REPORT DOCUMENTATION PAGE

AFRL-SR-AR-TR-03-

0354

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPO... DATES COVERED
	16 SEP 03	FINAL REPORT 15 APR 01 TO 14 APR 03

4. TITLE AND SUBTITLE
MICRO-FABRICATION OF SPRAY COOLING NOZZLES FOR HIGH-POWER DIODE LASER ARRAYS

5. FUNDING NUMBERS
F49620-01-1-0350
3484/US
61103D

6. AUTHOR(S)
DR LOUIS C. CHOW

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
UNIVERSITY OF CENTRAL FLORIDA
DEPT. OF MECHANICAL, MATERIALS & AEROSPACE ENGINEERING
ORLANDO, FL 32816-2450

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AFOSR/NL
4015 WILSON BLVD. SUITE 713
ARLINGTON, VA 22203-1954

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT
APPROVE FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
An important growing field in today's engineering is the development of Micro-Electrical and Mechanical Systems (MEMS). Over the years there have been many different fabrication processes that have been developed to meet these new demonds. Most of the current micro-fabrication techniques work well for simple two-dimensionalk components. However, the demand for more complicated three0dimensional parts requiring a high aspect ration requires that a new approach must be taken to make these ideas a reality. A novel fabrication method was developed in the late 1980's called stereolithography. This process involved using a low power laser to introduce free radicals in a polymer in which the molecules would cross-link and become solid. Using this ideal the stereolithography process was developed by 3D Systems to fabricate three-dimensional parts in a layer-by-layer manner.

20031006 084

14. SUBJECT TERMS	15. NUMBER OF PAGES
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLAS	UNCLAS	UNCLAS	

Final Property/Performance Report

FY 2001 University Research Instrumentation Program (DURIP)

Grantee: University of Central Florida
4000 Central Florida Blvd
Orlando, FL 32816-0150

Grant Period: April 15, 01 through April 14, 2003

Grant No.: **F49620-01-1-0350**

Grant Purpose: The grant was issued for the purpose of upgrading Grantee's research capability by acquiring several critical pieces of equipment to support research in **"Micro-Fabrication of Spray Cooling Nozzles for High-Power Diode Laser Arrays".**

Principal Investigator: Dr. Louis C. Chow,
Department of Mechanical, Materials and Aerospace Engineering
University of Central Florida
Orlando, FL 32816-2450

Program Officer: Dr. Charles Lee AFOSR/NL
Air Force Office of Scientific Research
801 N Randolph Street, Room 732
Arlington, VA 22203

Administrative Grants Officer:
Office of Naval Research Regional Office Atlanta
Suite 4R15
100 Alabama Street NW
Atlanta, GA 30303-3104

Date: August 28, 2003

Description of Activities

An important growing field in today's engineering is the development of Micro-Electrical and Mechanical Systems (MEMS). Over the years there have been many different fabrication processes that have been developed to meet these new demands. Most of the current micro-fabrication techniques work well for simple two-dimensional components. However, the demand for more complicated three-dimensional parts requiring a high aspect ration requires that a new approach must be taken to make these ideas a reality.

A novel fabrication method was developed in the late 1980's called stereolithography. This process involved using a low power laser to introduce free radicals in a polymer in which the molecules would cross-link and become solid. Using this idea the stereolithography process was developed by 3D Systems to fabricate three-dimensional parts in a layer-by-layer manner.

There are two major characterizations of the stereolithography process, vector irradiation and layer irradiation. In the vector irradiation method a highly accurate mirror is used to control the laser beam. The mirror rotates and reflects the laser to different points on the resin. The process traces the outside and inside contours of the part and then fills in the rest using a cross hatching pattern. Vector irradiation method is much different then the layer irradiation method. The Layer irradiation method expands the laser beam or uses a UV light source to cover the entire build area. A mask is used to create the pattern for the current layer. This method is not used as often because creating a mask for every layer is time consuming.

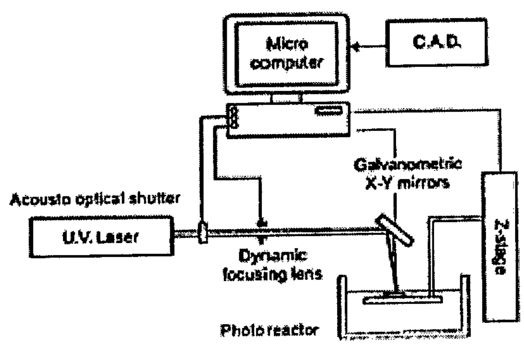

Figure 1 Traditional Stereolithography using the vector irradiation method

There is ongoing research throughout the world to apply this technology to smaller high accuracy parts. The current fabrication techniques do not allow for complicated geometry in small parts. However this geometry can be created using a process known as microstereolithography. Microstereolithography (msl) uses the same concepts as mentioned above but also adds the challenge of keeping a very high accuracy. Currently the highest precision commercially available stereolithography machine has an accuracy of around 50 microns. This is not acceptable for high accuracy applications. Using an msl technique accuracies of 10 to 15 microns can be created. This is due to recent developments in the computer display industry.

The computer industry is always trying to make things smaller and more powerful and they haven't forgotten about the displays. Due to the development of near eye monitors very small LCD screens have been developed for heads up personal displays. It turns out that these screens can be very useful in the micro fabrication of parts. Small LCD screens can be used as a dynamic mask for the layer irradiation technique mentioned above. Due to their small pixel size high accuracy masks can be created on the screen. Some pixel sizes are as small as 12 microns. Below is a picture of the basics of a microstereolithography machine using an LCD screen also called a spatial light modulator or SLM.

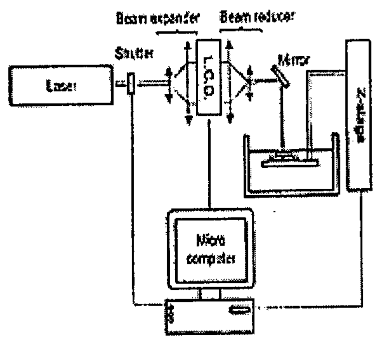

***Figure 2** Microstereolithography using a SLM screen*

The first step to developing our microstereolithography system was to determine the requirements of the machine. Why build a new design? What type of parts do we want to make? How large do we need the build area to be? What resolution do we require for our application? These are the types of questions that needed to be answered before the design was started.

There are many parts that we would like our msl machine to build, however there is one part that it must build, spray nozzles. These nozzles are roughly 2.5 cm in diameter however only the atomizer needs to be built with a higher accuracy. The atomizer is roughly 12 mm in diameter and needs to be fabricated with a resolution of around 50 □m in order to function properly. Traditional stereolithography cannot meet these build requirements. Also, all of the other msl machines that were developed at other institutions cannot fabricate anything that is this large. Therefore, a new system needed to be developed to build this part.

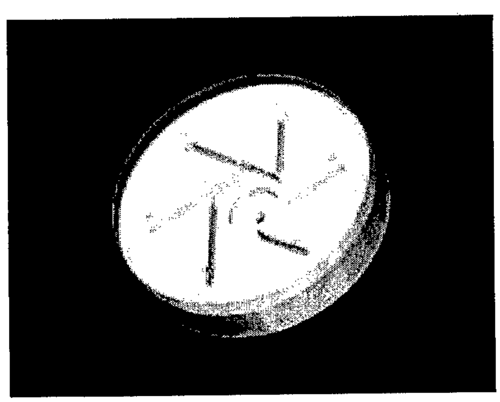

***Figure 3** Spray Nozzle*

After an extensive literature search about microstereolithography machines that were being developed at other institutions a similar design was constructed. Our initial design was composed of four main systems. (Figure 9)

1) A high power laser and optics used to illuminate the active layer mask.
2) A reflective liquid crystal display (LCD) or digital micro-mirror device (DMD) used as an active mask.
3) A series of translation stages used to move the part around in the vat of polymer.
4) A computer based control system that automates the build process.

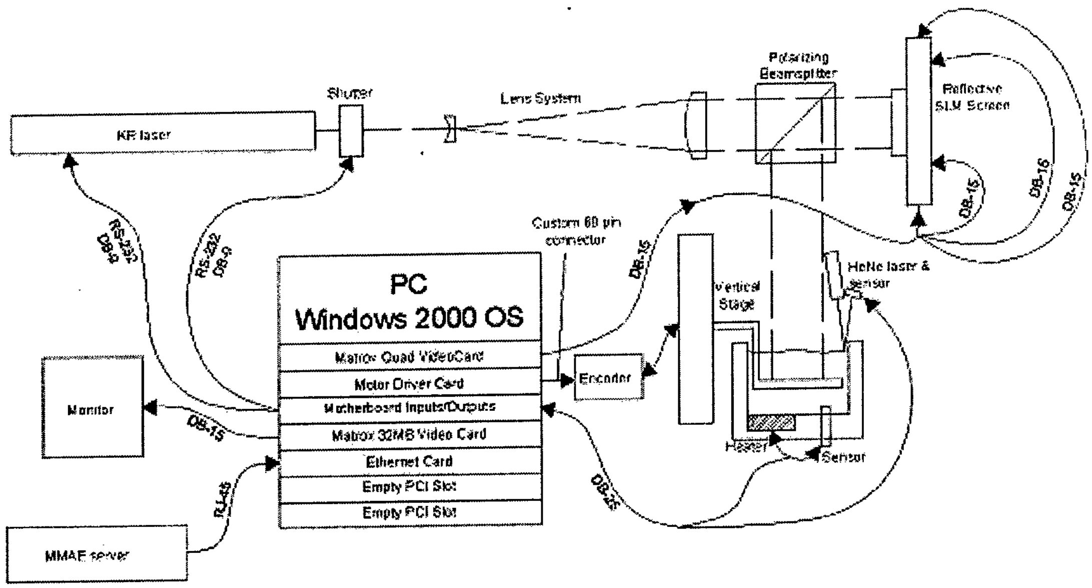

Figure 4 Microstereolithography setup

A Spectra Physics diode pumped solid-state laser is the first major component in the msl process. This laser has 3.5 watts of power and operates at a wavelength of 355 nm. We chose to use this wavelength due to the availability of commercial resins that will cure in this wavelength range. We also chose to use a solid state laser over the alternative, krypton gas lasers, because it can operate from a standard outlet and does not require a large heat exchanger and water cooling system. The optical components for the entire system will be made from fused silica to prevent damage from the short UV wavelength. The beam will be polarized and expanded through two lenses in order to illuminate the active layer mask.

The layer-by-layer technique, which will be used in our microstereolithography machine, uses an active layer mask that will be either a reflective liquid crystal display (LCD) or a digital micro mirror device (DMD) from Texas Instruments. See Table 2 for a simple comparison between these two options. The screen will show the pattern for the entire layer which will allow an entire layer to be created in one shot and will reduce the residual stresses within the layer itself as well as save laser time. This approach is not done on any commercially available rapid prototyping machines.

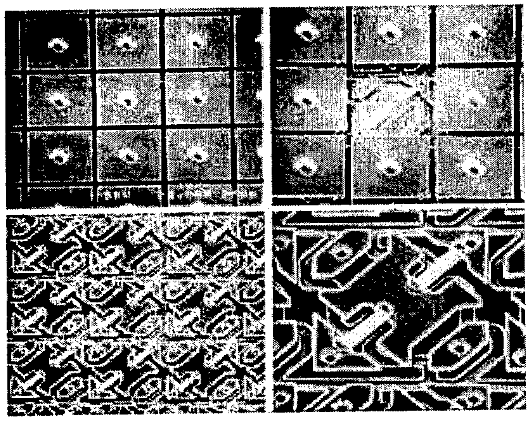

Figure 5 SEM Photograph of a DMD

	Three Five Systems **MD 1280 LCD**	Texas Instruments **DMD**
Resolution	1280 X 1024	1280 X 1024
Imaged Dimensions	15.36 mm X 12.29mm	20.48 mm X 16.38mm
Pixel Pitch	12 um	16 um
Pixel Gap Width	.6 um	1 um
Fill Factor	> 92 %	>90 %
Operating Temperature	-1°C to 70°C	up to 65°C

Table 1: *DMD and LCD specifications*

The reflective LCD screen is chosen over a transmissive screen due to the fill ratio. With a transmissive screen a part of each pixel is blocked by the electrodes that activate the pixel. With the reflective screen this electrode is attached to the back of the pixel and reflects the light when the pixel is off. These LCD screens can be made with a 1280 by 1024 array of 13μm pitch pixels. This is better than the micro mirror alternative. The DMD has a pixel pitch of 16 μm. A problem arises with the wavelength of the laser used to illuminate the mask. Wavelengths in the UV range (<400 nm) may cause damage to the screen. The major problem with using a LCD is that the crystals are damaged by the UV wavelength. Therefore it was decided that a DMD was the best route for our machine. The DMD was purchased in a development kit form from Productivity Systems, Inc. We were able to obtain a new DMD that works well with the UV light and can be implanted into our optical system easily.

One major drawback of the DMD method is that a complicated light engine needed to be developed to illuminate the DMD and project the image to a plane. This optical system is being developed and built by Brilliant Technologies.

Our msl machine at UCF is different than any other due to a series of high-resolution translation stages. These Newport stages have resolutions of 1 μm. Every rapid prototyping method has a vertical or Z stage to move down to the next layer. We have decided to add X and Y stages to create horizontal motion for the same layer. We plan to use the active layer mask as a stamp to create parts that will be much larger than the screen itself. With this approach the cross section can be split into four pieces and make the part four times larger than any other microstereolithography machine. This will allow us to build larger parts but still maintain the surface accuracy of one pixel of the screen (12 μm). The computer based control system will also take measures to make this stamping process as effective as possible.

These high accuracies require a control system that is efficient and accurate. We will be using a computer with LabVIEW to run the processes of the machine. This program will make the build process automated which is necessary due to the length of time it will take to build one part, up to 48 hours, depending on the polymer used. The computer program will control the stages, active layer mask, laser, and external shutter. The control program is an integral component in order to get high-resolution parts.

The initial msl design shown in figure 4 was modified slightly to solve an important problem, creating a thin 10μm layer of polymer. In traditional machines a blade is used to sweep the viscous polymer off the part between each layer. Due to the very small layer thickness this is not an option for our microstereolithography machine. In order to combat large wait times for the polymer to flow off the part from gravity an inverted design was created.

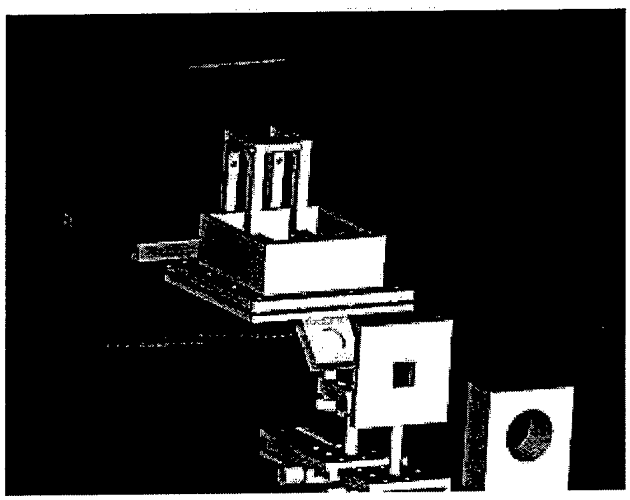

Figure 6 *Inverted Build Design*

Inverted builds have both advantages and disadvantages. The advantages are that costly hardware or long wait times to ensure the build layer thickness is to the accuracy we desire is eliminated. In many stereolithography devices involving critical accuracies the technique used to solve the surface tension and viscous bulging of the polymer surface over the platform is solved via high accuracy surface sweeping blades or rollers. Another advantage is that when dealing with object builds at our tolerances an inverted approach will reduce or eliminate any concerns over dust or environmental contaminants affecting the build. One disadvantage is that even though there is low surface energy present at the vat bottom window via a non-stick coating this surface energy is not completely eliminated. Surface energies could be a factor when building certain part geometries that have fine protruding/extruding structures that do not have support structure support those points. However some of these issues will be able to be reduced or eliminated through software via support structures and part orientation.

The inverted build technique brings up other issues that needed to be resolved. One of the main issues that have surfaced with the inverted technique is that the polymer will adhere to the surface of the vat bottom window (fused silica) when polymerized. This has been the deciding factor in whether or not to pursue the inverted technique. The question has been; can we find a coating that will stick to the fused silica and not to the polymer? We investigated coatings available and found a new form of Teflon that appears to be the perfect candidate for our application. Teflon AF is a relatively new anti-stick coating that is transparent to light above 200nm and will adhere to the surface of optical materials while providing a low surface energy that is consistent with our needs.

Over the next few months the msl prototype will be completed. The optical system will be delivered in approximately four weeks and coding for the DMD has already begun. We are almost at our final goal of having a complete automated microstereolithography machine.

Publications:

The assembly of the microstereolithography system has resulted in or will lead to the following publications.

C. Walsh, L. An, J.S. Kapat and L.C. Chow, "Feasibility of a High-Temperature Polymer-Derived Ceramic Turbine Fabricated Through Micro-Stereolithography," Proceedings of IGTI, ASME Turbo Expo, Amsterdam, June 2002.

B. Carman, J.S. Kapat, L.C. Chow and L. An, "Impact of a Ceramic Microchannel Heat Exchanger on a Micro Turbine," Proceedings of IGTI, ASME Turbo Expo, Amsterdam, June 2002.

T.Y. Chung, M. Bass, L.C. Chow, J.H. Du, Y.R. Lin and D.P. Rini, "A Novel Approach to High Power Diode Laser Arrays," Fifteen Annual Solid State and Diode Laser Technology Review, Albuquerque, NM, June 3-6, 2002.

L.C. Chow, J.H. Du, Y.R. Lin, A. Marcos, J. Recio, M. Bass, T.Y. Chung and D.P. Rini, "Spray Cooling of Diode Laser Arrays with Water at Low Pressure," Fifteen Annual Solid State and Diode Laser Technology Review, Albuquerque, NM, June 3-6, 2002.

Y.R. Lin, T.Y. Chung, J.H. Du, L.C. Chow, M. Bass and D.P. Rini, "Thermal Design in Diode Array Packaging," presented at SAE Power Systems Conference, Coral Springs, FL, October 29-31, 2002.

D.P. Rini, L.C. Chow and M. Bass, "Lightweight Cooling Systems for Solid State Lasers," Sixteenth Annual Solid State and Diode Laser Technology Review, Albuquerque, NM, May 19-22, 2003.

L. Bharadwaj, A. Dhamne, L. An, B. Fookes, J. Kapat and L.C. Chow, "Polymer-Derived SiAlCNO Ceramics for High Temperature Applications," Proceedings of IGTI, ASME Turbo Expo, Atlanta, GA, June 2003.

Papers in progress:

Fabrication of High Aspect Ratio Micro-Parts Using a Microstereolithography Process with Commercial Polymers

Microstereolithography Control Software Developed in the G Programming Language

Novel Inverted Microstereolithography Utilizing Digital Light Processor with Pulsed UV Laser Light Source

3D CAD Image Slicing to Stacked 2D Bitmaps Utilizing the Visualization Tool Kit and G Programming Language

Curing Properties of Pre-ceramics Polymers Using UV Light

Electrical Properties and Microstructure of Polymer Derived Ceramics

Random Shrinkage of Polymer Derived Ceramics and Its Implication on High Temperature MEMS Applications

Equipment Requested in the Proposal

Description	Vendor		Cost
Innova 300 FreD system (Ar^+ laser and accessories)	Coherent Laser Group		$87,398
3-axis translation stages with sub-micron positioning accuracy	Newport Corporation		$44,145
Pluto 652X488 back illuminated, high frame rate CCD camera*	Pixel Vision, Inc.		$30,482
300mm focal length monochromator/spectrograph and gratings	Roper Scientific		$9,968
SZX-ZB12 stereo microscope	Olympus		$12,000
Miscellaneous items and optical components	Different vendors		$10,000
		Total	$193,993

Equipment Purchased

Description	Vendor		Cost
Motorized translation stages and driver	Newport Corporation		$24,954
Manual translation stages	Newport Corporation		$1,760
355 nm solid state laser	Spectra Physics		$82,900
Lens, holder, and polarizing beam splitter mount	Melles Griot		$1,360
Action spectra Pro-306, monochromator/spectrograph	Roper Scientific		$8,820
Temperature circulating bath	Koehler Instrument, Inc.		$2,391
High resolution HR2000 spectrometer	Ocean Optics, Inc.		$3,177
Olympus BX41TF microscope	C. Squared Corporation		$10,628
U-V micro mirror display*	Productivity System		$12,885
Image projection light engine*	Brilliant Technologies		$26,000
Miscellaneous items and optical components			$22,948
		Sub-total	$197,823
Cost Share by UCF			**($51,640)**
AFOSR Portion		Total	**$146,183**

* Since the grant was approved, we determined it is much better to have the active layer mask based on the digital micro mirror device instead of the reflective liquid crystal display. So, we chose to purchase the U-V micro mirror display from Productivity System and the image projection light engine from Brilliant Technologies.