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?

- Cardiovascular
- Diabetes
- Drug Delivery
- In-vitro Diagnostics
- Neurovascular
- Ophthalmic
- Peripheral Vascular
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

WE HAVE FIVE LOCATIONS

Our world class laser micro manufacturing facilities include 24/7 operations, 5 cleanrooms, 3 Lightspeed ADL™ development centers, over 75 laser systems and more than 250 team members.

Contract Manufacturing
Lightspeed ADL
Systems Group
55,000 Sq. Ft.

Contract Manufacturing
Lightspeed ADL
20,000 Sq. Ft.

Contract Manufacturing
Lightspeed ADL
20,000 Sq. Ft.

Contract Manufacturing
Lightspeed ADL
9,000 Sq. Ft.

Contract Manufacturing
Lightspeed ADL
9,000 Sq. Ft.
Business Model

Advanced Technology Group
Next Generation Laser Micro Manufacturing Technology

Lightspeed ADL™
Quick Turn Prototypes

Contract Manufacturing
Volume Production
Custom Laser Systems
Technologies

- Ablating
- Drilling
- Welding
- Cutting
- Additive
Technologies

- Ablating
- 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
Braided Catheter
Wire Stripping – Assure End-Point Detection™

![Diagram showing wire stripping process and emission spectra progression](image)

**Emission Spectra Progression**

- Ideal 2-layer coating
- Real 2-layer coating
- Open-loop stripping
- EPD stripping

**United States Patent**

**Broude et al.**

**Patent No.:** US 8,772,671 B2

**Date of Patent:** Jul 8, 2014

**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)

**References Cited**

- 4,626,652 A 12/1986 Bjork et al.
- 5,011,626 A* 4/1991 Ma et al. 252/582
- 5,208,517 A* 4/1993 Cates et al. 219/121.62
- 5,284,798 A* 1/1994 Haum et al. 219/121.62

(Continued)

Resonetics. The leader in laser micro manufacturing for life sciences.
Reel-to-Reel Wire Stripping System

- Excimer laser
- Dimensional metrology
- EPD
- skive
- Reject marking

STRIPPING

- Laser or Mechanical Blade
- Reject mark detection
- Singulate
- Sort

CUTTING

- accept
- reject
Wire-Stripping – High Resolution

MicroVision Labs
MAG: 1500x  HV: 20kV  WD: 25.4mm

MicroVision Labs
MAG: 200 x

Resonetics. The leader in laser micro manufacturing for life sciences.
Wire Stripping – Examples
Electrode Exposure

- Parylene/Au/ceramic
- 25 um PI/Cu
- PI/Au/PI
- Parylene/Au/PCB
Zero-Kerf Glass Cutting
Application:
3D Ablation
Image Trepanning for Taper Control

United States Patent
Bernstein et al.

Method and apparatus for controlling the taper angle of the walls of laser machined features

Inventors: Jeffrey Bernstein, Pascal Miller, both of Nashua, NH (US); Hideyuki Morishita, Yorikashi, Japan

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

Patent No.: US 6,501,045 B1
Date of Patent: Dec. 31, 2002

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Tailored Profiles

COP, by mask motion

PEEK, by gray-scale mask

CrNi by UF direct write
Tube Lathe – Polyimide, Pebax
Tube Lathe – Polyimide
Metals: Platinum, Nitinol, Stainless Steel

Platinum Iridium

Stainless Steel

0.040”

Resonetics. The leader in laser micro manufacturing for life sciences.
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
  - \( \Phi C = 0.2mm \)
  - \( \Phi D = 0.343mm \)
  - \( \Phi E = 0.254mm \)
  - \( \Phi F = 0.06mm \)
  - Tip Taper = 20°
On a Dime for Scale
Application:
Surface Texture
Surface Texturing – Micron to Nano Scale

Titanium

Silicon Carbide
(Balloon) Surface Texturing

![Surface Texturing Image]

MicroVision Labs 43-9mj,30HZ,50
MAG: 6000 x HV: 10.0 kV WD: 21.0 mm

MicroVision Labs 36mj,50HZ,50
MAG: 6000 x HV: 10.0 kV WD: 21.5 mm
Technologies

- Ablating
- Drilling (highlighted)
- Welding
- Cutting
- Additive
Mask Projection Hole Drilling: Filters

Holes
100 um

10 mm

United States Patent
Broude et al.

(12) United States Patent
(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)

FOREIGN PATENT DOCUMENTS

EP 0 575 850 A2 12/1993
JP 2001096389 4/2001

OTHER PUBLICATIONS

Resonetics. The leader in laser micro manufacturing for life sciences.
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

- Entrance = 12um
- Exit = 5um
- Exit dia = 5 um
- Exit dia = 7 um
Small Holes: 1 um dia holes in 25 um PI
Holes in Glass

0.5 mm thick
Single, Multi Lumen Tube – Drilling, Skiving

dia = 1.7mm, wall = 0.2mm
Femtosecond Drilling Workstation

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 (322) 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 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 $1 \times 10^{-9}$ 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

Part-specific Process Validation

1. Software Qualification PRO-136
2. Equipment Qualification PRO-137
3. Operator Qualification PRO-134
4. Laser Welders Qualified
5. Process Validation Plan
6. Operation Qualification Record OQR F-214
7. Performance Qualification Record POR F-214
8. Part Process Validated
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

0.003” OD Nitinol Wire
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

Presented with Permission of Silicon Microstructures Inc.
Technologies

- Ablating
- 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

PLLA

0.043mm Thickness

Nitinol
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

PEEK dia=2.5mm, wall=150um

PTFE, dia=750um
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
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

Resonetics. The leader in laser micro manufacturing for life sciences.
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