Title: Micro-Engineering with Lasers

by

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Summary

• A brief review of our Microstereolithography System, which led us to be invited into the BRITE EuRAM project.

• A brief review of some of the results from the BRITE- EuRAM project which used optical and laser systems to Manufacture Macro/Micro Ceramic components.

• After de-binding and sintering ceramic parts with relative densities of 95% have been produced.
Experimental Set-up

Microstereolithography System Diagram

- **UV LASER** (351 or 363nm)
- **Shutter**
- **SLM**
- **D.O.E**
- **Slice Images**
- **Polarizer**
- **Lens**
- **Mirror**

- **T132 Shutter controller**
- **Sync.** (0.1ms resolution)
- **RS-232**
- **Frame Grab (Ultra-II drive)**
- **I/O Ports (PC-DIO-10)**
- **I/O Interfacing (AT-MIO-16DE-10)**

- **IBM PC** (Main control)
- **Encoder Module**
- **Encoder driver Card (37-1039)**
- **Network (ftp) or GPIB Interfacing**

- **SunSparc** (DUCT CAD/CAM)

- **Translation Stage**
- **DDI**
- **Parallel Interface of data acquisition**
- **Serial**

- **Resin Bath**

- **Technology Hub**
Micro-component Prototyping

Microstereolithography System

SVGA SLM 800x600 pixels

Technology Hub
Micro-components

A micro-gear (50 micron layers)  Micro-motor case (50 micron layers)  A helix (50 micron layers)

Double helix (50 micron layers)  Micro-pyramid (35 micron layers)  Micro-pyramids (50 micron layers)
MicroSLA System
Fabrication of Dense Ceramic Micro-Components

Dispersant: Phosphate ester 1.5% wrt Al₂O₃
Solvent: Ethanol or Acetone 50%

Ceramic Powder 50% Al₂O₃
Dispersant 1.5%
Solvent 50% MEK/Et
Deagglomerated powder with adsorbed dispersant dry/grind
Mixing 3 Pa.s.
Suspension
Forming by stereolithography
Green part
Debinding-Sintering

Photopolymerizable monomer HDDA
Initiator: DMPA - 0.5%

Monomer: hexane-diol-diacrylate (HDDA)

Photoinitiators:
Irgacure 651 (DMPA) absorbs 300-390 nm - 0.5%
Irgacure 819 absorbs up to 450 nm - 0.5%

50 mJ/cm² for 100 μm cure depths, resolution of 50 μm
Alumina Powder

Alumina (Al\textsubscript{2}O\textsubscript{3}) Powder: Average diameter 0.5\(\mu\)m; Refractive index 1.7

Aggregate of Al\textsubscript{2}O\textsubscript{3} powder
Absorption spectra of photoinitiators for 0.25 wt.% of dispersant in HDDA

Photoinitiators Cover Emission peaks from:
- Hg Lamp - 365nm, 405nm;
- Argon Ion Laser - 363nm;
- Pulsed YAG Lasers - 355nm.

They are soluble up to 5 wt. % into the monomer, 0.5% seems about optimum.
Cure Depth Versus Dose for three Sources

Cure depth $C_d$ (µm)

$D_p$: is the penetration depth,
$E$: the exposure or energy at the surface,
$E_c$: is the critical energy or the minimal exposure dose for the resin to gel.

$C_d = D_p \cdot \ln\left(\frac{E}{E_c}\right)$

Pulsed YAG Laser - 355nm
Hg Lamp - 365nm
Argon Ion Laser - 363nm

Cure depth versus dose (80 wt.% alumina, 1 wt.% DMPA)
Effect of Photoinitiator on Penetration

Penetration depth versus wt.% photoinitiator; irradiation with an argon laser at 363 nm

Optimum about 0.5 wt.%
Influence of the radiation wavelength on the depth of penetration in alumina suspension

<table>
<thead>
<tr>
<th>Irradiation Conditions</th>
<th>Laser UV (364 nm)</th>
<th>Laser Visible (488 nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Composition in wt. % Alumina</strong></td>
<td><strong>80</strong></td>
<td><strong>Suspension 2: 85</strong></td>
</tr>
<tr>
<td>wt. % Initiator (I 784)</td>
<td><strong>2</strong></td>
<td><strong>3</strong></td>
</tr>
<tr>
<td>$D_p$ (μm)</td>
<td><strong>31</strong></td>
<td><strong>69</strong></td>
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Debinding/Sintering Process

Debinding must be done with a low heating ramp to avoid swelling, distortion and cracking of parts.

Typical thermal treatment for the debinding/sintering process in air
Cracks appear at the Interface between layers if Debinding is too Rapid.

Debinding at 5°C/min up to 220°C/10 hours in air.

Debinding at 5°C/min up to 600°C/50 min. in air.
Relative Density and Shrinkage Versus Temperature

- Temperature (°C): 1500, 1550, 1600
- Relative Density: D/D₀ (%): 15, 20, 25
- Linear Shrinkage (%): to layers, parallel to layers

Diagram shows the relationship between temperature and relative density, as well as linear shrinkage to layers and parallel to layers.
13 Layer Cylinder with 100 micron layers

Some deformation due to faults in deposition layers and bad recoating

Before Sintering

After Sintering

11% Shrinkage
17% Shrinkage

Demonstration parts sintered at 1600°C for 5 hours
Monolayer - Typical Lateral Resolution 50 microns

Mask

Cured at 365 nm with Hg Lamp

8mm x 8mm 120 micron thick polymerised layer, resolution 50 microns; 80 wt% alumina, 0.5 wt% DMPA wrt HDDA monomer
Demonstration Sintered Parts

Demonstration part sintered at 1600°C for 5 hours

Ceramic parts produced with visible source and CRL XGA mask
Conclusions

- It is possible to formulate highly loaded suspensions containing well-dispersed colloidally stable alumina particles.

- The practical limit for the suspension viscosity, which is about 3 Pa.s, is reached for 85 wt.% of alumina with respect to the photopolymer resin content.

- It has been shown that with an optimised photoinitiator fraction above 0.5 wt. %, and energy densities less than 50 mJ/cm²; 100 µm cured depths can be obtained.

- A good lateral resolution of 50 µm has been demonstrated.
Conclusions

• The modification of the formulation by changing the amount of photoinitiator allows the depth of penetration to be increased by a factor 2 or 3 depending on the alumina loading.

• Satisfactory parts with 100 μm thick layers were built with a 20 seconds exposure and a laser power of 2 W.

• Ceramics with relative densities up to 95% have been produced.

• Some sample cracking occurred during the final thermal processes, the control of this process requires further investigation.
References

1) C Chatwin, M Farsari, S Huang, M Heywood, P Birch, R Young, “UV microstereolithography system that uses spatial light modulator technology,” Applied optics 37 (32), 7514-7522, 1998


9) P Birch, R Young, C Chatwin, M Farsari, D Budgett, J Richardson, “Fully complex optical modulation with an analogue ferroelectric liquid crystal spatial light modulator,” Optics communications 175 (4), 347-352, 2000

