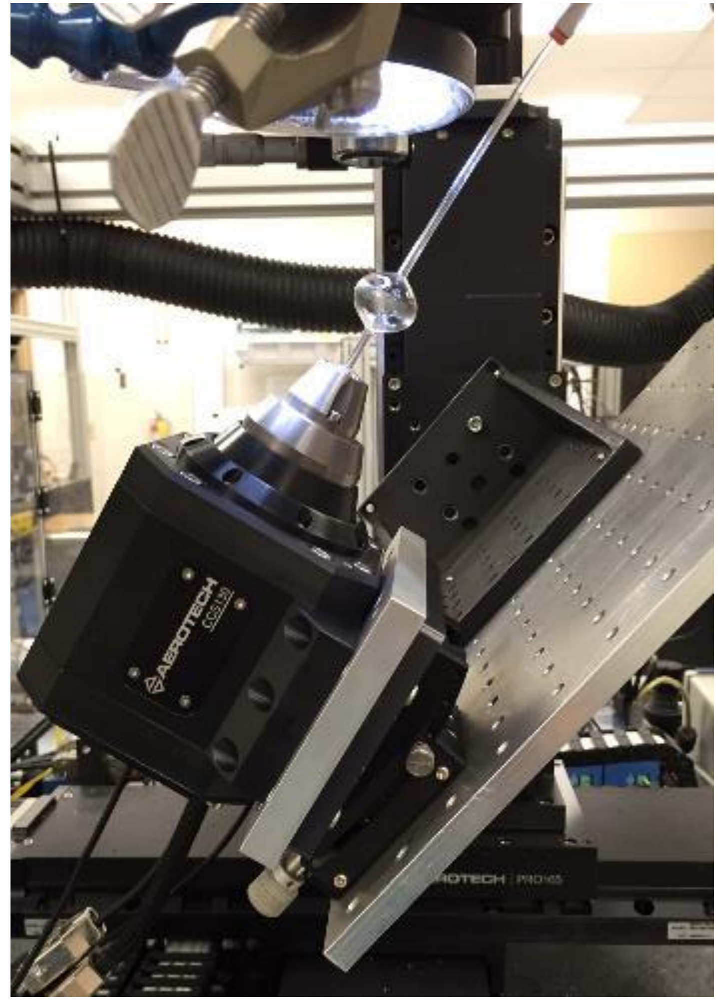
Direct Focus Hole Drilling: Balloon



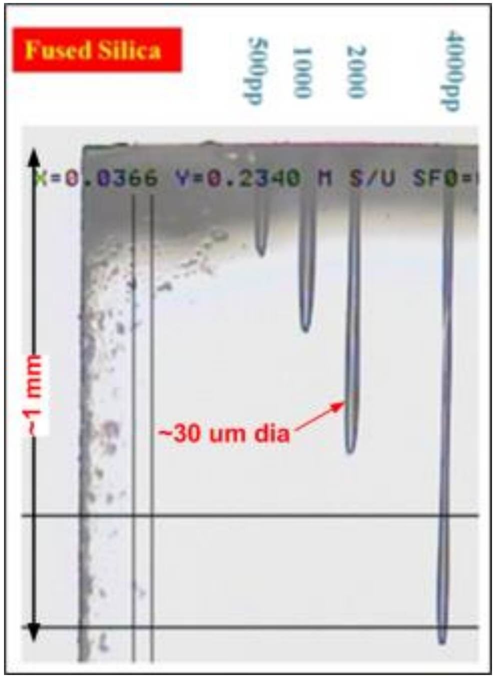
0.002” Diameter Holes

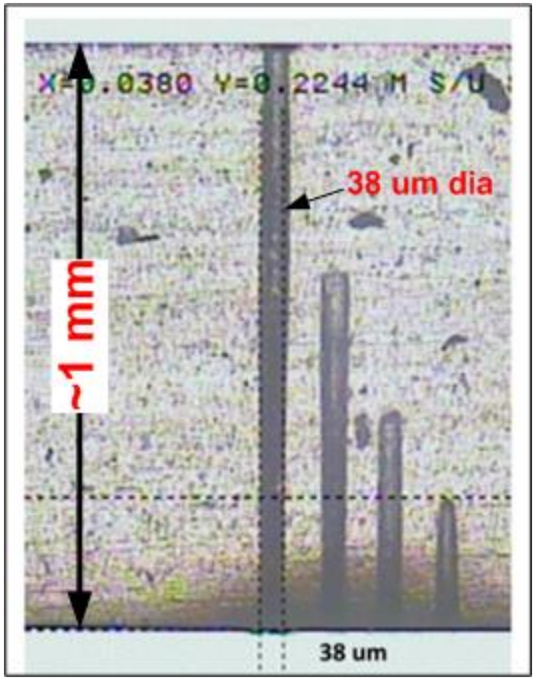


0.004” Diameter Holes

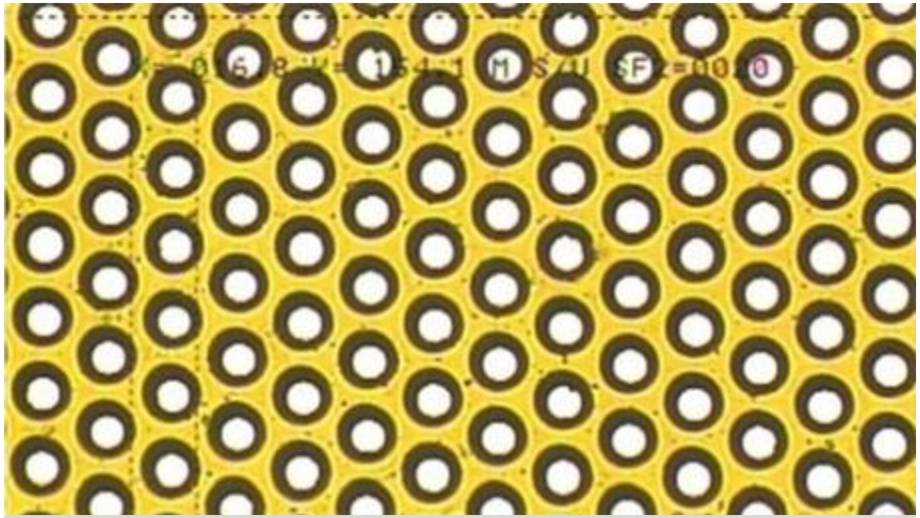


Deep Hole Drilling

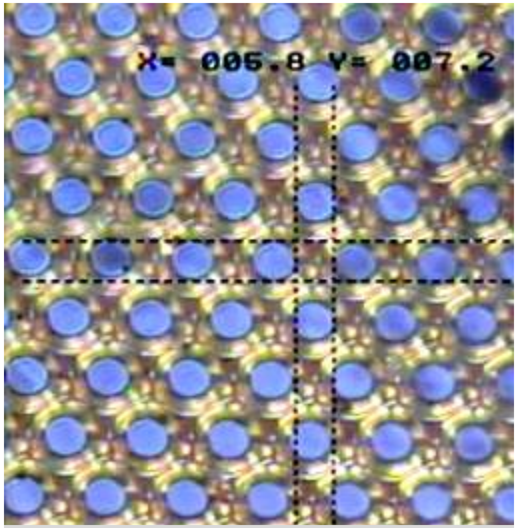




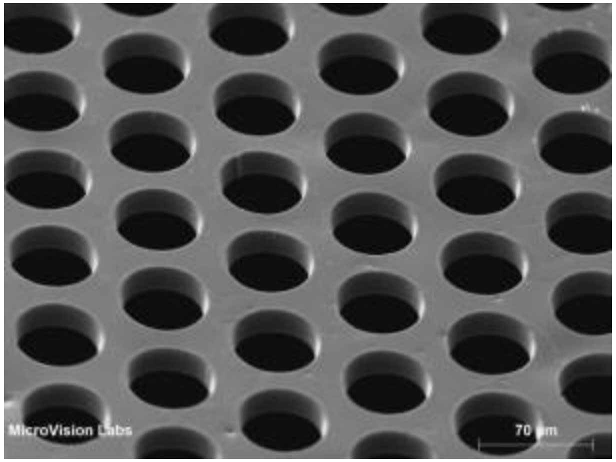
Hole Arrays



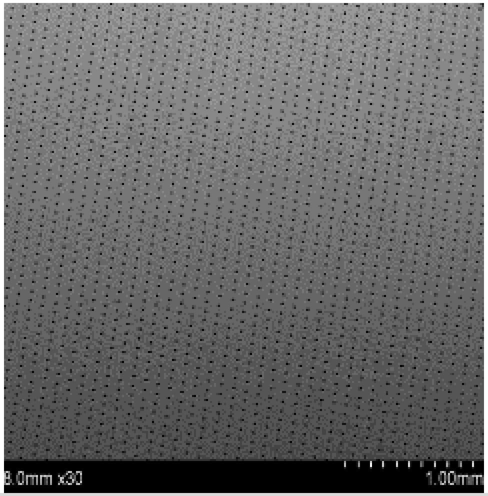
17 um dia in 50 um PET film



7 um dia in 13 um PI film

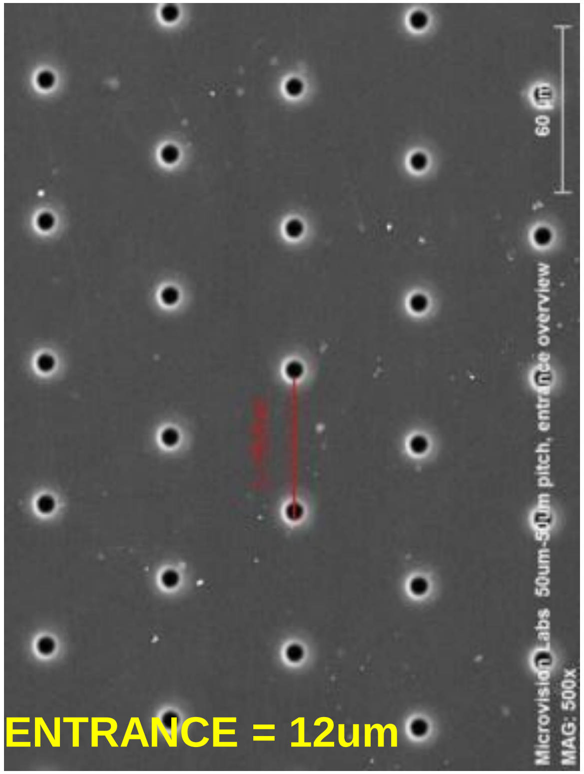


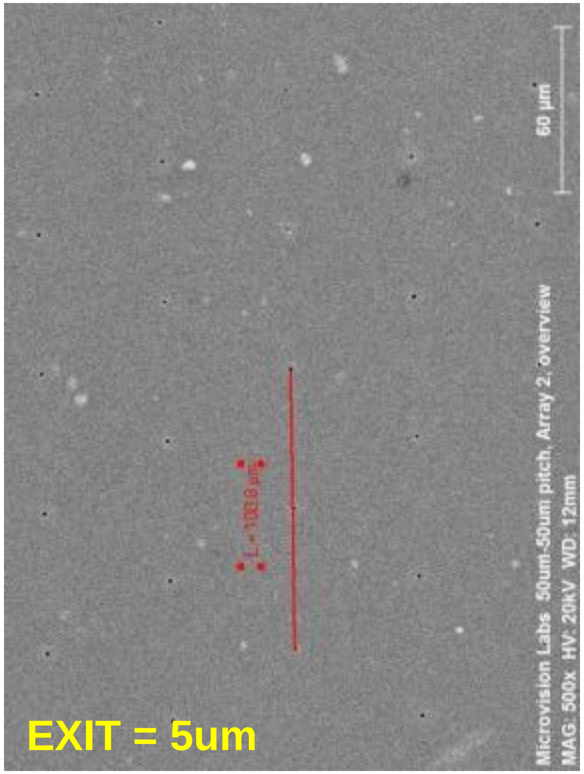
50 um dia in PU 25 um thick

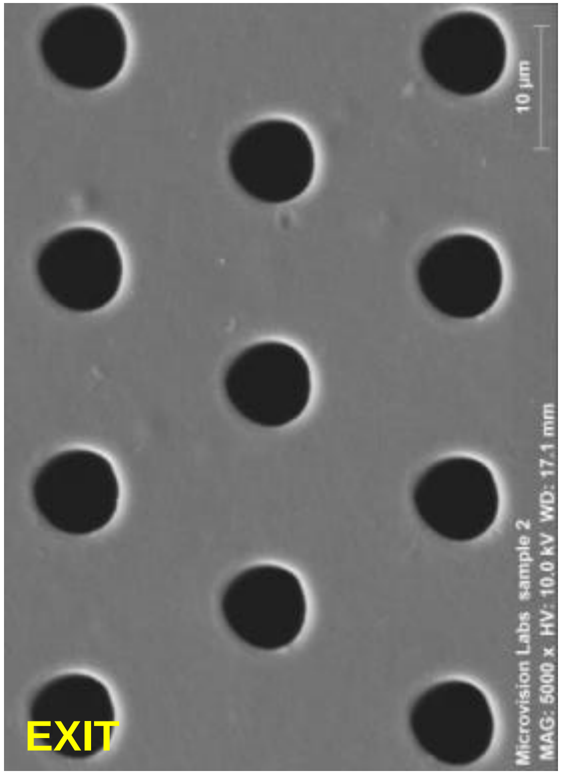


20 um dia in 75 um thick SS

Small Holes: 25 um PI



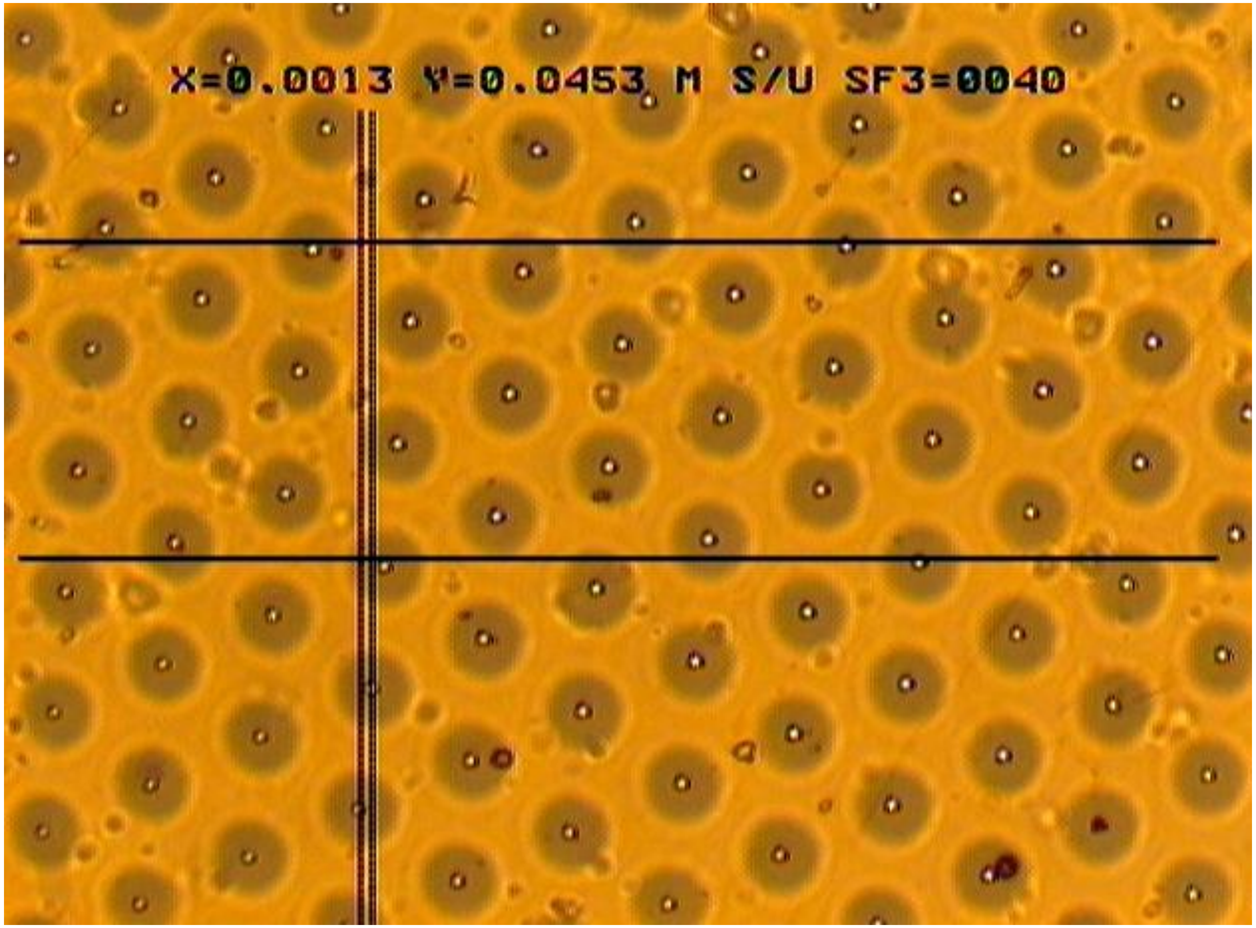




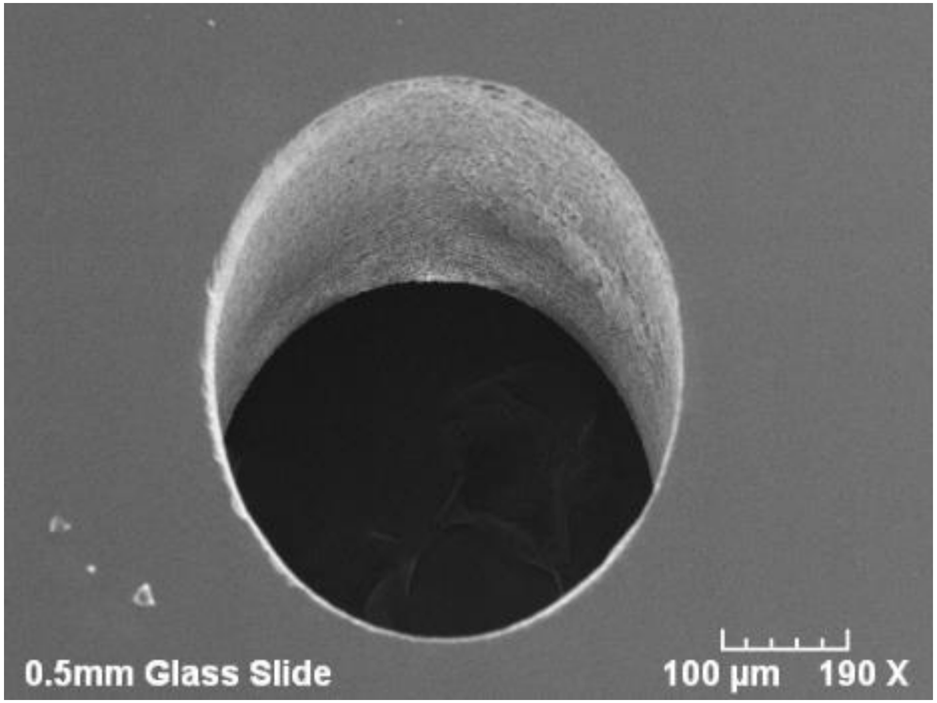
Exit dia = 5 um

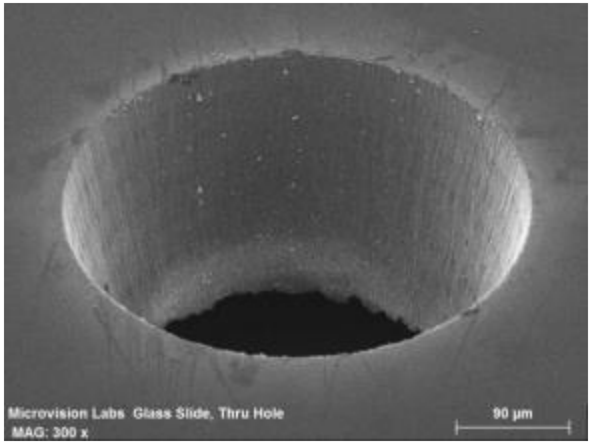
Exit dia = 7 um

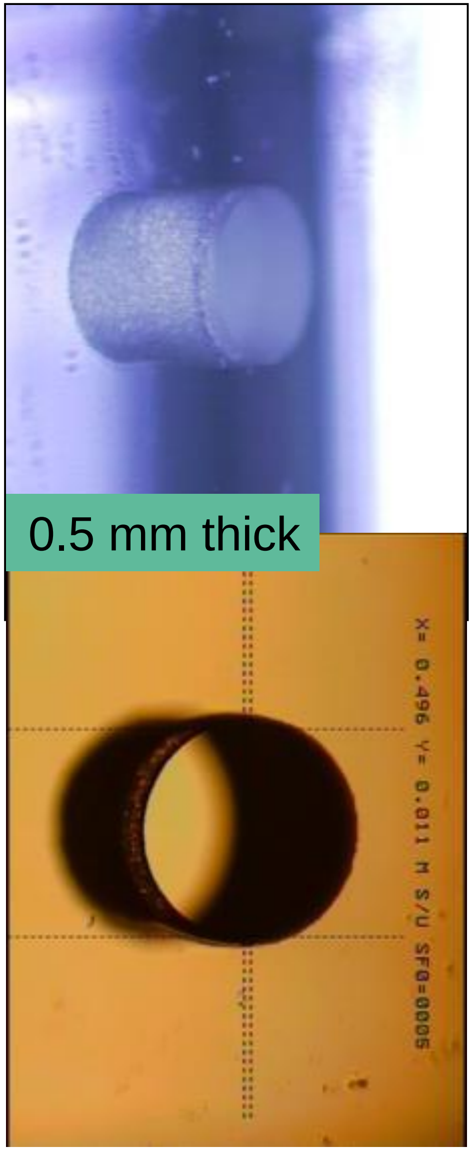
Small Holes: 1 um dia holes in 25 um PI



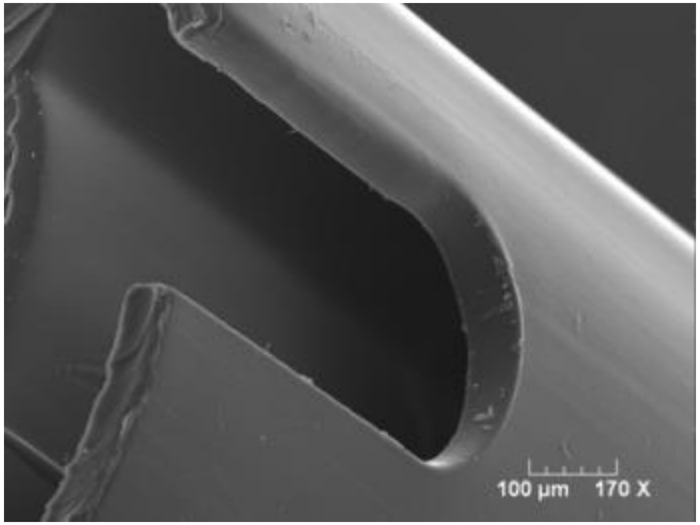
Holes in Glass

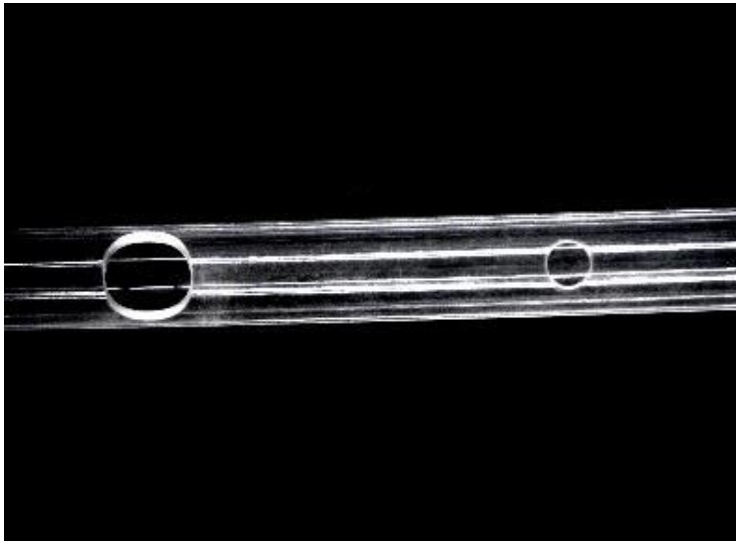


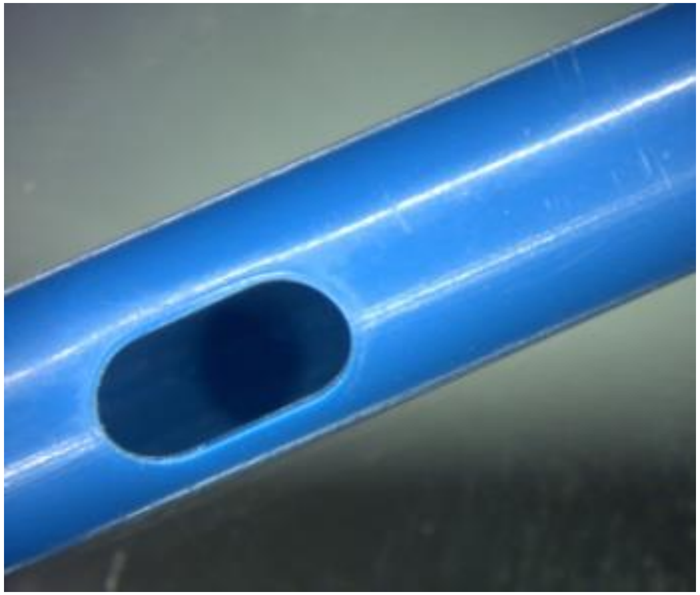


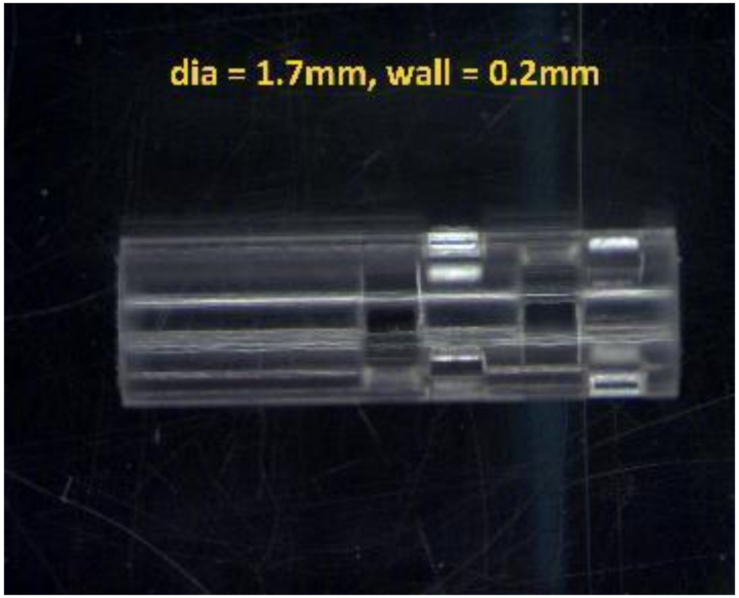


Single, Multi Lumen Tube – Drilling, Skiving

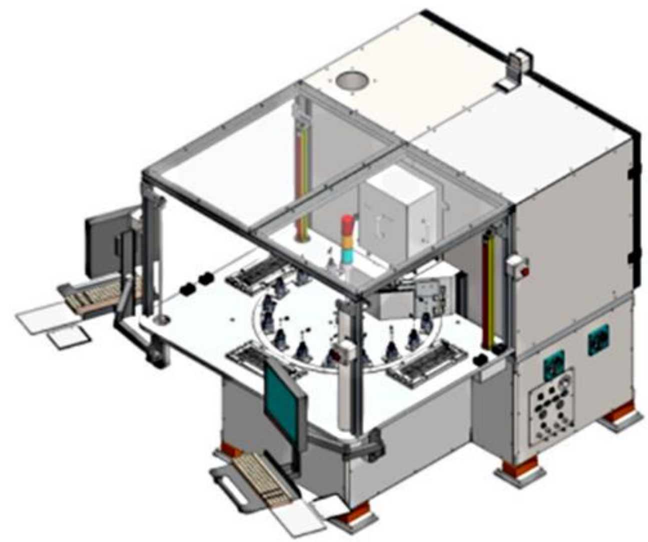








Femtosecond Drilling Workstation



US 20130193618A1

(19) **United States**

(12) **Patent Application Publication**
Miller et al.

(10) **Pub. No.: US 2013/0193618 A1**
(43) **Pub. Date: Aug. 1, 2013**

(54) **LASER MACHINING SYSTEM AND METHOD FOR MACHINING THREE-DIMENSIONAL OBJECTS FROM A PLURALITY OF DIRECTIONS**

(75) Inventors: **Pascal Miller**, Groton, MA (US); **Sergey Broude**, Newton Center, MA (US); **David L. Wall**, Burlington, MA (US); **Kenneth Todd McDaniel**, Merrimack, NH (US)

(73) Assignee: **RESONETICS LLC**, Nashua, NH (US)

(21) Appl. No.: **13/520,089**

(22) PCT Filed: **Dec. 30, 2010**

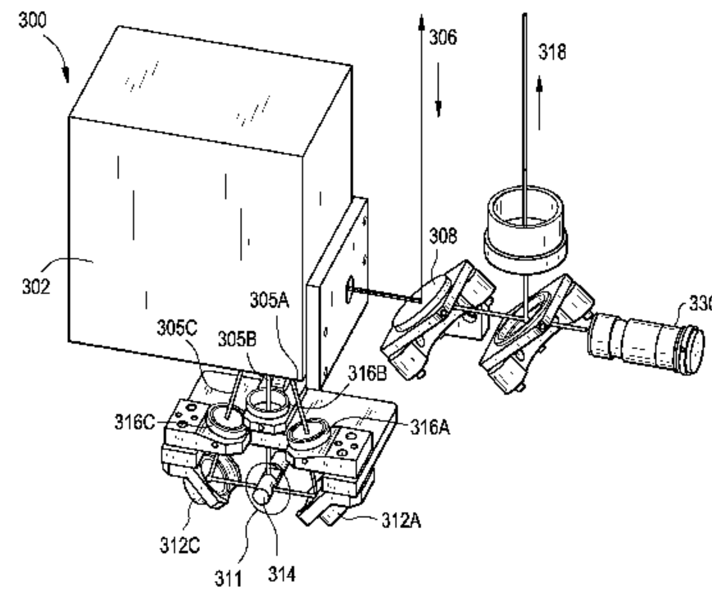
(86) PCT No.: **PCT/US10/62498**

§ 371 (c)(1), (2), (4) Date: **Sep. 24, 2012**

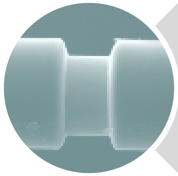
(52) **U.S. Cl.**
CPC ***B29C 59/16*** (2013.01)
USPC **264/400**; 425/174.4; 425/150; 425/169

(57) **ABSTRACT**

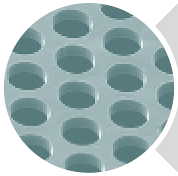
Embodiments of the present disclosure are directed to systems (**300**), devices and methods for machining a work-piece from a plurality of directions using a single laser beam and galvanometer scan head (**302**). In some embodiments, such a system includes, for example, a scanning galvanometer head ("scan-head") (**302**), having one or more mirrors (**323**) for directing a laser beam in at least one plane. Preferably, in some embodiments, the scan-head includes two mirrors for deflecting the laser beam in the at least one plane (e.g., an X-Y plane). A plurality of second mirrors (**312A**, **312B**, **312C**) is arranged after the scan-head (**302**) to direct the laser onto a



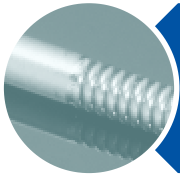
Technologies



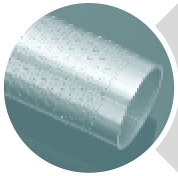
Ablating



Drilling



Welding

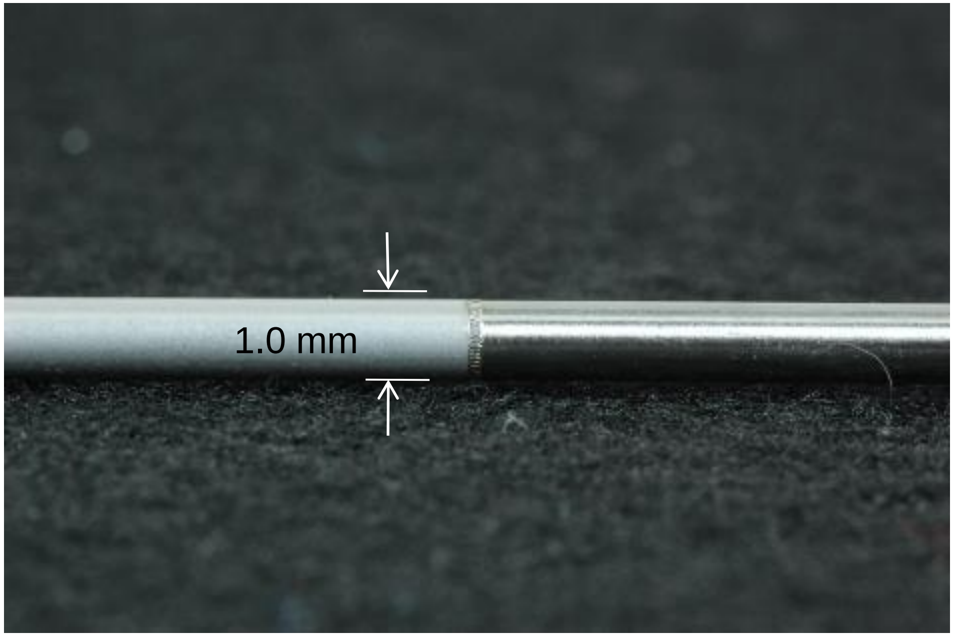


Cutting

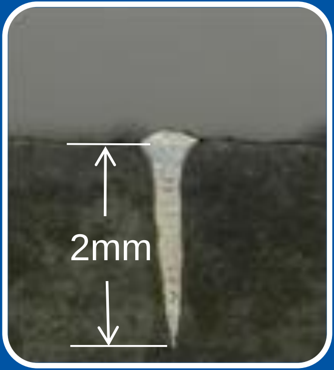
Additive

Why Use Laser Welding?

- Parts Requirements:
  - Structural strength
    - Up to 80% of base material
  - Hermetic (gas tight)
    - Down to 1x10-9 cc/sec He
  - Cosmetic
    - No post process finishing
  - Size
    - Features
    - 1mm to 0.075mm
    - Low heat input

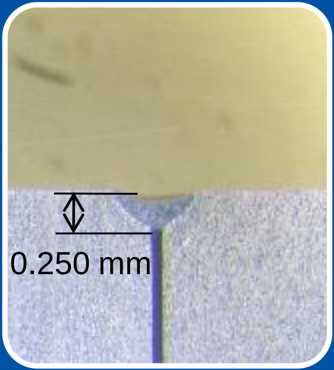


Types Of Laser Welding



Keyhole

- Power Density >10^6 W/cm^2
- Depth : Width Ratio > 3:1
- High Speed – Fiber Laser – up to 1 meter/second
- Typical - CW Solid State, CO_2

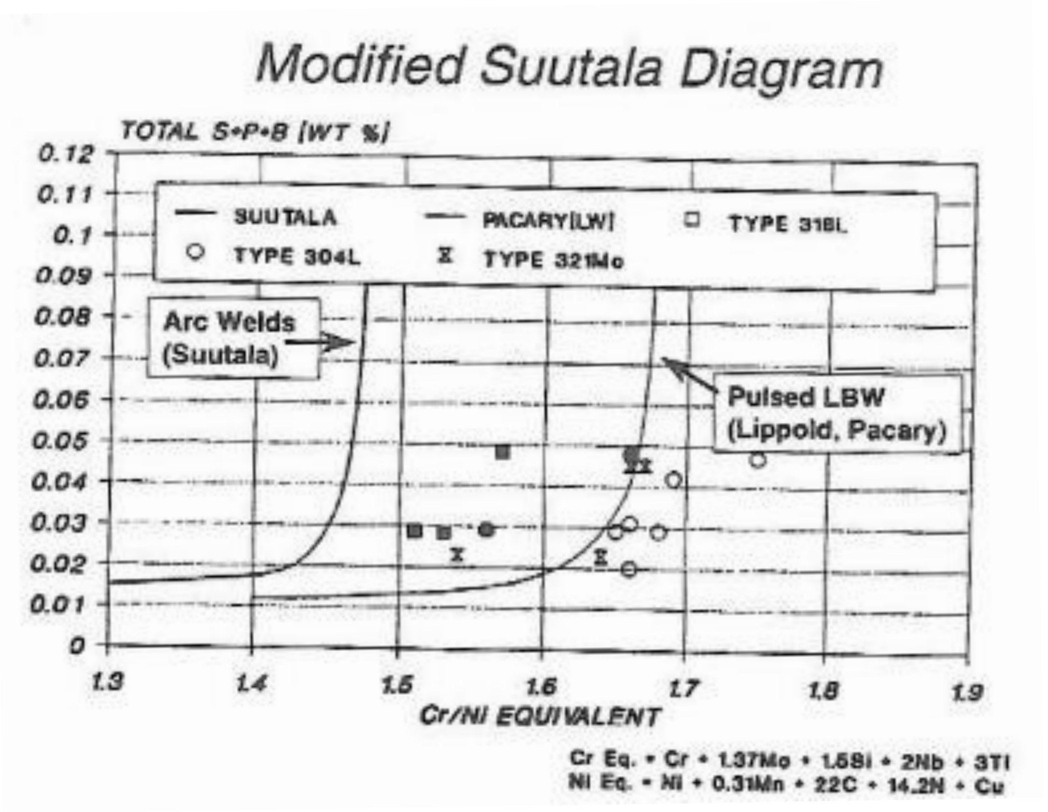


Conduction

- Power Density <10^6 W/cm^2
- Depth : Width ratio < 3:1
- Typical - Pulsed Nd:YAG, fiber laser

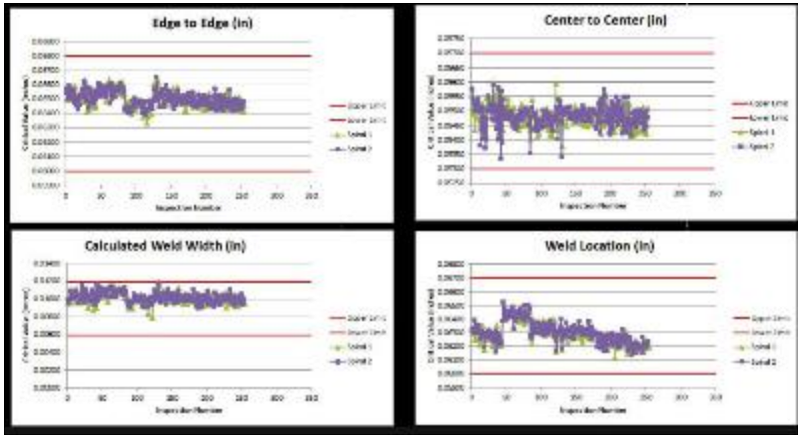
Laser Weldable Metals

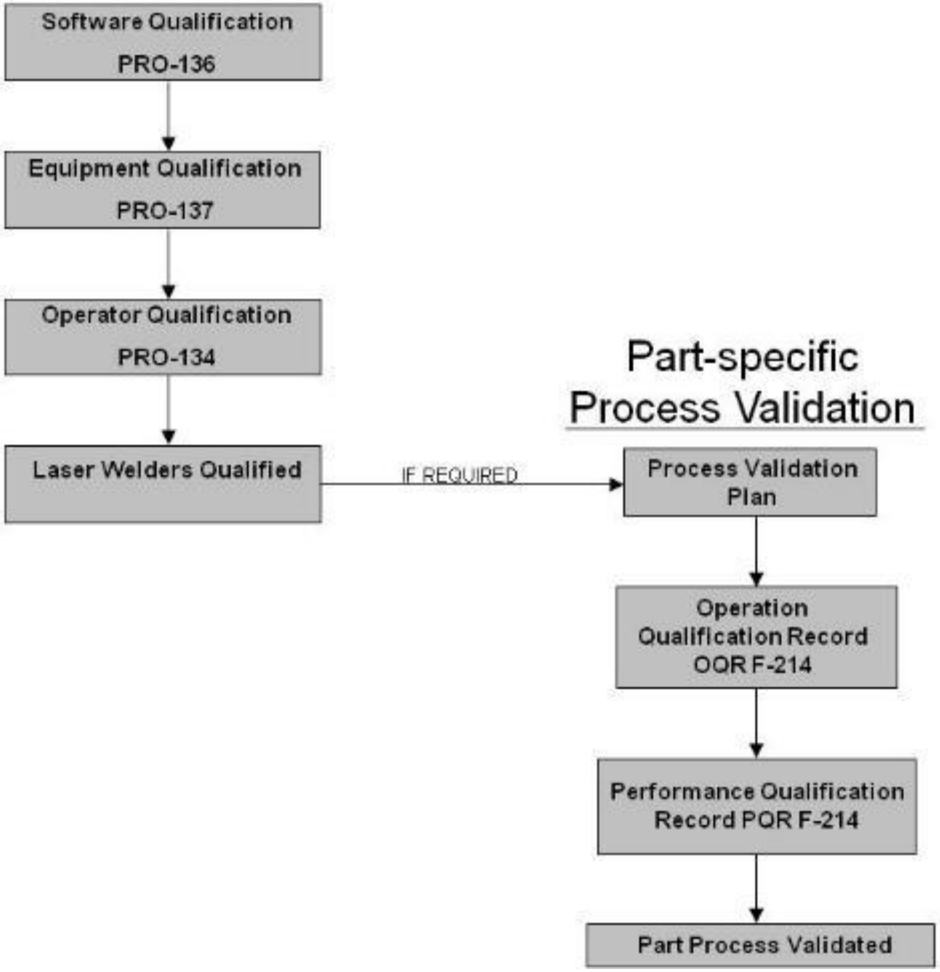
- Stainless Steel
  - Problem Elements – Sulfur, Oxygen, Carbon
- Titanium, Titanium Alloys
- Nitinol – nickel rich
- Cobalt Chrome
- Copper, Nickel
- Gold, Platinum, Silver
- Nickel-Based Alloys
- Some Aluminum



Process Validation

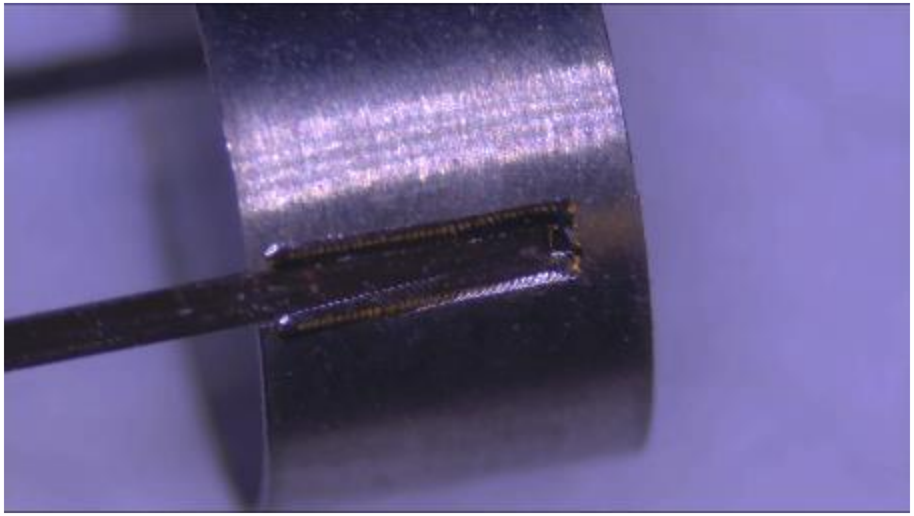
- OEM approved validation protocol
  - Feasibility
  - Engineering Study
  - Validation
- Process capability driven

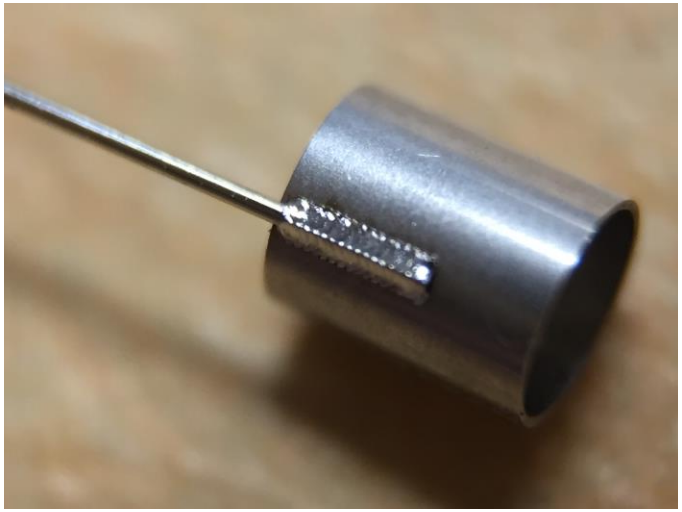


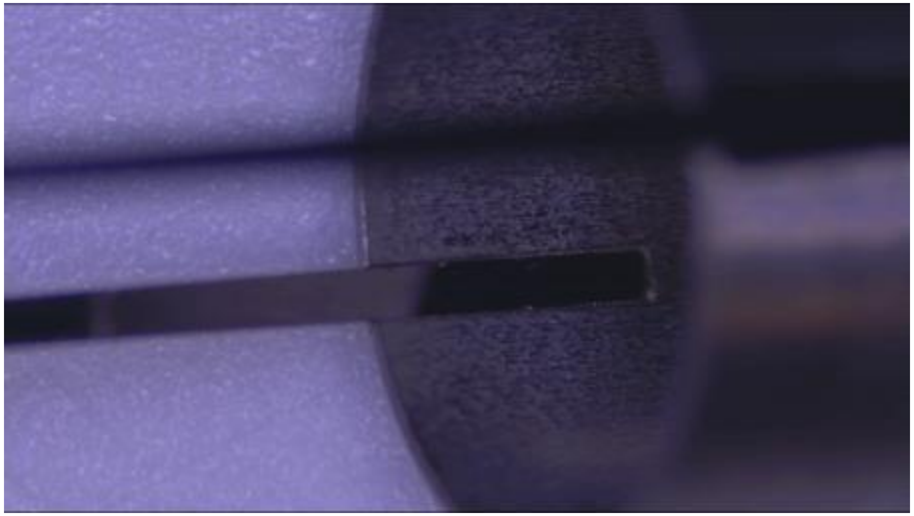


Pull Ring Welding

- Stainless Steel
- Laser cut pull ring
- 15 lbs. + pull strength
- Semi-automated system in development

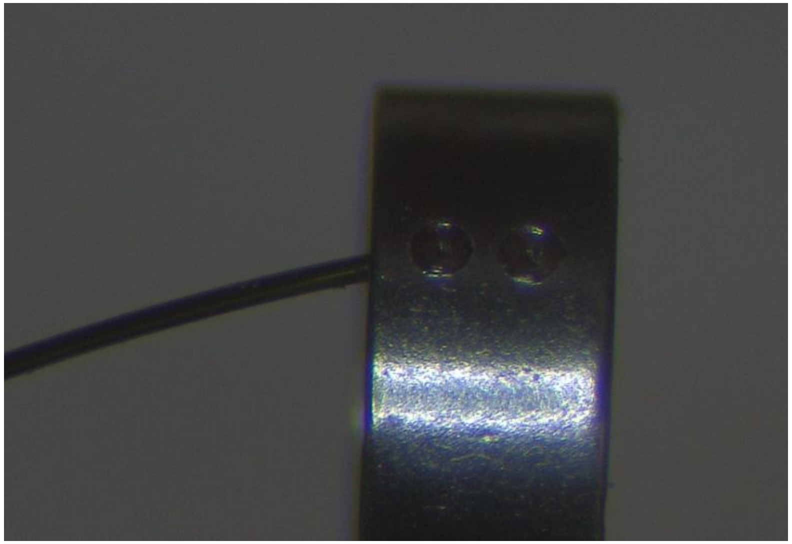


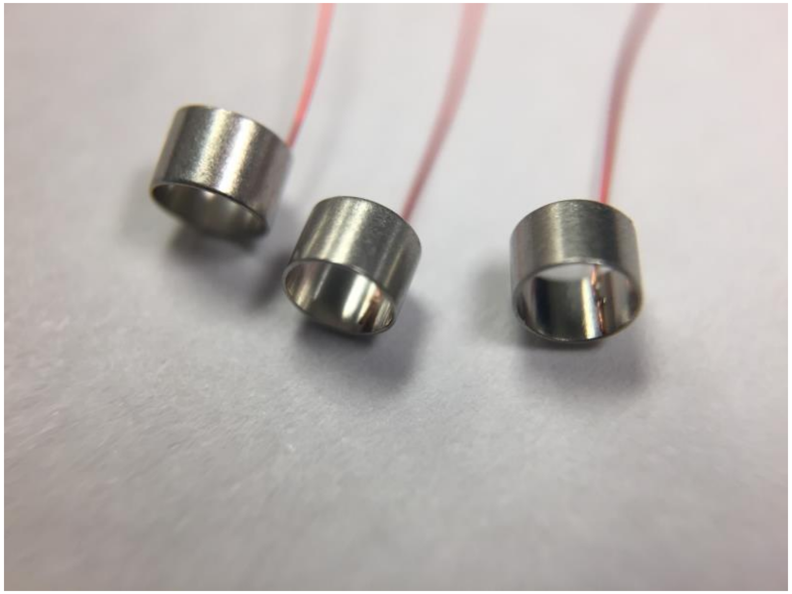




Wire Stripping, Electrode Welding

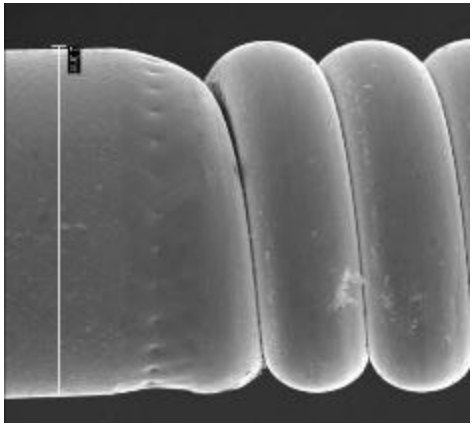
- Platinum/Iridium, Stainless Steel electrodes
- Wire stripping
  - 0.003" diameter nickel wire
- Laser weld assembly
- Semi-automated, automated system in development



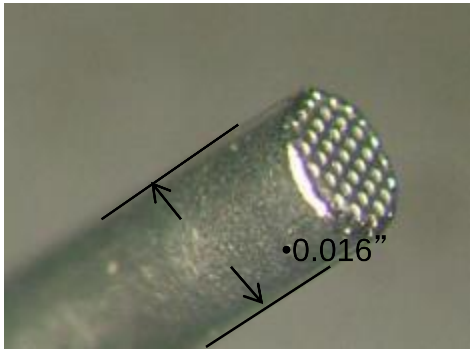


Applications

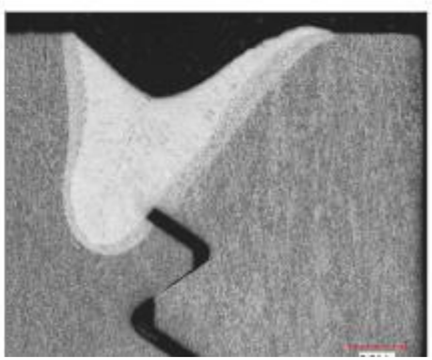
– Coil to hypotube (304SS)



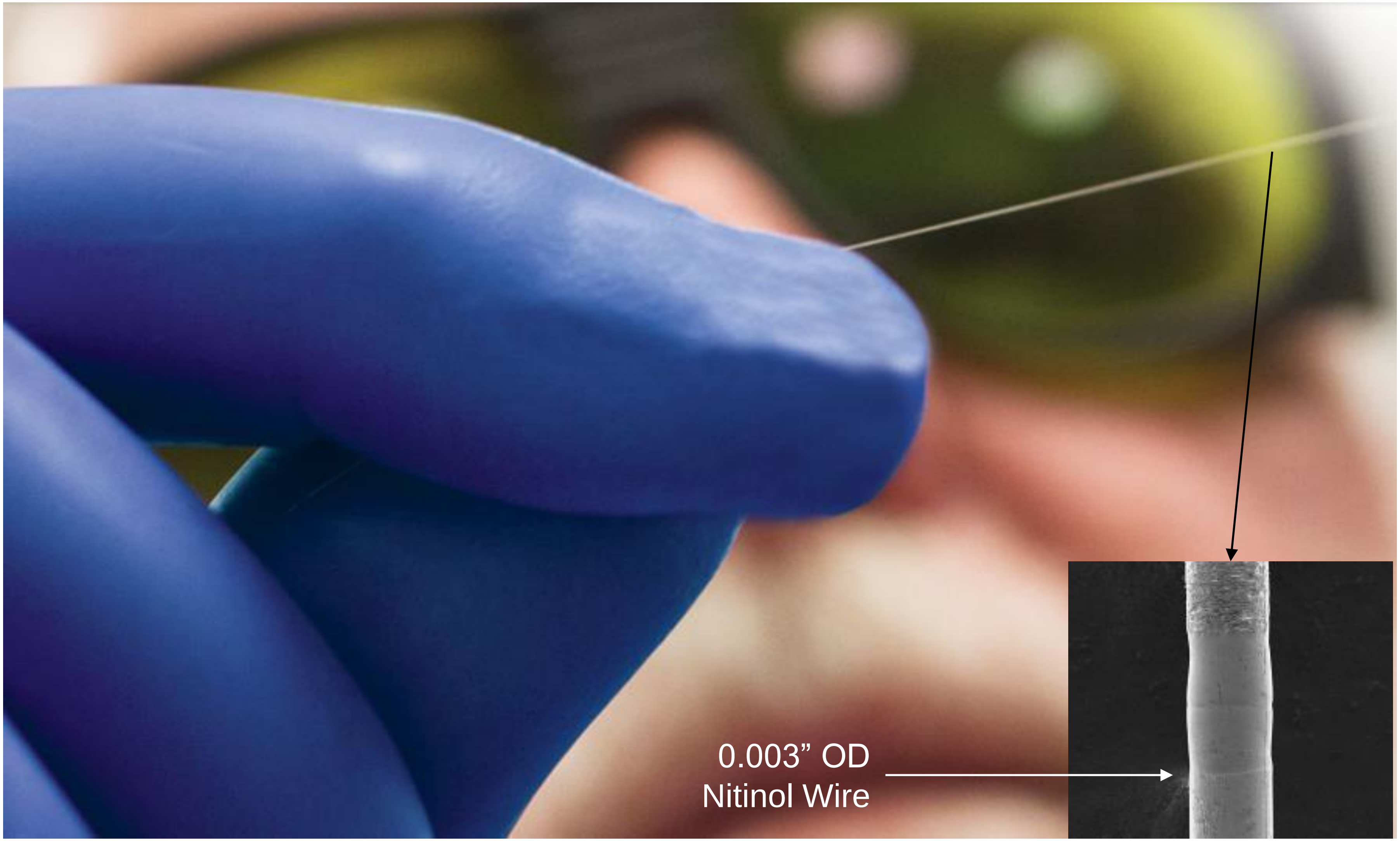
– Hypotube to filter (304SS)



– Spinal implant (Ti 6-4)

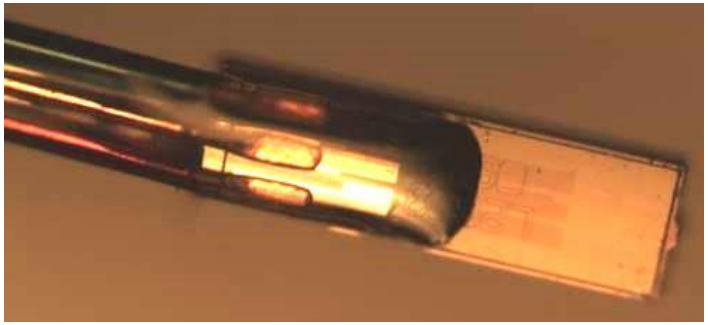


Laser Micro Welding



Micro Pressure Sensor

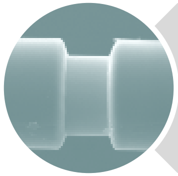
- Selective coating removal on trifilar wire
  - 0.001” copper wires
- Bonded to silicon pressure sensor
  - Copper to platinum solid state bond
- Encapsulated
  - Protect the bond from in-vivo environment



SMi PRESSURE SENSORS

Presented with Permission of Silicon Microstructures Inc.

Technologies



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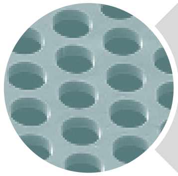
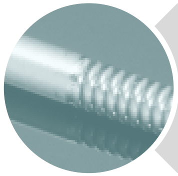
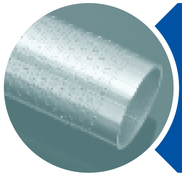


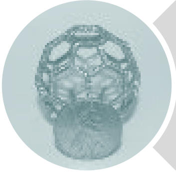
Drilling



Welding



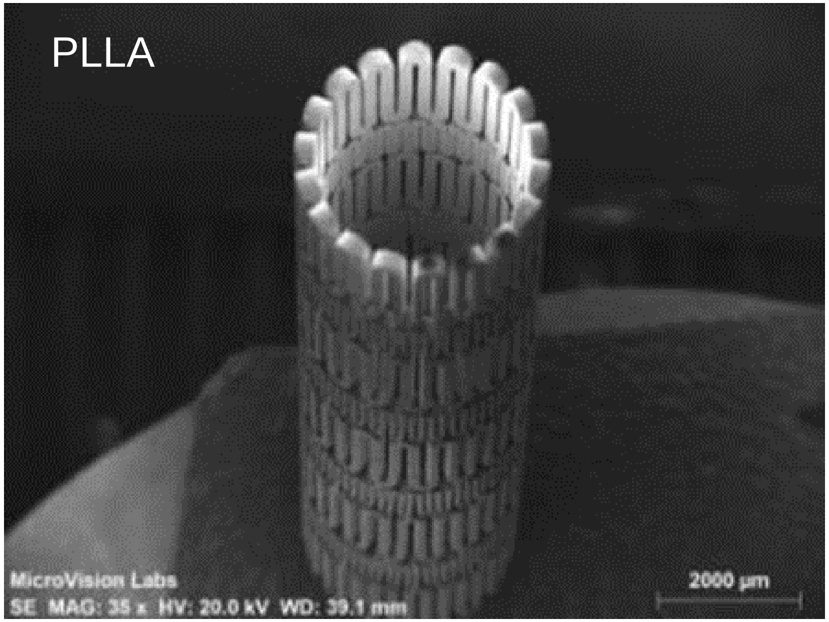
Cutting

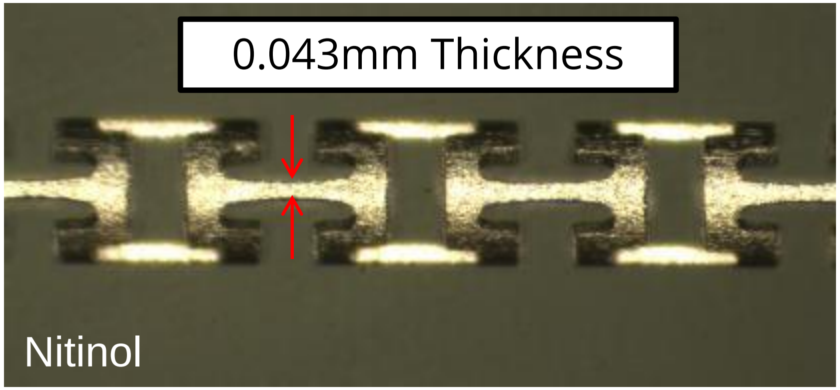


Additive

Why Use Laser Micro Cutting?

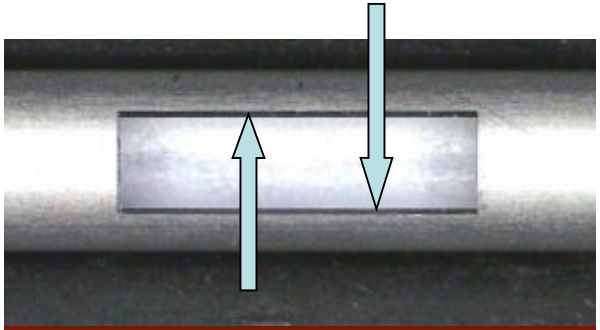
- Part Requirements:
  - Features down to 0.025mm
  - Custom part flexibility
    - Vary along length
  - Hypotube or flat
  - Metals and polymers



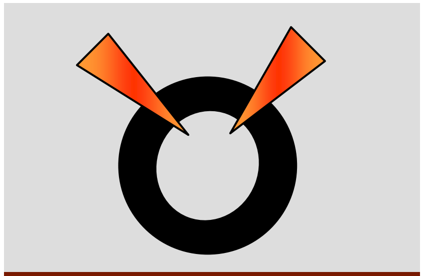


Types of Cut on Hypotubes

- On axis (Radial)

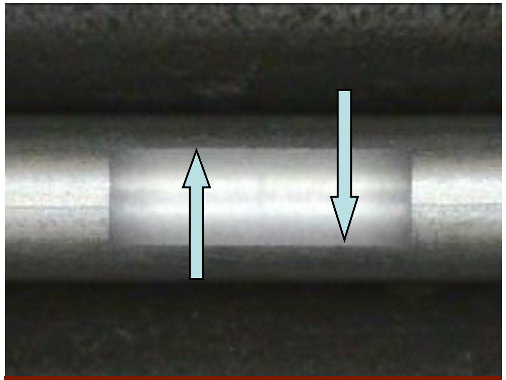


•Window with tapered walls

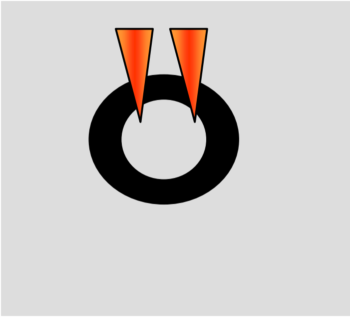


•Radial cut (2 axis)

- Off axis (Offset)



•Window with parallel walls



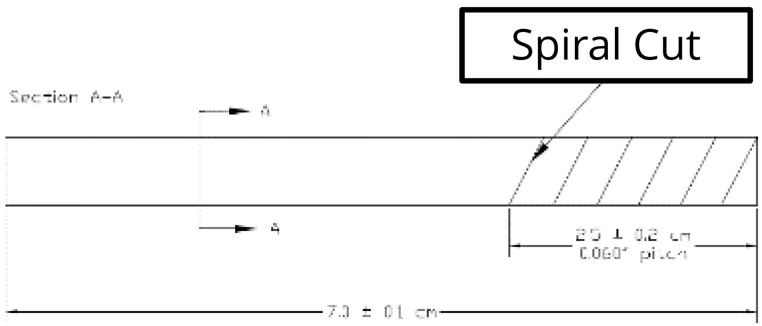
•Offset cut (4 axis)

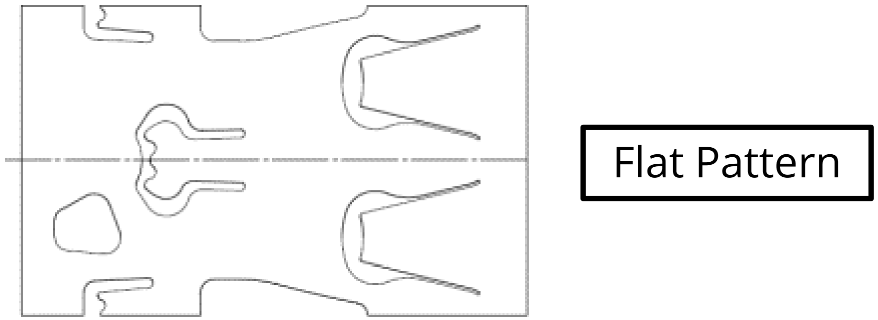
Hypotube Cutting Capability

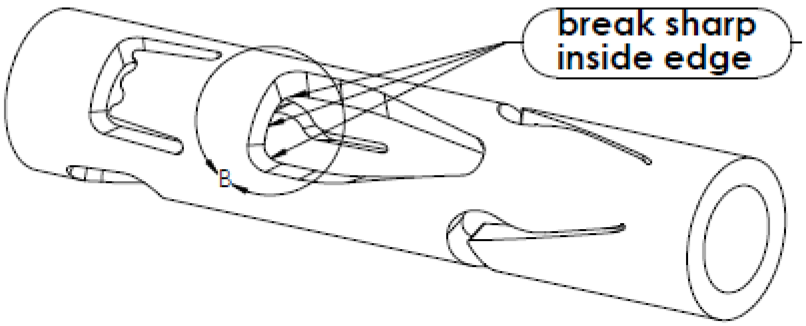
- Metal or polymer
- Tube Dimensions
  - Variable OD and ID as long as the wall thickness is ~.010" or less.
  - OD can range from .010" to .375"
- Part length is limited to the length of raw material
  - This is typically 10 ft. or less
- Material
  - Straight without kinks or bends to process
  - 2.50"- 4.00" longer than the part in order to cut an entire part

Programming Requirements

- Spiral cut patterns can generally be programmed from the drawing.
- Other geometry may require the customer to send a solid model or the flat pattern for programming.



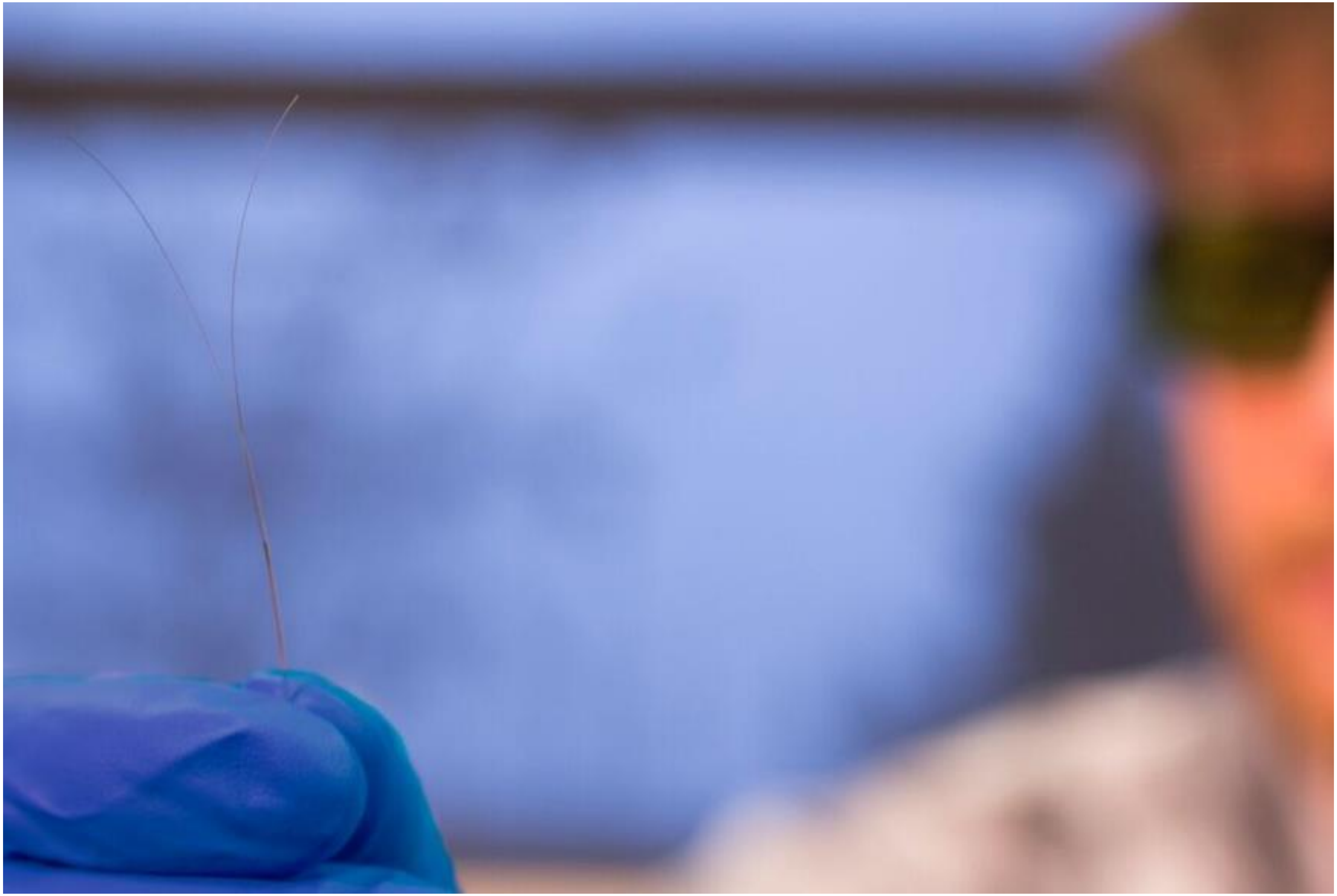




Post Processing

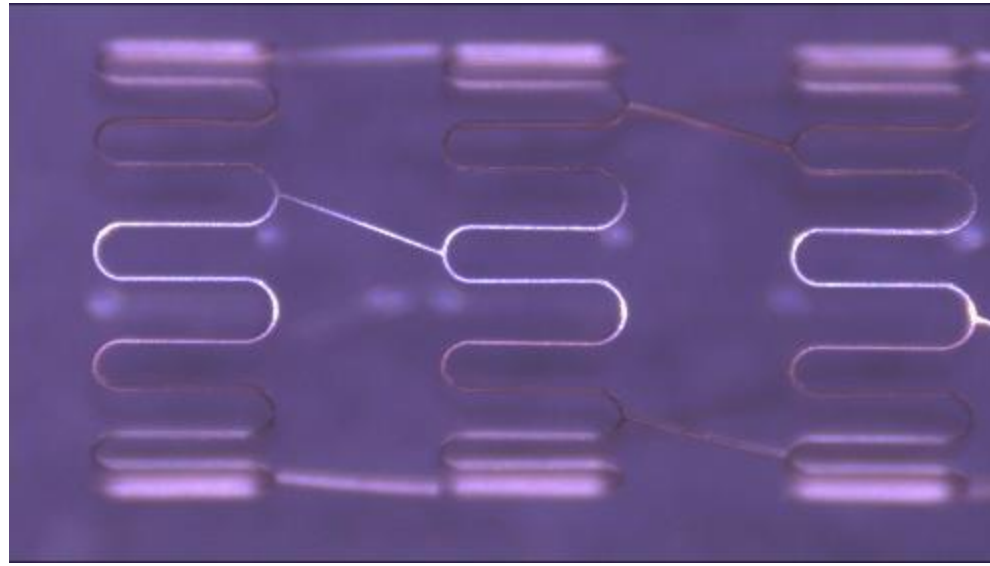
- Metal cut using long pulse (microsecond) lasers go through post processing to remove the oxide created near the cut surface.
- Parts can also be passivated to prevent oxidation (rusting) during storage. Passivation is the process of removing free iron from the surface of parts.
- Small ID parts (Less than .030” ID) require an additional flushing process to remove oxide and acids prior to drying.

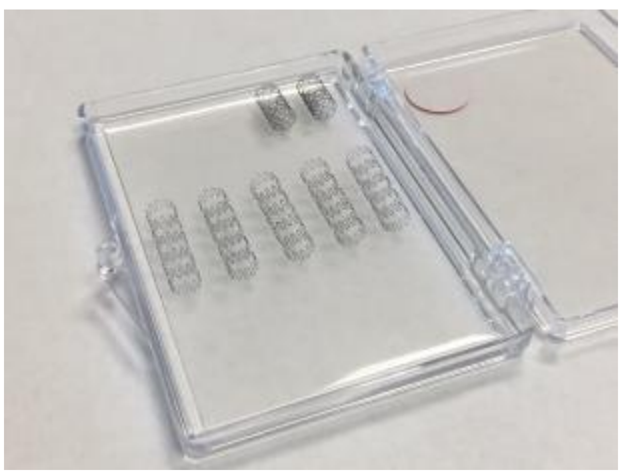
Laser Micro Cutting

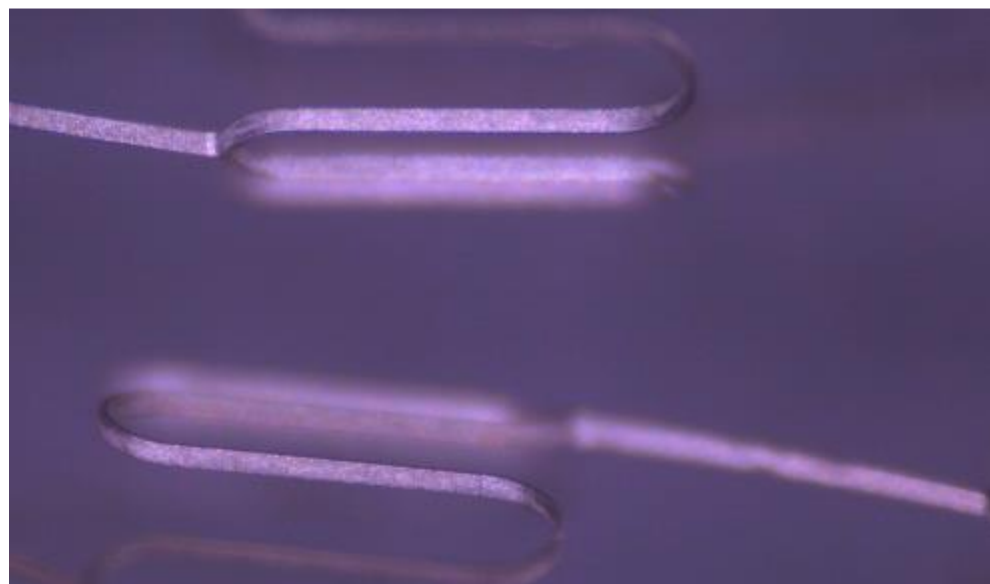


Nitinol Stent Cutting with 25 micron struts

- 25 micron strut with single micron standard deviation on geometry
- No thermal damage
- Custom laser system design





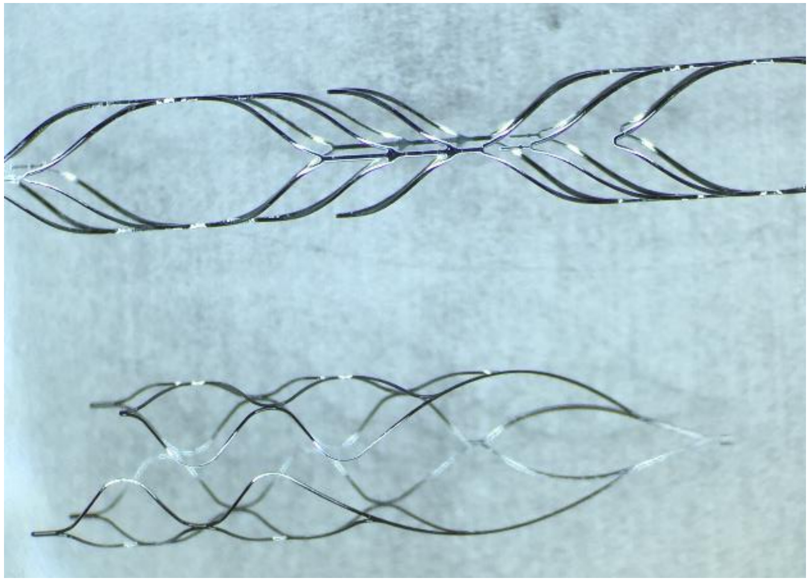


Nitinol – Heat Set and Electropolish

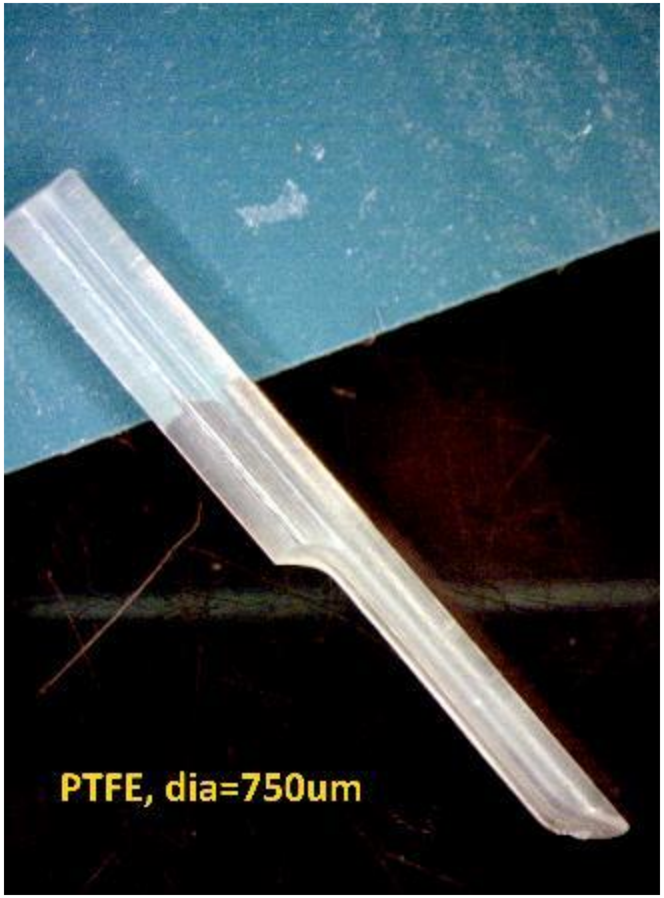
Current: Prototype

- Heat Set
  - Fluidized Sand Bath
- Part Cleaning
  - Oxide Removal
- Electropolish
  - Refrigerated Epolish

2017: Production



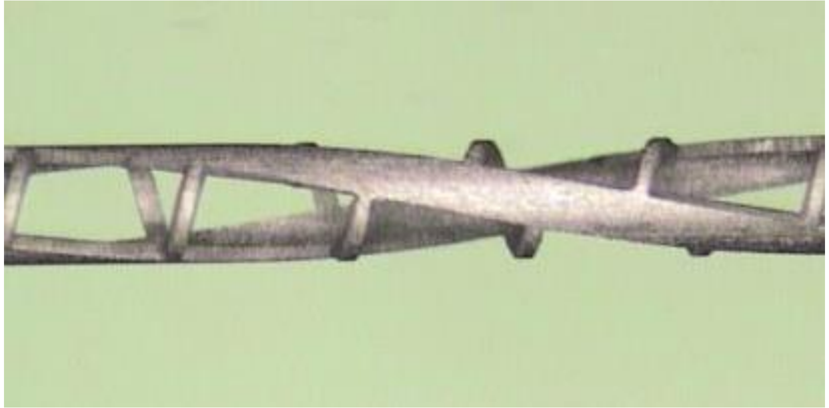
Polymer Cutting

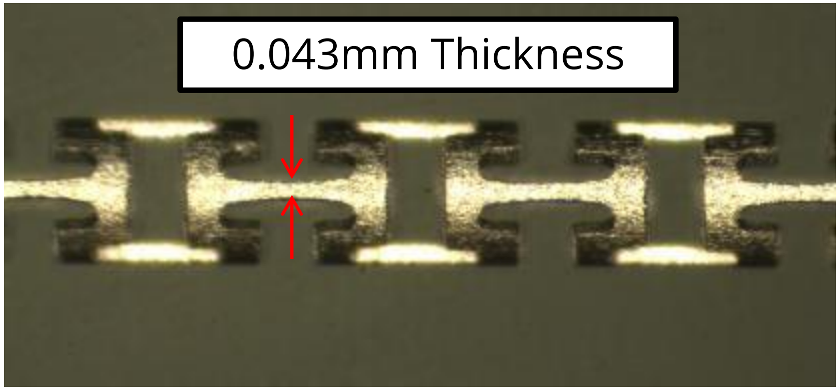


Nitinol Hypotube Cutting

– Hypotube (0.0135” OD)

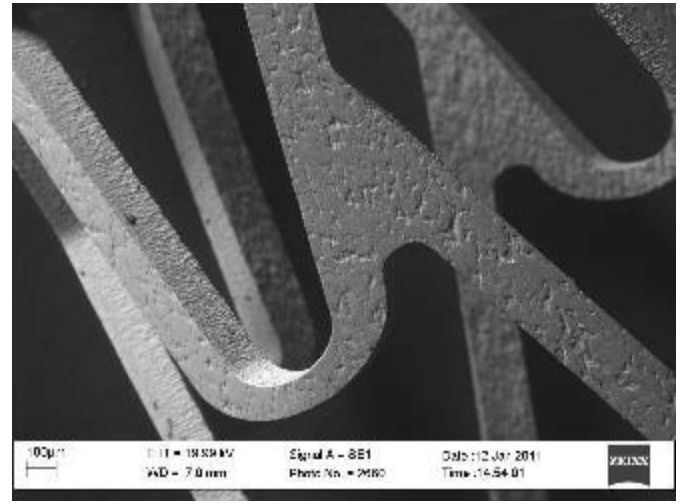
– Life science applications
  - Neurovascular stents
  - TAVR Frames & Baskets
  - Delivery catheter components
  - Micro implants

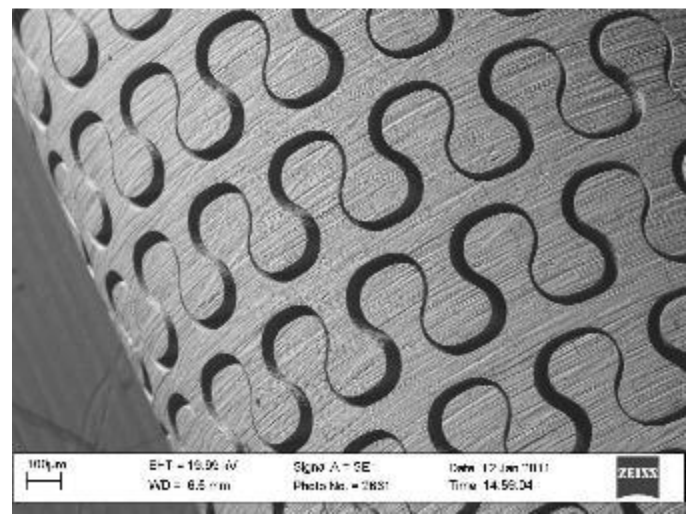




Stainless Steel Hypotube Cutting

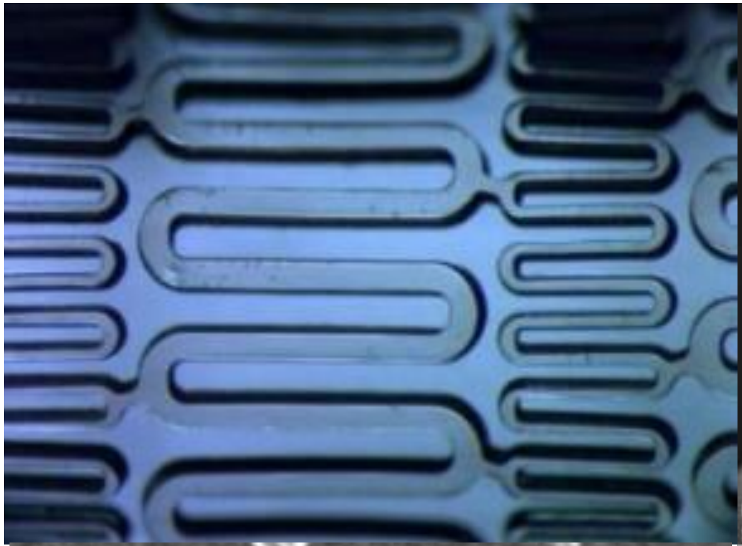
- Stent Structure
  - 0.040” OD
- Flexible Hypotube
  - Interlocking features
  - 0.040” OD
- Life Science Applications
  - Neurovascular delivery system components
  - Transcatheter delivery system components

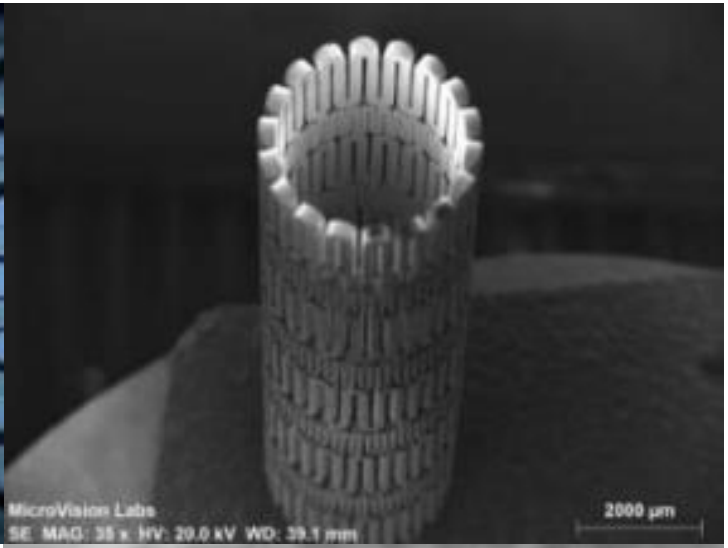


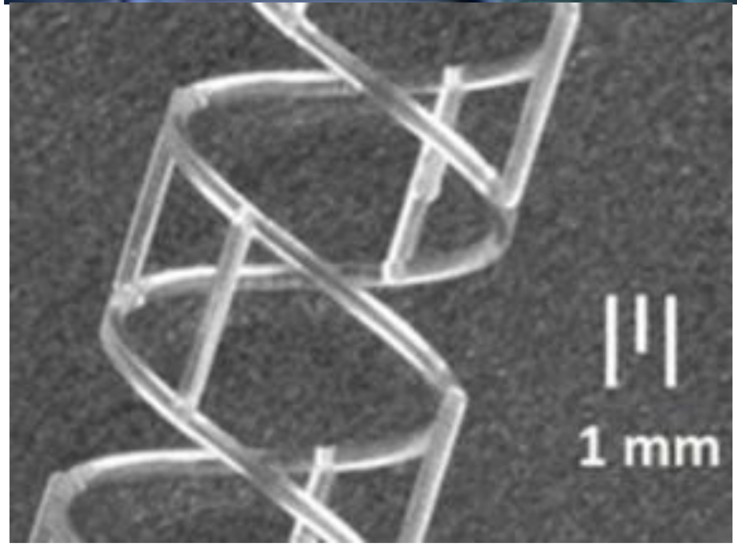


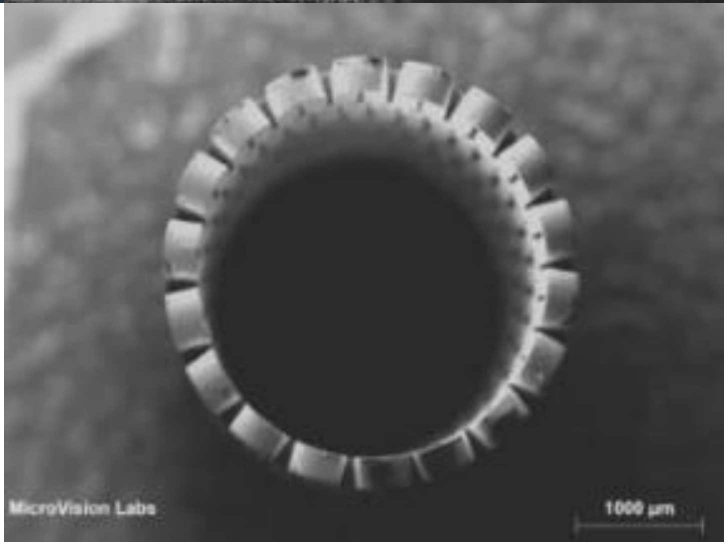
Applications – Stainless Steel Hypotube

Applications – Bioresorbable polymer

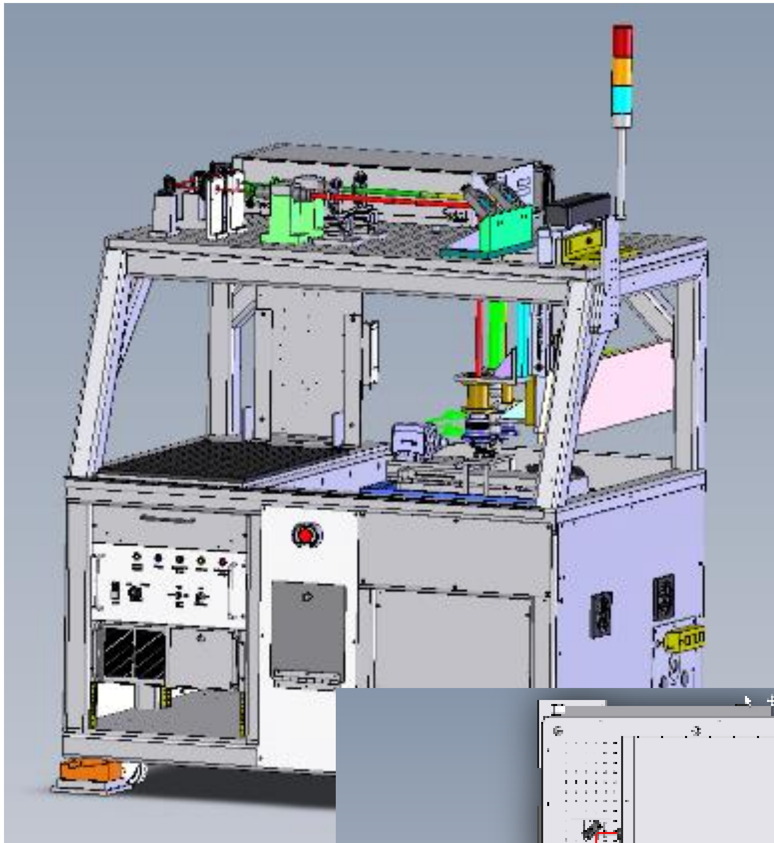


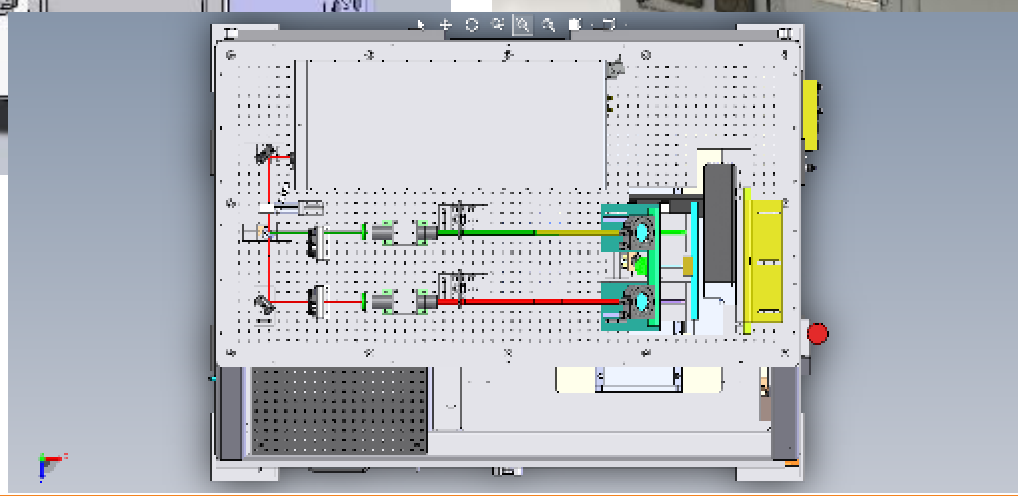




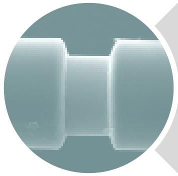


Cutting System – Dual Wavelength Femtosecond

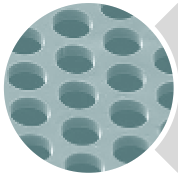




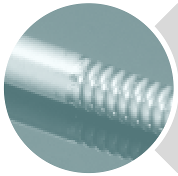
Technologies



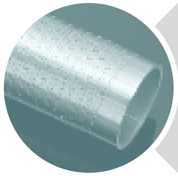
Ablating



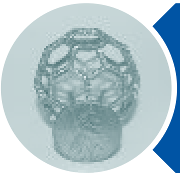
Drilling



Welding

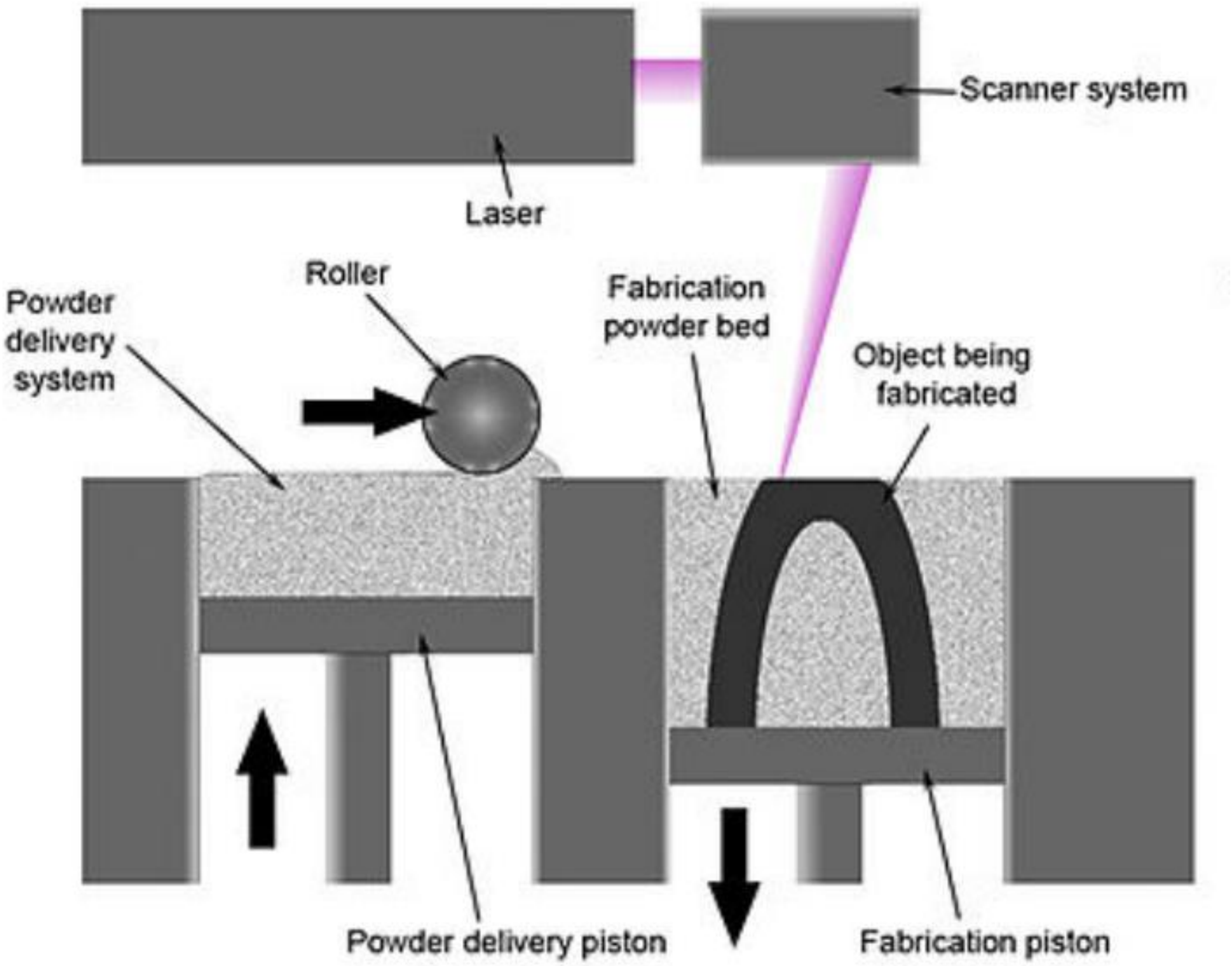


Cutting



Additive

Selective Laser Sintering



Metal Additive Manufacturing

- Myth versus Reality
  - Myth
    - CAD File
    - Print
  - Reality
    - CAD Design with process knowledge – material, supports, process limitations, overhangs etc.
    - Part Build
    - Heat Treat and/or Hot Isostatic Press
    - Remove from Build Platter
    - Remove Support Structures
    - Post Machine, Polish
    - Geometrical Inspection, CT Scan for Internal Features

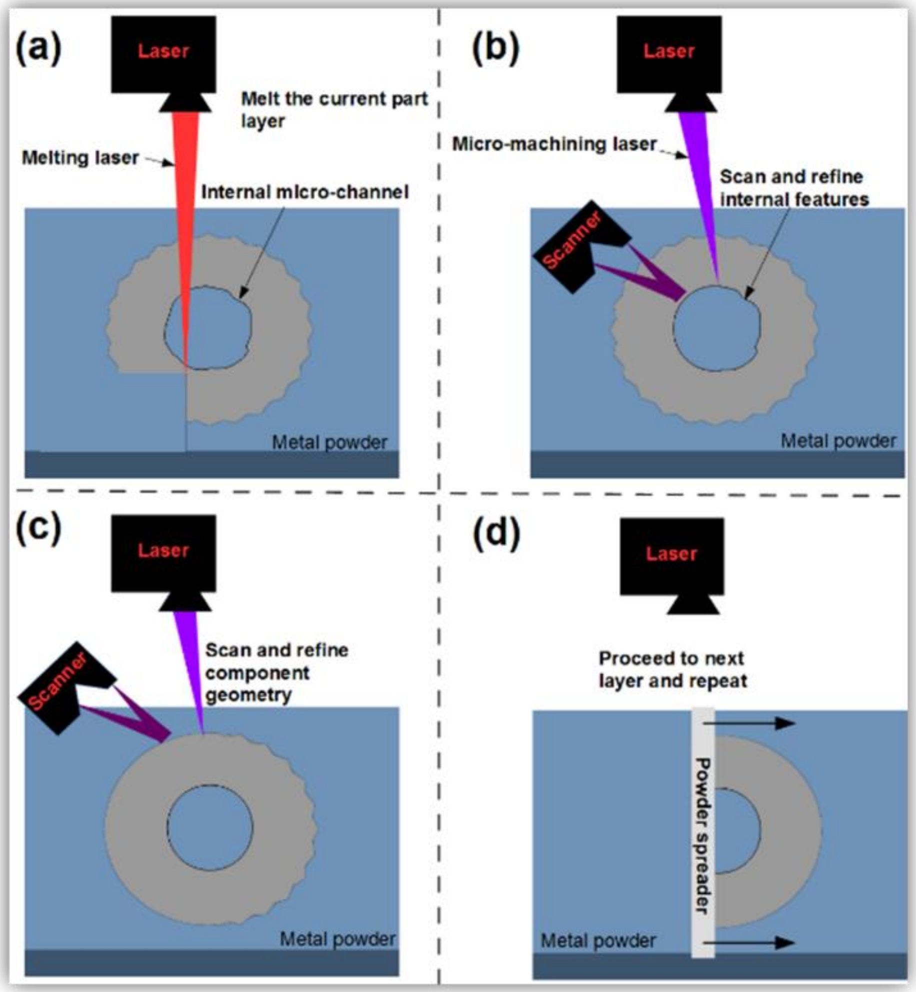
Image Courtesy of Morris Technologies

Metal Additive Manufacturing

- Cobalt Chrome
- Titanium
- Stainless Steel
- Nickel-Based Alloys
- Refractory Materials

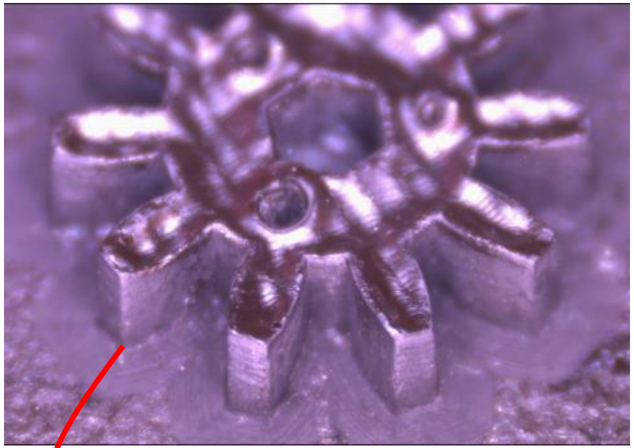
Additive + Subtractive

- **Problem:** Small features remain difficult for current AM technologies without post-machining processes
- **Solution:** A new additive/subtractive hybrid approach that combines powder bed additive manufacturing with laser micromachining processes; layer-by-layer

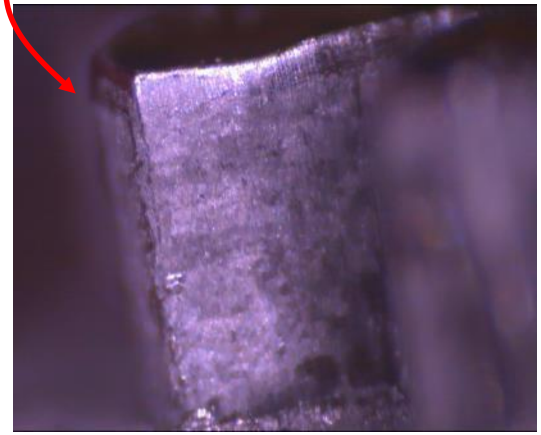


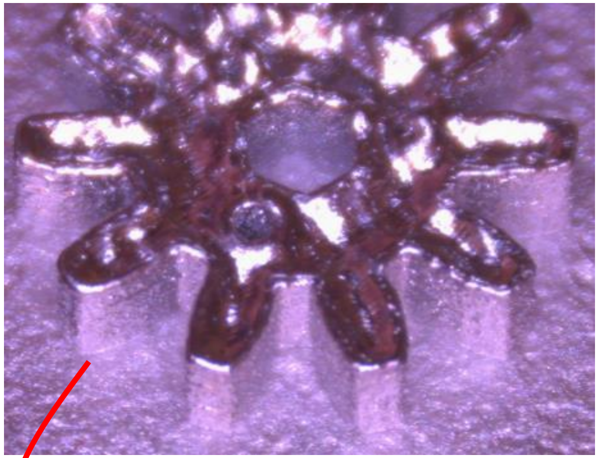
Patent Pending

Gear Example – Cobalt Chrome

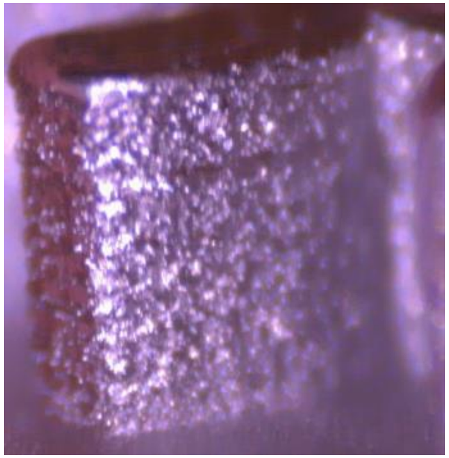


Additive + Subtractive



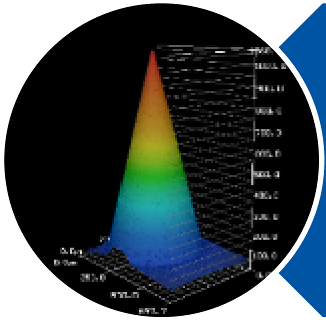


Additive Only



Patent Pending

Business Model



Advanced Technology Group

Next Generation Laser Micro Manufacturing Technology

Lightspeed ADL™

Application Development Lab

Quick Turn Prototypes

Contract Manufacturing

Volume Production

Custom Laser Systems