Laser Ablation of Metal Doped Polymers with CO$_2$ Laser

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Properties of Laser Ablation Products of Delrin with CO$_2$ Laser

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# Laser Ablation of Metal Doped Polymers with CO2 Laser

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OUTLINE

- Who is DLR – Institute of Technical Physics (TP)?
- Lightcraft Research at TP
- Experimental Setup and Sample Types
- Results: Flat samples in air
  - 3-D expansion
  - Vacuum
  - Comparison of different sample types
  - Tests with a light concentrating structure
- Scanning electron micrographs
- Conclusions and proposal
DLR - INSTITUTE OF TECHNICAL PHYSICS

German Aerospace Center

Astronautics
Traffic
Energy
Aeronautics

Institute of Technical Physics

HEL / COIL
SSL / NLO
Active opt. Systems

Studies & Concepts
Akquisition & Support
HOW IT ALL BEGAN ... (1998)

Bicycle Headlight Reflector
LIGHTCRAFT FLIGHT
ACKNOWLEDGEMENT

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Dr. Ingrid Wysong (EOARD - London)
(and all the others in the background)

for making our research and this visit possible.
**EXPERIMENTAL EQUIPMENT**

**Lightcraft**
- Parabola with Diameter 10 cm
- Focal Distance 1 cm

**Vacuum Tank**
- Diameter 80 cm
- Height 110 cm

**E-beam sustained CO₂ Laser**
- Pulse Energy ... 420 J
- Repetition Rate ... 100 Hz
- Wavelength 10.6 µm
- Pulse Length 3 ... 12 µs

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INVESTIGATIONS FOR EOARD (Phase I – 2002)

Comparison of measurement techniques and performance of US and German lightcraft

![Graph showing comparison of coupling coefficient and pulse energy for US and German lightcraft with and without Delrin.]
Air breathing propulsion possible to altitudes of about 30 km!

With Delrin in vacuum $v_{ex} = 2400 \pm 200$ m/s
LASER LAUNCH SYSTEM DEVELOPMENT ROADMAP

Phase 1
Basic Research
16 Mio Euro

Phase 2
Pre-Prototype
85 Mio Euro

Phase 3
Commercial
275 Mio Euro

Launch of sounding rockets
Launch of satellites

LASER POWER (kW)
EXPERIMENTAL SETUP

- CO2 Laser
- PD2
- Energy Meter
- Target
- Focusing Cu Mirror \( R = 2 \) m
- Bending Cu Mirror \( R = \infty \)
- Range Finder
- PD1
- KCl Wedge
- Focussing Cu Mirror \( R = 2 \) m
- Tank Windows
- Bending Mirror
- Attenuation Screen
- CO2 Laser
- PD2
- HeNe Laser
- Scatter Plate
- Energy Meter
- Tank Windows

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EXPERIMENTAL SETUP

Laser Pulse Profile

Sample
SAMPLE HOLDER

Guiding Tube

Sample

Guiding Tube for 1-D Expansion

41 mm

15.5 mm

20 mm
SAMPLE FORMULATIONS

POM = PolyOxyMethylene = Polyacetal = Delrin®

POM + Al  0, 20, 40, 60 % by wt.
Epoxy + Al  0, 3, 5, 10, 17, 30, 40, 50 % by wt.
Epoxy + Mg  0, 3, 5, 10, 17, 30, 40 % by wt.

Others:  Polybutadiene + Al, POM + Fe, POM + Ti
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REPRODUCIBILITY

Shot to shot result on one sample

Scatter for individual shots
ABLATED MASS IN AIR

Ablated Mass vs. Pulse Energy

Apparent Deposited Energy

→ Upper limit
EXAMPLE: LIMITS TO THE VELOCITY

Upper Limit: 8500 m/s
No air exhausted

Lower Limit: 1200 m/s
All air in tube exhausted
3-DIMENSIONAL EFFECTS

Mass Loss: 3-D vs. 1-D

Impulse: 3-D vs. 1-D
REDUCED PRESSURE

Ablated Mass vs. Pressure

Apparent Deposited Energy
Correct only in vacuum

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**REDUCED PRESSURE**

Coupling Coefficient vs. Pressure

Apparent Jet Velocity

Jet Efficiency in vacuum < 0.03
REduced Pressure

Deposited Energy vs. Pulse Energy

Coupling Coefficient vs. Pulse Energy

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SAMPLE COMPARISONS - Ablated Mass

Pulse Energy
200 J

In Vacuum: Deposited Energy =

- 50 – 70 MJ/kg POM + Al
- 20 – 60 MJ/kg Epoxy + Al
- 30 – 90 MJ/kg Epoxy + Mg
SAMPLE COMPARISONS - Coupling Coefficient

Pulse Energy 200 J
SAMPLE COMPARISONS - Jet Velocity

Pulse Energy 200 J

η < 0.03
COMPARISON WITH LIGHT CONCENTRATING STRUCTURE ("BELL NOZZLE") IN AIR – 200 J

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POWER PROFILES

POM + 40 % Al in air

40 J

Energy 40 J
Atmosphere: POM + 40% Al
Average over 4 pulses

0,000 0,002 0,004 0,006 0,008 0,010
0,012 0,014

Transmission
Reflection
Signal

Time (µs)

Transmission
Reflection

Pulse Energy 120 J
Atmosphere: POM + 40% Al
Average over 4 Pulses

0,000 0,002 0,004 0,006 0,008 0,010
0,012 0,014

Transmission
Reflection
Signal

Time (µs)

Pulse Energy 200 J
Atmosphere: POM + 40% Al
Average over 4 Pulses

0,000 0,005 0,010 0,015 0,020 0,025
0,030 0,035

Transmission
Reflection

Time (µs)

Pulse Energy 280 J
Atmosphere: POM + 40% Al
Average over 4 Pulses

0,000 0,005 0,010 0,015 0,020

Transmission
Reflection

Time (µs)

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ELECTRON MICROSCOPE PICTURES

Before Laser Irradiation

POM + 20 % Al 400x

RE-Mode

POM + 40 % Al 400x
ELECTRON MICROSCOPE PICTURES

Before Laser Irradiation

Epoxy + 17% Al 1000x

RE-Mode

Epoxy + 17% Mg 100x
ELECTRON MICROSCOPE PICTURES

After Laser Irradiation

POM – edge 100x

SE-Mode

POM - center 100x
ELECTRON MICROSCOPE PICTURES

After Laser Irradiation

SE-Mode 200 J vacuum

POM + 20 % Al - center 100x

POM + 40 % Al 1500x
CONCLUSIONS

- Goals for $I_s = 800$ s not met
- In air → accelerated air fraction unknown
  → all related values are wrong
- In vacuum → deposited energy goes up with increasing metal fraction, but coupling coefficient decreases
- Strong evidence for large energy loss in a decoupled laser absorption wave
- Nature and characteristics of absorption wave need investigation
- Can shorter pulse lengths help prevent decoupling?
PROPOSAL FOR NEW EXPERIMENTS

Absorption TOF-measurement

Sample

CO₂ Probe Laser

CO₂ Laser Pulse

Energy

Variation of pulse length 2 ... 12 µs
THANK YOU

POM after laser irradiation  3000x