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LASER CUTTING OF KAPTON FILM CABLES

MLM - MU-89-69-002

MOUND

operated by
EG&G MOUND APPLIED TECHNOLOGIES
P.O. Box 3000, Miamisburg, Ohio 45343-3000

for the
U. S. DEPARTMENT OF ENERGY
Contract No. DE-AC04-88DP43495

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MASTER

P.O. BOX 3000 MIAMISBURG, OHIO 45343-0987 • TEL (513) 865-4020

TO : Michael Lucas
Sandia National Laboratories
Albuquerque, New Mexico

DATE : September 6, 1989

RE : Laser Cutting of Kapton Film Cables (MLM - MU-89-69-002)
Reimbursable Number - E10219
Purchase Order No. - 42-0985

Mike,

Enclosed you will find a detailed report on the use of laser techniques for cutting of kapton film cables. This report is based only on the authorized funding EG&G/Mound used as of this date.

Sincerely,

A handwritten signature in cursive script, appearing to read 'Allen L. Poe'.

Allen L. Poe
Development Engineer

A handwritten signature in cursive script, appearing to read 'Christopher Heitkamp'.

Christopher Heitkamp
Electrical Engineer

DISCLAIMER

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I. STATEMENT OF INTENT

The intent of this research is to investigate the feasibility of cutting Kapton film cables using laser technology as the primary research instrument. The desired results are based on a comparison of laser cuts with die/punch cuts. The depth and detail of this report is dictated by the funding base allowed for in this research.

II. Introduction

The original work, began as an autoschediastic inquiry into alternate ways of cutting multi-layer kapton cables. The initial tests, started with continuous wave carbon dioxide (CO_2 1060 nm), and pulsed copper vapor lasers (Cu 578 nm). The continuous wave CO_2 laser produced an unacceptable cut; but, the pulsed copper vapor laser produced a cut that looked promising. At this point, a contract for additional research work was issued by Sandia National Laboratory to EG&G Mound Applied Technologies. The additional work started by identifying the cutting process variables and developing a design experiment. Then experimental work proceeded to cutting multi-layer kapton cables with a 10 watt pulsed copper vapor laser using a shielding gas, then a 300 watt pulsed CO_2 laser with no shielding gas, and finally a 150 watt pulsed CO_2 laser using compressed air to remove abraded material and smoke. The following material explains the details of our methods and results. The various cutting methods were qualitatively evaluated using pictures obtained from a scanning electron microscope.

III. SYSTEM CONSTRAINTS

In establishing the desired results for this research certain variables must be considered for the selection of each laser technique. These variables were imposed based on requirements for integrating a system into our production environment, since this technique may replace a production punch press operation that is currently being used.

1. Laser System foot print - Max. of 40 sq. ft.
(This 1/2 of the total estimated workcell size)
2. Laser Cost - < \$100,000.00
3. Laser Safety - Must be able to safely integrate into a production area, for operation by production personnel.
4. Laser High End Limit - Final operation settings must be at a minimum 10% below the maximum possible system setting.
5. Laser cut samples should have similar qualifying characteristics as die cut components (see fig.1 for die cut component).
6. Laser must be able to cut a multi-layer Kapton film component, with a minimum thickness of .25mm and a maximum thickness of .75mm.

FIG. 1B. DIE CUT COMPONENTS USING 4 TON MINSTER PRESS AT 200X

FIG. 1A. DIE CUT COMPONENT USING 4 TON MINSTER PRESS AT 100X

IV. DESIGN EXPERIMENT

An initial meeting was held to develop a plan for tracking of system variable changes as the experiment proceeded. Brian Leahy a statistician at EG&G/Mound was called on to develop a Design Experiment for the supplied variables we considered to be as controlling influences. Attached is the letter from Brian on the finalized Design Experiment and the variables that would be tracked.

**** NOTE ****

Do to cost estimates by The University of Dayton for performing a complete Design Experiment on all of the different techniques proposed, it became cost prohibitive to run the complete Design Experiment on each laser technique. In view of this only a small sampling of components (2 to 5) were cut on each Technique.

M o u n d E-Mail

From :Brian T. Leahy
LEAHBT
Dept. :Technology
Tel. No :4225
Date :2-Jun-1989 10:07am EDT
Subject :Laser Cutting notes

TO :Christopher A. Heitkamp (HEITCA)
TO :Allen L. Poe (POEAL)

Attached are the notes of the meeting with Alan Lightman of UDRI, June 1, 1989. As I understand the schemes to approach the improvement of the Laser cutting method we are to examine each for its practicality and merits.

The objective of the investigation is to isolate and reduce the factors effecting the charring of tape product when the laser cutting method is used. During the discussion six factors worthy of investigation were identified. These factors are:

a) Pulse repitition frequency	1000	10,000 pulses/sec
b) Energy per pulse	10	100 Watts
c Diameter of focus spot	25	250 micron
d) Atmosphere	oxygen	argon assist
e) Feed rate of tape	0.5	3 in./sec
f) Gas flow rate	2	100 cc/sec

The range of interest is listed next to each factor. The result of the cutting is the subjective degree of charring observed and was suggested to be followed by SEM surface structure. It is undecided at this time who, UDRI or Mound will do the SEM or Auger.

Please contact me if you have any suggestions, additions, or questions. Perhaps the three of us should get together to hash these schemes over.

Dr. Lightman proposes a tailored approach to the trials which he would like to use on two lasers, copper vapor and carbon dioxide lasers. In his scheme

a) Pulse repetition frequency	3 (1000 3000 10,000 pulses/sec)
b) Energy per pulse	1 setting in the 12-15 watt range
c) Diameter of focus spot	2 diameters sizes not set as yet
d) Atmosphere	2 oxygen and argon assist
e) Feed rate of tape	1 @ 3" per sec
f) Gas flow rate	3 gas flow rates

This results in 36 initial trials specifically for the copper vapor laser. As Lightman suggests the results of these trials should be used to describe trials on carbon dioxide lasers at two sites. The question this poses is whether Mound pursues information on carbon dioxide lasers. A suggested sum total of 100 trials was heard to be split among three sites.

An experimental plan for six factors is presented in the following table based upon the factors described and the complete range of interest.

a) Pulse repitition frequency	1000	10,000 pulses/sec
b) Energy per pulse	10	100 Watts
c) Diameter of focus spot	25	250 microns
d) Atmosphere	oxygen	argon assist
e) Feed rate of tape	0.5	3 in./sec
f) Gas flow rate	2	100 cc/sec

Table 1
Experimental Plan for Six Factors

a	b	c	d	e	f
-	-	-	-	-	-
+	-	-	-	-	-
-	+	-	-	-	-
+	+	-	-	-	-
-	-	+	-	-	-
+	-	+	-	-	-
-	+	+	-	-	-
+	+	+	-	-	-
-	-	-	+	-	-
+	-	-	+	-	-
-	+	-	+	-	-
+	+	-	+	-	-
-	-	+	+	-	-
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-	-	-	-	+	-
+	-	-	-	+	-
-	+	-	-	+	-
+	+	-	-	+	-
-	-	+	+	+	-
+	-	+	+	+	-
-	+	+	+	+	-
+	+	+	+	+	-
-	-	-	-	-	+
+	-	-	-	-	+
-	+	-	-	-	+
+	+	-	-	-	+
-	-	+	-	-	+
+	-	+	-	-	+

-	+	+	-	-	+
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-	-	-	+	-	+
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-	-	-	+	+	+
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-	+	+	-	+	+
+	+	+	-	+	+
-	-	-	-	+	+
+	-	-	+	+	+
-	+	-	+	+	+
+	+	-	+	+	+
-	-	+	+	+	+
+	-	+	+	+	+
-	+	+	+	+	+
+	+	+	+	+	+

The table is a complete factorial for six factors and can be fractionated to include only those trials for which specific factor interactions are to be measured. Thus, of the 64 trials in the table some fraction say a half, a quarter, an eighth, and so on may be what is needed. Consideration of the cost to set up the laser cutter was pointed out as being a key expense. Some more information regarding the set up may be needed. 3 added trials at 0,0,0,0,0,0 settings will allow a check for non-linearity among factors. Thus a fractional factorial involving 32, 16, or 8 trials may be considered after resolving the need to investigate particular interactions. To expand this to a second laser a repeat of a selected set of trials can be performed.

V. COPPER VAPOR LASER

The first step in the Design Experiment was to run our test on the Copper Vapor laser. This decision was based on the preliminary test ran in march of 1989 on the Copper Vapor, which provided a cut on the kapton film but left a smoke residue. The consensus was that by possibly introducing a given volume of inert gas, such as Argon, as an assist at the focal point may eliminate the residue.

The initial setup was with the laser focal length at 250mm, focal point size at .25mm, the laser output at 8 watts and the inert gas assist at 250 feet per minute. After establishing this initial setup a test component was cut to check all of the parameters before starting the actual Design Experiment. With examination of the the test component all parameters showed they were functioning properly, but with the smoke residue still present. Next, we ran another component to check the high end of the inert gas assist at 10,000 feet per minute. To our surprise the amount of residue had not changed, at this point we examined our settings and cut another component at the same high end settings. Again the same results, with no noticeable abatement of the smoke residue (see fig. 2 and 3).

A meeting was held to determine if the Design Experiment for the Copper Vapor Laser should proceed or be stopped, and the next possible steps to take. It was decide after examining the other parameters that they would at best have a very negligible effect on abatement of the smoke residue. At this point the Copper Vapor Laser was dropped from any further evaluation.

0°

FIG. 2. LASER CUT USING 8 WATTS FROM A COPPER VAPOR LASER
IMAGE SHOWN AT 100X

45°

FIG. 3. LASER CUT USING 8 WATTS FROM A COPPER VAPOR LASER
IMAGE AT 100X AND ROTATED 45 DEGREES

VI. CO2 PULSE LASER (WPAFB)

After dropping the Copper Vapor Laser the next was to cut the Master Components on the CO2 Laser at Wright Patterson Air Force Base (in Dayton, Ohio). The settings used were the same as for the Copper Vapor with the exception of not using the inert gas assist. After cutting our Master Component an examination was made of the unit for quality of cut and contamination. The Master Component showed the cut to be of comparable quality as the die/punch cut component, with no noticeable smoke residue (see fig. 4).

WPAFB CUT

FIG. 4A. LASER CUT AT 300 WATTS ON A CO2 LASER
IMAGE AT 100X AND ROTATED 45 DEGREES

WPAFB CUT

FIG. 4B. LASER CUT AT 300 WATTS ON A CO2 LASER
IMAGE AT 200X AND ROTATED 45 DEGREES

VII. CO2 PULSE LASER (LUMONICS)

After being encouraged by the quality of the CO2 Pulse Laser at WPAFB we decided to contact The Lumonics Company in Livonia, Michigan, to make arrangements for the cutting of samples on their 150 watt CO2 Pulse Laser. A 300 watt laser was not available at the time for the experimentation hence the choice to cut samples on the 150 watt system. With Lumonics help we cut five (5) components using the following settings. The output wattage was 150, focal length and focal point size were the same as for the Copper Vapor Laser, the assist was compressed air. The laser was synch-pulsed with the table motion to give us a 35/IPM cutting rate. In reviewing the sample components the amount of smoke residue had been reduced by approximately ninety (90) percent (see fig. 5). Quality of the cut was extremely high in comparison to the Copper Vapor Laser and was of approximately eighty (80) percent the quality of the WPAFB CO2 Laser. Also, the Lumonics 150 watt laser would meet all of our system constraints.

FIG. 5A. LASER CUT USING 150 WATTS FROM A CO2 LASER
IMAGE AT 100X

FIG. 5B. LASER CUT USING 150 WATTS FROM A CO2 LASER
IMAGE AT 100X AND ROTATED 45 DEGREES

VIII. SUMMARY

In summary, the Copper Vapor Laser did not give us the desired results as expected. The system produced a very excessive amount of smoke residue and some charring of the surface edge, which makes this technique undesirable for our application.

The CO2 Pulse Laser in the 150 watt range gave us very good results as compared to the Die/Punch cut samples and the Master Laser cut sample. We feel that the 150 watt laser produced a cut higher in quality than the Die/Punch cut and was approximately eighty (80) percent of the quality of the WPAFB 300 watt laser.

In examining the different cutting techniques, including Die/Punch cutting, we concluded that the Die/Punch technique seem to be compressing the material as it cuts as well as possibly tearing the layers as it progresses through the component. The Copper Vapor seem to be causing a delamination of the layers as well as some additional damage to the surface texture. The Lumonics CO2 Laser at 150 watts gave the best results of all the tested techniques, with still meeting the system constraints.

In conclusion, after receiving positive results on the CO2 Pulse Laser, we feel that continued research would advance the manufacturing capabilities of producing high quality flexible circuits.

IX. RECOMMENDATIONS

The Instrument and Process Automation Group at EG&G Mound Applied Technologies would like to make the following recommendations based on the previous research performed.

1. Drop any further research on Copper Vapor Laser for this application.
2. Do a Design Experiment on a CO2 Pulse Laser in the 250 to 500 watt range.
3. Secure the funding to perform Design Experiment referenced in point number two(2). A "guesstimate" for this experiment would be \$10,000.00 to \$20,000.00

X. TECHNICAL REFERENCES

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