Precision Electroforming in High-Strength NiColoy®
Electroforming - an electroplating technology where a thick metal layer is deposited onto a mandrel, or original to be replicated, and is then separated from it. The part thus obtained is called an electroform.

- Molds for Optics (Gratings, Screens, Couplers, Fresnel lenses, Diffusors) and CD stampers
- Net-Shape 3-D Electroforms: bellows, air scoops, membranes, etc.
- Microfluidic and Biotechnology molds
- Medical Catheter Tip-Forming Dies
- Mold inserts for injection and compression molding of plastics
- Build-up and repair of worn machine parts, molds, dies, etc.
- Waveguides for the communications, aerospace and electronics industries
Common Mandrel Types

What can be replicated?

- Mechanically produced (diamond-turned or polished) or electroformed **metal mandrels**: copper, nickel and its alloys, brass, electroless nickel, aluminum, stainless steel
- **Photoresist** or **epoxy** on glass patterns - holograms, micro arrays, diffraction gratings, screens, 3D structures, etc.
- **Plastic** originals - SLA models, molded or machined originals
- **Silicon or Glass** mandrels - lenses, gratings, etc.
- **Cast** mandrels - metallic (Cerro alloy) of non-metallic (Wax)

**Note**: nonconductive mandrels must be metalized prior to electroforming
Precision Electroforming

Process requirements

- True reproduction of surface textures and finishes (specular brightness or diffusivity, freedom from such blemishes as haziness, stains, pits, etc.)
- Overall dimensional accuracy within several μm, angular fidelity within fractions of a minute, flatness, parallelism, radius of curvature reproduction within 1-2 wave lengths for precision optics
- Electroforms must be hard and wear resistant to assure long service life of molds, corrosion resistant to withstand molding fumes and environmental effects during extended storage periods as well as chemical environment during replication
Electroforming Principles

What is taking place in the solution

Nickel and Cobalt ions are attracted by the negatively charged mandrel, travel to its surface and, gaining two electrons turn into atoms of nickel and cobalt, forming a metallic layer on the mandrel’s surface. The electroformed layer faithfully replicates the microgeometry of the surface.
Deposit Internal Stress

Electroformer’s Enemy #1

Deposit stressed in **Tension** (expanded spring) is “trying” to contract relative to the substrate.

**Compressively** stressed deposit (contracted spring) is “trying” to expand relative to the substrate.

**STRESS** (Noun): The act, condition, or effect of exerting force on someone or something

*(Roget's Electronic Thesaurus)*
Real-life Electroforming

Stress-induced electroform distortions upon mandrel separation

Compressive stress - electroform expands, angles become more obtuse

Tensile stress - electroform contracts, angles become more acute

Zero stress - electroform is undistorted with true angles

Mandrel
Mitigating Internal Stress and Non-uniform Current Distribution

Overcoming Obstacles

- **Shielding** to suppress high edge current density
- Chemistry modification to improve *throwing power* and promote uniform current distribution
- Screening and stress profiling of chemistries and selection of one with a shallow stress vs. current density relationship
- Real-time stress monitoring and control
- Plating **cell geometry** design minimizing non-uniform current distribution
Traditionally, Nickel and Copper have been the most widely electroformed metals.

Although not as strong as steel, Nickel was used for applications requiring strength and wear resistance.

NiColoy®, NiCoForm’s proprietary Nickel-Cobalt alloy, is twice as hard and has a 50% higher tensile strength than electroformed Nickel, greater modulus of elasticity and matches stainless steels in mechanical properties and corrosion resistance.
NiCoForm’s Nicoloy® in Comparison to Other Metals

<table>
<thead>
<tr>
<th>Material</th>
<th>Mod Elast, 10^3 MPa</th>
<th>UTS, MPa</th>
<th>Hardness, Rc x10</th>
<th>Therm. Cond., W/m*K</th>
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</thead>
<tbody>
<tr>
<td>Nickel</td>
<td>1000</td>
<td>800</td>
<td>100</td>
<td>400</td>
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<tr>
<td>Steel</td>
<td>800</td>
<td>600</td>
<td>200</td>
<td>300</td>
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<tr>
<td>Cobalt</td>
<td>600</td>
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<td>100</td>
<td>200</td>
</tr>
<tr>
<td>Iron</td>
<td>400</td>
<td>300</td>
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<td>100</td>
</tr>
<tr>
<td>Copper</td>
<td>200</td>
<td>100</td>
<td>10</td>
<td>5</td>
</tr>
</tbody>
</table>

Niccoloy®
Nickel
Steel
Cobalt
Iron
Copper
Electroform Characteristics

Processing of NiColoy® Electroforms

- **Thickness** - .001" - 0.250" +
- **Hardness** - 40-55 Hr_c
- **Ultimate Tensile Strength** - 150,000 psi min.
- **Machineability**: can be ground, milled, EDM machined, drilled, tapped, etc.
- **Attaching** to mating elements: NiColoy® can be soldered, electrojoined, epoxied, bonded with various adhesives
- **Dimensions** - from fractions of an inch to 20" x 30"
Examples of Electroforms

Molds for Optics and Microfluidic Embossers

Electroformed Submicron Moth-Eye Surface Texture
Courtesy: Optical Switch, Inc. and NiCoForm, Inc.

Mold Insert for a Single Use Camera Lens Source: NiCoForm, Inc.

Electroformed microfluidic 50 micron grid pattern replicated from a Si wafer
Source: NiCoForm, Inc.
Electroformed Optics

Fresnel lenses, molded with electroformed tooling.

Electroformed Aspheric Mirror

Molded Fresnel Lenses
Source: Fresnel Optics, Rochester, NY

Electroformed High Curvature Mirror
Source: NiCoForm, Inc., Rochester, NY
Electroformed Bellows

NiColoy® Bellows and Bellows Assemblies

Electroformed bellows electrojoined to stainless steel hubs

Electroformed NiColoy® Bellows
Net Shape 3-D Electroforms

Aircraft engine air ducts

Split Mandrel and two Electroforms

Source: NiCoForm, Inc.
A fully assembled wax mandrel ready for electroforming (left) and finished part after mandrel removal (right)
Electroforming with NiColoy®

NiCoForm’s Approach to Electroforming

- **Real time stress monitoring** - ability to accurately control conditions in the tank preventing electroform distortions
- **Low-stress NiColoy®** electroforming chemistry with a flat section on the stress vs. current density curve
- **Automatic alloy composition control**
- **Tank design for solution purity and high circulation rate**
Advantages of Electroforming

How You can Benefit from this Technology

- Multiple replicas from a single mandrel drastically reduce manufacturing costs
- Rapid turnaround - .010-.030"/day average electroforming rate
- Exact replication of fine surface finishes/textures and intricate geometries, excellent dimensional stability
- Mounting and alignment elements can be incorporated in the electroform
- Desired material properties - hardness, UTS, Young’s modulus, wear resistance, thermal conductivity, corrosion resistance are assured
- Thin wall (down to 10 μm) He leak tight components (bellows, membranes) can be consistently electroformed
NiCoForm’s Electroforming Capabilities

- Near zero-stress high-strength Nicoloy® electroforms produced from customer-supplied mandrels or per customer drawings
- In house precision CNC machining capabilities
- Electroform size - up to 20" x 30"
- Full attention to your needs
- Rapid turnarounds
Taking the Stress out of Electroforming