MAX LEVY AUTOGRAPH

PRECISION ELECTROFORMED PRODUCTS

120 YEARS OF PRECISION MANUFACTURING

BULLETIN 2100

ELECTROFORMING is the manufacture of Products and Replication Tooling by the deposition of metals. Electroformed products include Clear Optical Path Apertures and Slits, Fine Mesh Screens and Masks. These parts require extremely close tolerances that are beyond those achievable using photochemical machining.

ELECTROFORMING is an additive process. Metal is electrodeposited on a Mandrel. This Mandrel may contain three dimensional structures for the manufacture of complex, Three Dimensional Parts or Replication Tooling. After the electrodeposition process is completed, the electroform is separated from the Mandrel.

ELECTROFORMS have exceptional structural strength and rigidity. The three dimensional nature of Electroforming allows small, close tolerance apertures and similar features to be incorporated with more robust structures to achieve exceptional structural strength and rigidity.

ELECTROFORMING is cost effective for the manufacture of Parts and Replication Tooling with close tolerances and complex features. Electroforming is usually less expensive for multiple parts when compared to EDM and laser drilling.

ELECTROFORMED METAL PARTS: Examples of Metal Parts that are replicated through Electroforming as Flat or complex Three Dimensional Structures include:

- Metrology Standards for Surface Roughness.
- Metrology Step Wedge Standards for Surface Height Measurement.
- Clear Optical Path Apertures, Targets and Masks.
- Encoder Disks and Scales.
- Antenna Arrays and Wave Guides.
- Focusing and Light Pipe Arrays.
- Three Dimensional Tension Masks and Screens.
- Mesh Products and Foils.
- Light and X-Ray Diffusers and Masks.
- Ink Jet, Electrographic and Liquid Diffusion Precision Hole Arrays.
- Micro-Miniature Valves, Orifice Plates, Sprockets and Gears.
- Precision Sensor Diaphragms, Vanes, Tuning Forks and Accelerometer Elements.

LENTICULAR LENS MASTER & REPLICATED NICKEL ELECTROFORM

The Concave Lenticular Lens Master, shown at the top of the photo, has been Contour Machined with Single Point Diamonds, Nickel Plated, Passivated, and used to manufacture a Nickel Convex Lenticular “Father” Electroform. This “Father” in turn, is used as a Master to Electroform Concave Lenticular Hard Nickel Replication Dies. These Dies are then used to mass-produce the Convex Lenticular Lens Array in Plastic.

This process is diagramed on page 4 of this brochure and in BULLETIN 2050. The entire process of Diamond Contour Machining, Electroforming and Replication, provides the engineer with the ability to design, prototype and economically mass produce complex, large format micro structures.

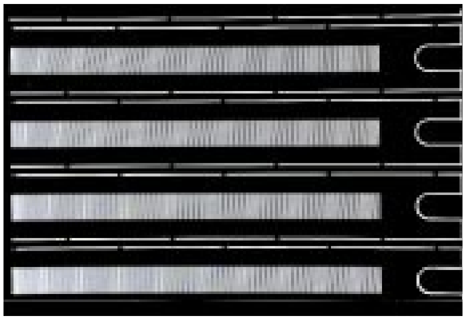
REPLICATED PLASTIC PARTS: Examples of Plastic Parts that can be manufactured from Electroformed Replication Tooling mounted in Injection Molding Machines or Vacuum Presses include:

- Plastic Lenticular, Rear Projection, Fresnel and other Lens Arrays.
- Compact Disks, (CD’s) and Replicated Holograms.
- Binary replicated Optics, Focusing Arrays, Spherical and Parabolic Mirror Blanks, Plastic Cuvettes and similar fine featured optical parts.
- Plastic Crystal, Costume Jewelry, Artistic Relief’s, Coins, Plastic Miniatures, Toy and other complex plastic parts.

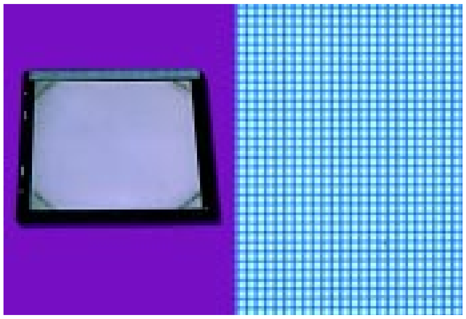
TYPICAL MAX LEVY AUTOGRAPH HIGH PRECISION ELECTROFORMED PARTS

The three set of tools in the Photo to the right illustrate the many ways in which **ELECTROFORMS**, replicated from Diamond Machined original tooling, can be used to produce a variety of **3 DIMENSIONAL PARTS**. The first set of items is the Diamond machined 3 dimensional master, Replication Electroform and replicated Plastic Parts. The second set of items is the Replication Electroform, set in a fixture, and used to produce Silastic Rubber Molds. The third set is the Replication Electroform in combination with the Silastic Rubber Mold. This is used to produce very thin, three dimensional precision film structures.

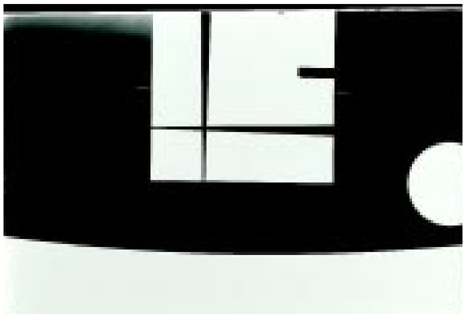
This photo illustrates one of the assemblies for the **HUBBLE SPACE TELESCOPE STIS OPTICS**. A series of the assemblies were required to enable the slit to function as designed.



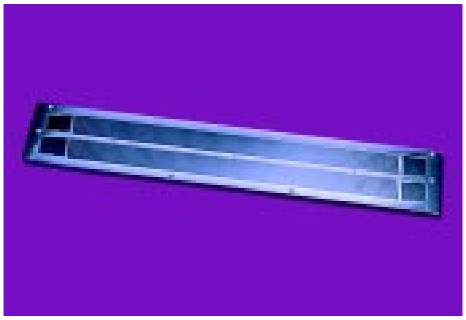
This photo magnifies a small section of a 15 up, 10" long **ELECTROFORMED ENCODER ARRAY**. The clear optical path encoder frequency is 500 lpi (.001" lines and .001" spaces).



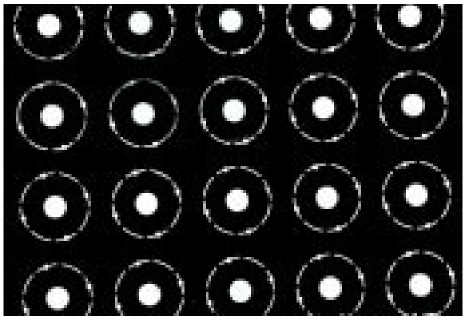
This photo is of a 6" x 6" 500 Lines per Inch 70% clear **TRANSMISSIVE MESH**. The required active area is 5" X 5". The section on the right is a blow up photo of the actual mesh.



This photo is a magnification of one section of the **HUBBLE SLIT WHEEL SEGMENT** pictured above. The section displays the required precision required to form the thin tapered sections to the required ±1 micron tolerance. Another important requirement was that the tapered slivers had to be flat within 5 microns over the 1" opening.



This photo is of a **4 LEVEL PRECISION ELECTROFORMED PART**. The first layer is 15 microns thick with 3048, 31 micron diameter holes. The second layer reinforces the first layer. The third layer adds the cross ribs and bezel. The forth layer takes the mounting bezel to a total part thickness of 175 microns.



This photo is an enlarged section of a 8" x 10" **APERTURE ARRAY**. This replication technique allows the economic production of large quantities of small precision apertures.

TYPICAL MLA HIGH PRECISION MULTI-LAYER ELECTROFORMING PROCESS

The photo above is of two Electrographic Discharge Screens. The Screens are manufactured in Nickel using the Three Layer Electroforming Process described below. The Screen at the top is turned over to show the Multi-Layer Electroformed Structure. The Screen at the bottom is a view that shows the First Electroformed Layer and the surface that is in contact with the Metalized Mandrel during manufacture. The 7" long Screen has 2048 very small diameter apertures for charge ejection. These apertures are manufactured to a positional and diameter tolerance of 1 micron by this Electroforming Process. The total part thickness is 178 microns /.007".

MULTILAYER ELECTROFORMING PROCESS STEPS

A Chrome on Glass Mandrel is Patterned with the features necessary to produce the Correct Aperture Size. This delineation process requires that the Phototool be dimensionally compensated to achieve, in the part, the correct Aperture size after the First Electroformed Layer has been grown to it's design thickness. The delineation process is explained in detail on page 4 of **BULLETIN 1100**.

The First Nickel Electroformed Layer is grown directly on this Chrome on Glass Mandrel. In the illustrated Discharge Screen this thickness is 13 microns.

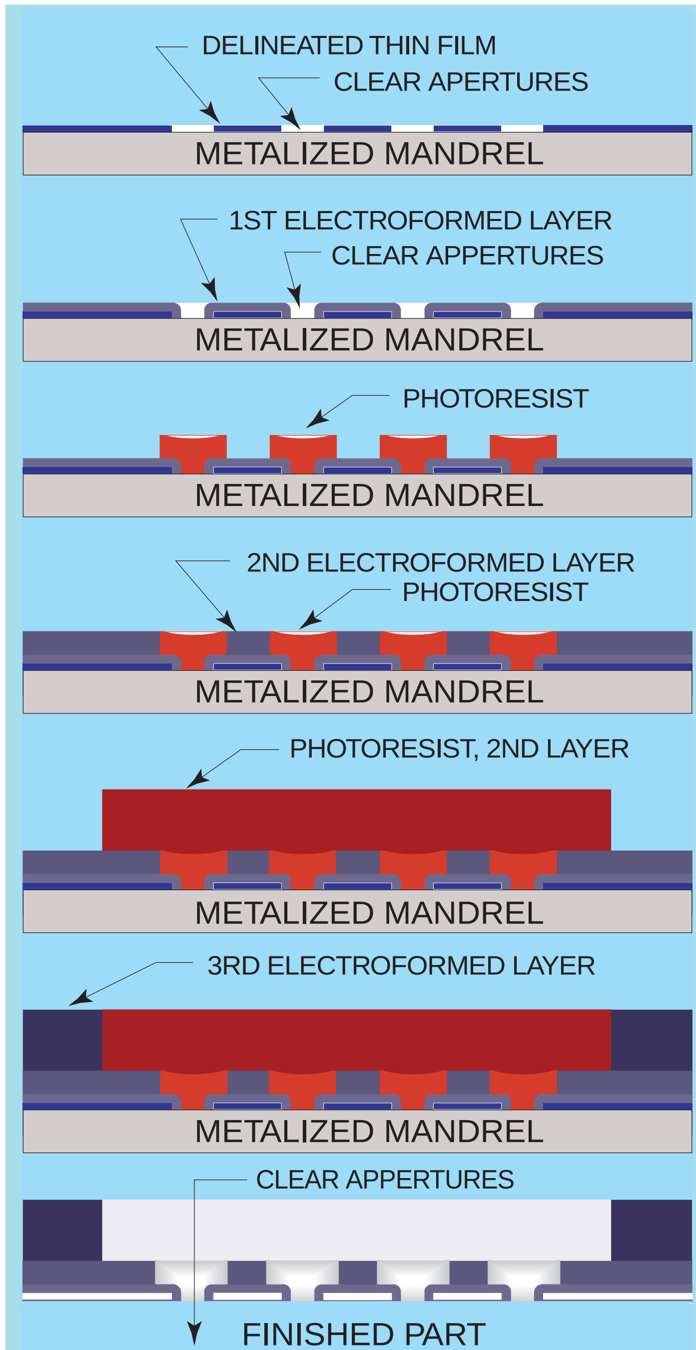
A Thick Film Photoresist is then applied over the First Electroformed Layer and Patterned. The thickness and type of Photoresist is selected to provide both conformation and adhesion to the entire surface; and, sufficient thickness to contain the entire height of the Second Electroformed Layer.

The Mandrel is returned to the plating bath and the Second Electroformed Layer grown to the 65 micron design thickness for the Discharge Screen. The total part thickness is now 78 microns.

A Second Thick Film Photoresist Layer is applied over the part and delineated with the required pattern for the Third Electroformed Layer. This Photoresist Layer must exhibit excellent conformation and adhesion to both the First Layer Photoresist and the Second Electroformed Layer. In the case of the illustrated Discharge Screen this Second Thick Film Photoresist layer is at least 100 microns thick.

The Mandrel is returned to the plating bath and the Third Electroformed Bezel Layer is grown to our required 100 micron design thickness. The total part thickness is now the required 178 microns /.007".

The part is removed from the Mandrel and the two layers of Photoresist stripped from the part. In this illustration, the critical Aperture Size and Location Tolerances are achieved by utilizing the more precise Thin Film Techniques. The more gross features necessary to achieve the required Three Dimensional Part Stiffness and Structural Integrity are achieved by utilizing the less precise Thick Film Photoresist Processes.

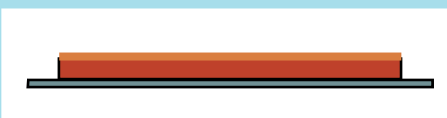


PRECISION THREE DIMENSIONAL SHAPED MANDREL FABRICATION, ELECTROFORM MANUFACTURING AND MASS-REPLICATION OF METAL AND PLASTIC PARTS

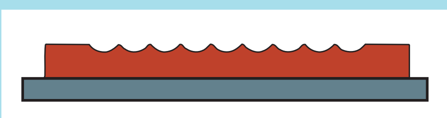
Precision Shaped Mandrels for Electroforming are generally fabricated in stainless steel using conventional machine tools. We also manufacture Shaped Mandrels by etching fine features into Glass Substrates. These Etched Glass Substrates are made into Three Dimensional Electroforming Mandrels by selectively metalizing the etched features to create conductive three dimensional surfaces for Electroforming. We also have **Patented Processes** where these etched features are filled with Thick Film Cermet and fired to form conductive paths. This allows the Electroforming of parts such as High Aspect Ratio Fine Mesh Screens using Permanent Mandrels. Where Optical Quality Surfaces or Small, High Aspect Ratio Features are required we also manufacture Shaped Mandrels on our **MLA 4000 AND 5400 SERIES DIAMOND MACHINING SYSTEMS.** These machines are described in detail in **BULLETIN 2050.**

A brief outline of the **DIAMOND MACHINING MASTERING PROCESS** is as follows:

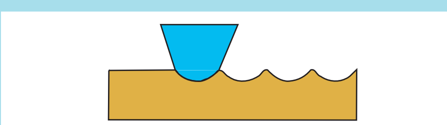
Machined Surface Substrate Copper, Aluminum or Composite Plastic



Planarize Top Surface with Flat Diamond to Establish Mirror Finish Reference Surface



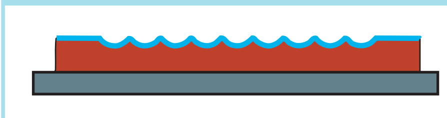
Cut Lens or Feature using Contoured Single Crystal Diamond



Enlargement of Surface with Machined Cuts

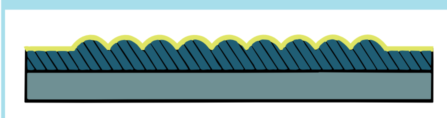
The **MLA 4000** and **MLA 5400 SERIES ULTRA PRECISION MACHINING AND CONTOURING SYSTEMS** as described in **BULLETIN 2050** have machining footprints of **39.37" X 40.00" (1.0 X 1.02 METERS)** and **54.00" X 60.00" (1.37 X 1.52 METERS)** respectively. **MANDRELS** for **ELECTROFORMING,** with optical quality surfaces**,** can be produced to these sizes with this proprietary equipment.

A brief outline of the **REPLICATION ELECTROFORM MANUFACTURING PROCESS** is as follows:

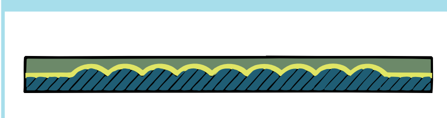


Electroless Nickel Flash & Passivate Diamond Machined Lens Surface

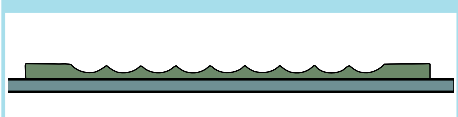
Grow Nickel Electroform Master (Father)



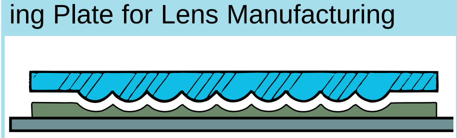
Remove Father Electroform & Mount to Backing Plate & Passivate Lens Surface



Grow Nickel Daughter Electroform



Mount Daughter Electroform to Backing Plate for Lens Manufacturing



Configure for Vacuum Forming or Injection Molding

The above **SEM** is a fractured section of a Vacuum Formed Acrylic Lenticular Lens Array. The **ORIGINAL SHAPED MANDREL** was produced on the **MLA 4000** (As described in the first column to the left.) The **REPLICATION ELECTROFORM MANUFACTURING PROCESS** for **MASS-PRODUCTION** of the Fine Pitch, (170 Microns) High Aspect Ratio Lenticular Lens Array is described in the center column to the left.

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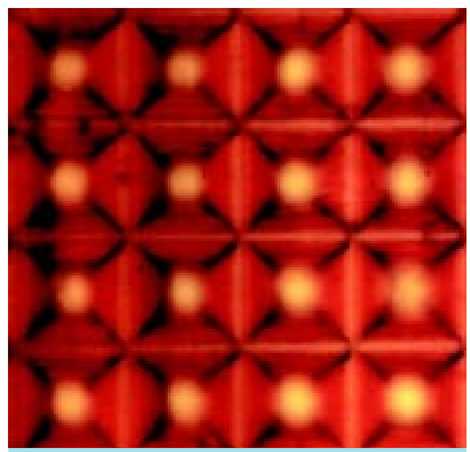
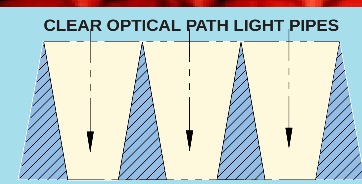




The above photo and magnified sectional view are of a **128 X 128 ELEMENT LIGHT PIPE ARRAY.** The **ARRAY PITCH** is **177 MICRONS** with **9.9 DEGREE SIDE WALLS.** The **COPPER MANDREL** that we required in order to produce the **ELECTROFORMED GOLD ARRAY** was manufactured on the **MLA 4000** These **ARRAYS** provide clear optical path collimators for emitter and detector arrays for long wavelength IR devices. They replace less optically efficient and more costly lens arrays.

GENERAL DESIGN GUIDELINES FOR ELECTROFORMED PARTS AND TOOLING

The design requirements of the final part or tooling determine the method of electroform fabrication and the size, geometry and tolerance constraints. With both chrome on glass and Diamond Contour Machined tooling the critical part dimensions can be generally held to tolerances in the micron range.

With chrome on glass tooling electroforming masters as large as 60" X 60" are possible. With Diamond Contour Machining masters as large as 39.37" X 40" can be produced on the MLA 4000 System. (See Bulletin 2050).

Typical Guidelines for the Clear Optical Path first layer apertures or features on an 8" X 8" chrome on glass electroform fabrication master and the cost implications are as follows:

CLEAR OPTICAL PATH FEATURE SIZE	HIGH PRECISION	MOST COST EFFECTIVE PRODUCTION
1.0 MICRON	±50% OR ± .5 MICRON	AVOID IF POSSIBLE
2.5 MICRONS	±40% OR ±1.0 MICRON	AVOID IF POSSIBLE
5.0 MICRONS	±20% OR ±1.0 MICRON	AVOID IF POSSIBLE
10.0 MICRONS	±10% OR ±1.0 MICRON	±30% OR ±3.0 MICRONS
25.0 MICRONS	±4% OR ±1.0 MICRON	±20% OR ±5.0 MICRONS
50.0 MICRONS	±3% OR ±1.5 MICRONS	±10% OR ±5.0 MICRONS
ABOVE 50.0 MICRONS	±2.0 MICRONS	±5.0 MICRONS

The most practical minimum first layer thickness for most electroformed chrome on glass fabricated structures is 2.5 microns (.0001").

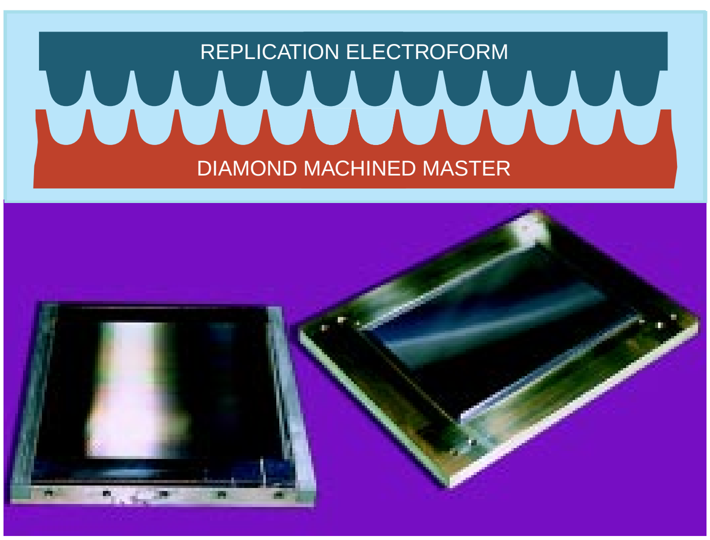
The generally accepted first layer thickness to clear aperture size is 1/1; however, we have developed special fabrication techniques that allow small features to have an aspect ratio of 3/1. This means that fine slit widths can be fabricated on close center to center spacing and still have sufficient structural strength to hold together and not distort.

The edge definition of the first layer of a precision electroformed part fabricated on chrome on glass tooling is as good as the chrome master. This edge definition is generally as good or better than the best high resolution commercial B&B line film.

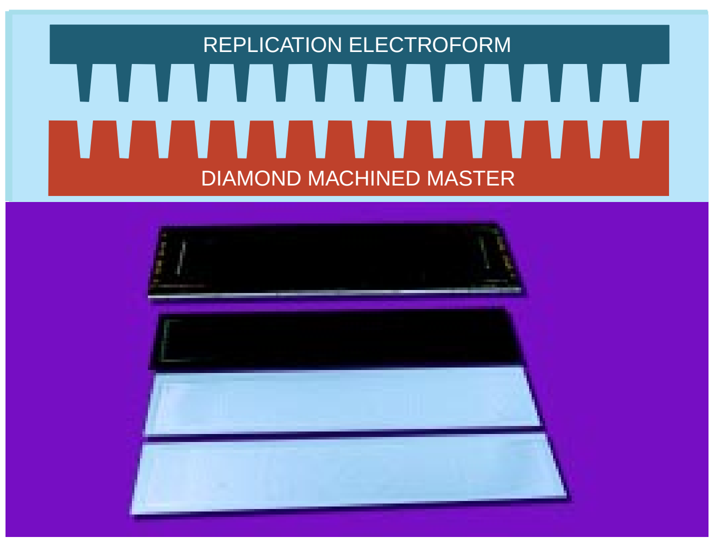
The second, third, and forth layers of an Electroform fabricated from chrome on glass tooling has the same line and feature tolerances, (±2.5-±7.6 microns or ±.0001"-±.0003") typically associated with thick film photoresists. Overall point to point tolerances are dependent on the tooling master fabrication method; and can be as good as ±1.0 micron. (See Bulletin 1100)

The feature tolerances and overall accuracy of Electroforms fabricated from Diamond Contour Machined Masters are as good as the Diamond Contour Machined Master. (See Bulletin 2050)

The High Volume Production costs of Electroformed Parts is generally less than Laser Machined Parts and offers better edge acuity and tolerances. Electroforming can also be competitive with Metal Etched Parts. In particular, where close tolerances are required, electroforming is generally the most cost effective and repetitive method.



The above photo and profile drawing are of a 7" high X 9" wide DIAMOND MACHINED MASTER and REPLICATION ELECTROFORM. The replication electroform is mounted on a die plate for the injection molding of parts. The electroform is recessed into the die plate and bonded with a high temperature thermosetting film using specially designed MLA high temperature vacuum lamination equipment. This bonding process withstands the repeated temperature shock and pressures associated with injection molding. The profile of the part is 150 micron (.0059') radius grooves, 340 microns (.0134") deep with a 420 micron (.0165") pitch.



The above photo and profile drawing are of an 8" wide X 24" long DIAMOND MACHINED MASTER, REPLICATION ELECTROFORM AND REPLICATED PLASTIC FORMS. These FORMS are used as tooling fixtures for display manufacturing. The profile of the REPLICATED PLASTIC FORM is identical to the DIAMOND MACHINED MASTER. The actual profile is 114.3 microns (.0045") at the base of the groove with a 5 degree wall and a 508 micron (.020") depth. The pitch is 529.17 microns (.02083"). Large Electroforms with similar profiles with a 165 micron (.0065") pitch have also been produced by us using these processes.

MAX LEVY AUTOGRAPH, INC. PROVIDES PRECISION ELECTROFORMED SPLIT WHEEL SEGMENTS FOR THE HUBBLE SPACE TELESCOPE IMAGING SPECTROGRAPH

MAX LEVY AUTOGRAPH was selected by **BALL AEROSPACE** to manufacture the critical **SLIT WHEEL SEGMENTS** for the new **HUBBLE TELESCOPE SPACE TELESCOPE IMAGING SPECTROGRAPH (STIS).**

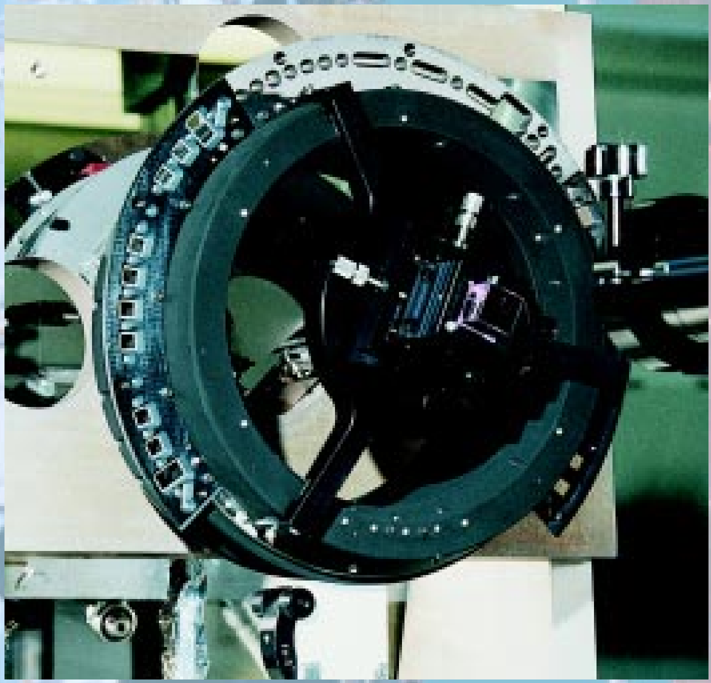
The **SLIT WHEEL** is shown mounted in the picture to the right and the overall **SYSTEM SCHEMATIC** of the **SPACE TELESCOPE IMAGING SPECTROGRAPH** is shown below.

The OPTICS AND DETECTORS on **STIS** have 30 times the spectral bandwidth and 2.4 times the resolution of previous **HUBBLE SPACE TELESCOPE SPECTROGRAPHS.**

The precision required for the **SLIT WHEEL** required that we manufacture **Multilayer Electroforms** to **±1 micron feature size tolerances**; and, **Vacuum Laminate** these **Electroforms** to **Stainless Steel Wheel Segments** to an overall tolerance of better than **± 25 microns.**

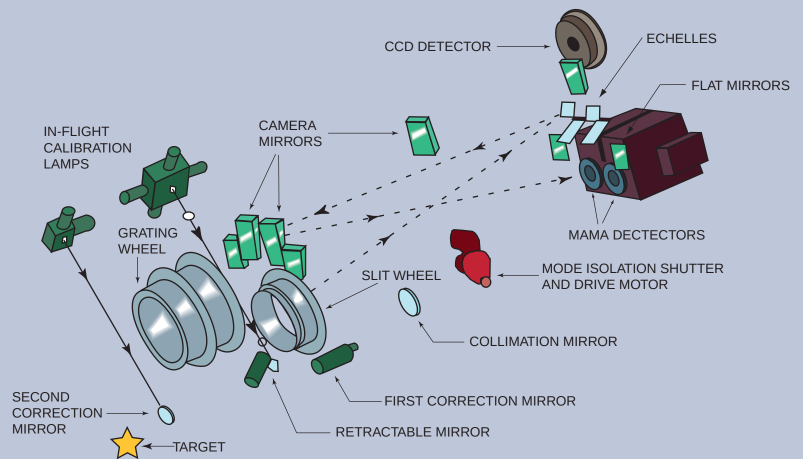
This **Precision Electroforming Capability** has enabled us to meet the needs of aerospace, military, industrial and commercial clients throughout the world.

The Images streaming back to earth from the **STIS** has allowed scientists to gain an accelerated look into the formation of the Universe. This new Imaging Capability is providing Space Scientists and Astronomers Images for analysis well into the 21st Century.



To view current web sites and images taken by the recently installed **STIS** use your Internet Search Engine and search "**NASA STIS**".

HUBBLE SPACE TELESCOPE IMAGING SPECTROGRAPH OPERATIONAL DIAGRAM



DESIGN DEVELOPMENT is supported from Design Concept to Production of deliverable Products.
MAX LEVY AUTOGRAPH Engineering Specialists are available to help you design for cost effective performance.

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