OPTICAL TECHNIQUE FOR THE MEASUREMENT OF HIGH TEMPERATURE MATERIAL EROSION (U) SPECTRON DEVELOPMENT LABS INC COSTA MESA CA K D ARUNKUMAR ET AL APR 86 UNCLASSIFIED SDL-86-2439-03 AFOSR-TR-86-1053
A differential Michelson's interferometer capable of measuring path length variation of the order of 0.002\(\mu\) has been developed and tested. It has also been proven that this interferometer can be used to measure surface heights on diffuse objects. This ability of the interferometer will be used in profiling surfaces eroded electrically. To generate electrically eroded surfaces, a discharge chamber has been built and tested. Using copper electrodes, glow discharge has been struck and characterized. Work done on an eroded electrode with holographic interferometry shows that overall surface erosion \(\sim \lambda\) can be detected using this technique.
11. (Title Concluded) High Temperature Material Erosion
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>NO.</th>
<th>WORK STATEMENT AND PROGRAM OBJECTIVES</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>WORK STATEMENT AND PROGRAM OBJECTIVES</td>
<td>1</td>
</tr>
<tr>
<td>1.1</td>
<td>Statement of the Problem</td>
<td>1</td>
</tr>
<tr>
<td>1.2</td>
<td>Program Objective and Achievements</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2.0</th>
<th>RESEARCH EFFORTS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Diffuse Point Interferometry</td>
<td>3</td>
</tr>
<tr>
<td>2.1.1</td>
<td>Analysis of DiP Interferometer</td>
<td>8</td>
</tr>
<tr>
<td>2.1.1.1</td>
<td>Mirror Surface</td>
<td>8</td>
</tr>
<tr>
<td>2.1.1.2</td>
<td>Diffuse Surface</td>
<td>10</td>
</tr>
<tr>
<td>2.1.2</td>
<td>DiP Interferometry Calibration and Measurement</td>
<td>14</td>
</tr>
<tr>
<td>2.1.3</td>
<td>Spatial Resolution</td>
<td>14</td>
</tr>
<tr>
<td>2.1.4</td>
<td>DiP Interferometer Sensitivity</td>
<td>14</td>
</tr>
<tr>
<td>2.1.5</td>
<td>Measurements on Diffuse Surface</td>
<td>16</td>
</tr>
<tr>
<td>2.2</td>
<td>Surface Erosion Through Electrical Discharge</td>
<td>21</td>
</tr>
<tr>
<td>2.3</td>
<td>Holographic Interferometry</td>
<td>29</td>
</tr>
<tr>
<td>3.0</td>
<td>SIGNIFICANT ACCOMPLISHMENTS</td>
<td>30</td>
</tr>
<tr>
<td>4.0</td>
<td>PROPOSED EFFORTS IN THE SECOND YEAR</td>
<td>31</td>
</tr>
<tr>
<td>5.0</td>
<td>REFERENCES</td>
<td>32</td>
</tr>
<tr>
<td>6.0</td>
<td>TECHNICAL ARTICLE IN PREPARATION</td>
<td>33</td>
</tr>
<tr>
<td>7.0</td>
<td>LIST OF PERSONNEL ASSOCIATED WITH THE PROGRAM</td>
<td>34</td>
</tr>
<tr>
<td>8.0</td>
<td>PAPER PRESENTED AT MEETINGS, CONFERENCES, SEMINARS, ETC</td>
<td>44</td>
</tr>
<tr>
<td>9.0</td>
<td>NEW DISCOVERIES, INVENTIONS, OR PATENT DISCLOSURES AT SPECIFIC</td>
<td>45</td>
</tr>
<tr>
<td>NO.</td>
<td>FIGURE</td>
<td></td>
</tr>
<tr>
<td>-----</td>
<td>--------</td>
<td></td>
</tr>
<tr>
<td>1a</td>
<td>Schematic of the Diffuse Point Differential Interferometer</td>
<td>4</td>
</tr>
<tr>
<td>1b</td>
<td>Diffuse Point Interferometer</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>Coordinate System</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>Addition of Random Phasor Amplitudes</td>
<td>11</td>
</tr>
<tr>
<td>4</td>
<td>Calibration of the Diffuse Point Differential Interferometer</td>
<td>15</td>
</tr>
<tr>
<td>5</td>
<td>Laser Interferometer Signal rms as a Function of Temperature Fluctuation for Both the Reflecting Mirror and the Scattering Surface</td>
<td>17</td>
</tr>
<tr>
<td>6a</td>
<td>Injector Lobe Surface Profile After Grinding Process Using Diffuse Point Differential Interferometry</td>
<td>18</td>
</tr>
<tr>
<td>6b</td>
<td>Injector Lobe Surface Profile After Grinding Process Using a Mechanical Stylus</td>
<td>18</td>
</tr>
<tr>
<td>7a</td>
<td>Cam Surface Profile After Polishing Process Using Diffuse Point Differential Interferometry</td>
<td>19</td>
</tr>
<tr>
<td>7b</td>
<td>Cam Surface Profile After Polishing Process Using a Mechanical Stylus</td>
<td>19</td>
</tr>
<tr>
<td>8a</td>
<td>Cam Surface Profile After Etching Process Using Diffuse Point Differential Interferometry</td>
<td>20</td>
</tr>
<tr>
<td>8b</td>
<td>Cam Surface Profile After Etching Process Using a Mechanical Stylus</td>
<td>20</td>
</tr>
<tr>
<td>9</td>
<td>Legends</td>
<td>22</td>
</tr>
<tr>
<td>9a</td>
<td>Top View of the Vacuum Chamber</td>
<td>23</td>
</tr>
<tr>
<td>9b</td>
<td>Side View of the Chamber</td>
<td>24</td>
</tr>
<tr>
<td>NO.</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>-----</td>
<td>------------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>10</td>
<td>Discharge Current vs. Gap Separation Under Dynamic Flow Condition</td>
<td>27</td>
</tr>
<tr>
<td>11</td>
<td>Discharge Current vs. Electrode Separation Under Static Flow Condition</td>
<td>28</td>
</tr>
</tbody>
</table>
1.0 WORK STATEMENT AND PROGRAM OBJECTIVES

1.1 Statement of the Problem

Material erosion at high temperatures occurs in various space and missile propulsion systems. For example, magnetoplasmadynamic (MPD) thruster electrodes erode during operation in high temperature plasma environments. Rocket engine nozzles also are subjected to erosive environments by particle laden combustion gases existing in the combustion chamber. Adequate methods for measuring erosion recession in hostile environments is not available to support development testing of propulsion systems. Some components of interest in space applications are acquired to have long lifetimes (10,000 hours or greater). Practical testing of such components require extremely sensitive methods to reduce test times to useful lengths. Present methods used to measure erosion recession include radioactive tracing and quartz crystal microbalances. Both measurements are indirect in so far as they measure loss of mass rather than change in dimension and shape. They are also only used at specific points because they must be implanted into the surface of the material.

Thus, a direct measurement of the shape of the eroding material with sufficiently high resolution would present significant advantages, particularly if it could be used to measure a complete surface rather than a few specific points. The research that is being conducted under this program is anticipated to provide a fundamental understanding necessary for making such measurements with optical techniques.
1.2 Program Objective and Achievements

The objective of the program in the first year was to identify and develop those optical technique(s) that can be used to characterize nonintrusively, eroded surfaces. Three primary optical techniques capable of direct measurement, were examined. They are:

a. Diffuse Point Interferometry
b. Holographic Interferometry
c. Astigmatic Ranging Probe

The feasibility of the last technique in measuring surface movement, to a high precision, has been proven(1). However, its applicability to an eroded surface has been severely restricted due to serious signal to noise ratio problem. Hence, this approach has been ruled out as a viable technique for studying surface recession caused by erosion.

Most of our efforts in the first year have been directed towards developing the Diffuse Point (DiP) interferometer since this interferometer when fully developed can profile the eroded surface down to sub-micron level. A detailed description of principle of operation of the interferometer and the initial experimental results are reported here.

Some effort has been spent in looking at erode surfaces using holographic interferometry (HI). Results of this preliminary study is also reported here.

Since the primary interest is in electrically eroded surfaces, an experimental test chamber has been assembled to provide an electrical erode on environment similar to that anticipated in electrical propulsion systems. Details of this set up along with the characteristics of the discharge are also included in this report.
2.0 RESEARCH EFFORTS

In this section we discuss in detail the diffuse point interferometer, the vacuum chamber, characteristics of the glow discharge and the preliminary HI results obtained on an eroded surface.

2.1 Diffuse Point Interferometry

The interferometer, in principle, is a variation of Michelson's interferometer 2, 3. A lay out of the DiP interferometer is given in Figure 1. The output of this He-Ne laser is polarized 45° with respect to the horizontal plane. The horizontal plane is defined as that plane which contains the beam k vector, detectors and the light source. A polarization sensitive beam splitter (PBS), splits this beam into two beams, one of which is polarized parallel to the horizontal plane (P-polarization) while the other has perpendicular polarization (S-polarization). The optical axis of the Pockel's cell is perpendicular to the plane whereas the Wollaston prism is so oriented as to have its optical axis parallel to the original polarization of the laser beam. The direction of optical axes of different components and the electric vector of the laser beam w.r.t. to an x-y coordinate system is shown in Figure 2. The S polarized reference beam and the P polarized object beam upon passing through the Wollaston prism are optically mixed if the Wollaston optical axis bisects the angle between the S and P polarization. The detectors $D_A$ and $D_B$ will, therefore, sense two signals which are 180° out of phase, such that:
Figure 1b. Diffuse Point Interferometer.
\[ S_A = S_0 + S_1 \cos (\phi + \gamma) \]

\[ S_B = S_0 - S_1 \cos (\phi + \gamma) \]

where \( \phi \) is the phase difference between the two beams due to path difference and \( \gamma \) is the additional phase introduced to the reference beam by the Pockels cell to achieve phase quadrature condition. \( S_0 \) is proportional to the input laser power and \( S_1 \) is dependent on fringe visibility. When the signals are combined in a difference amplifier, a signal proportional to the cosine of the phase difference is generated, that is:

\[ S_c = 2S_1 \cos (\phi + \gamma) \]

Under phase quadrature condition, i.e., when \( \phi + \gamma = \frac{\pi}{2} + 2m\pi \), the difference signal is zero and the corresponding path difference (introduced by surface features) is \( \Delta l = \frac{1}{k} (\frac{\pi}{2} - \gamma) \). Knowing the voltage applied to the Pockel's cell \( \gamma \) and/or \( \Delta l \) can be easily calculated. The voltage to be applied to the Pockel's cell will be determined by the magnitude of \( S_c \). This signal is usually normalized by the sum signal \( S_A + S_B \), to reduce the effect of laser power fluctuations. In the following sections, a detailed analysis of the interferometer as applied to polished and rough surfaces are given.
2.1.1 Analysis of DiP Interferometer

2.1.1.1 Mirror Surface

If the object beam is returned from a mirror like surface, the interferometer is identical to Michelson's interferometer. The initial analysis deals with such a surface and later extends the same to a rough surface.

The electric fields entering and leaving the polarizing beam splitter can be represented as:

\[ E_s = a_s e^{-i(\omega t + kz + \gamma)} \]  (3)

and

\[ E_p = a_p e^{-i(\omega t + kz)} \]  (4)

where \( \omega \) is the laser frequency, \( k \) is the wave number, \( \gamma \) is the phase change introduced by the Pockel's cell, and \( a_s \) & \( a_p \) are the amplitudes of the S and P waves respectively.

These amplitudes will be equal in magnitude if the electric vector incident on the polarizing beam splitter is oriented 45° to the horizontal plane. Since the reflecting surface has mirror like finish, the returning beam can be represented as:

\[ E^sc = E_s e^{-i\delta_x} \]  (5)

\[ E^sc = E_p e^{-i\delta_y} \]  (6)
where \((\delta_x - \delta_y)/k\) represents twice the path length difference between the object beam and reference beam.

Since the Wollaston prism optical axis is oriented parallel or normal to the original laser beam e vector an interference pattern will occur in the plane of the photodetectors. Using the coordinate system illustrated in Figure 2, the electric field amplitude at the detector plane, \(E_{\text{sig}}\), will be:

\[
E_{\text{sig}} = \frac{1}{\sqrt{2}} \begin{bmatrix}
1 & 1 \\
1 & -1
\end{bmatrix} \begin{bmatrix}
E_s e^{-i\delta_x} \\
E_p e^{-i\delta_y}
\end{bmatrix}
\]  

(7)

and the detector signals will be

\[
S_A = S_0 \left[ 1 + S_1 \cos(\delta + \gamma) \right]
\]

\[
S_B = S_0 \left[ 1 - S_1 \cos(\delta + \gamma) \right]
\]

(8)

where \(S_0 = a_s^2 + a_p^2\) is the laser power, \(S_1 = 2a_s a_p / S_0\) is the fringe visibility and \(\delta = \delta_x - \delta_y\).

The quadrature condition is achieved when the phase is an odd multiple of \(\frac{\pi}{2}\), i.e.,

\[
(\delta + \gamma) = (2n + 1) \frac{\pi}{2}; \quad n = 0, 1, 2, \ldots
\]  

(9)

An error signal, \(S_- = S_A - S_B\) is used to control the phase \(\gamma\), introduced by the Pockels cell such that the quadrature condition expressed in Equation (9) is realized. The path difference between the reference and object beams will then be:
\[ \Delta = (2n + 1) \frac{\lambda}{4} - \Gamma \]  

(10)

where \( \Delta = \delta/k \) and \( \Gamma = \gamma/k \) and \( \lambda \) is the laser wavelength. Since the introduced phase, \( \gamma \) is linearily proportional to the voltage applied to the Pockels cell, the path difference in the two arms, \( \Delta/2 \), can be obtained by measuring the voltage on the Pockels cell.

2.1.1.2 Diffuse Surface

When the object surface is a diffuse reflector, the incident P polarized light undergoes diffuse reflection (scattering). Hence, a speckle field appears at the face of the Wollaston prism. This speckle pattern will be a subjective definition one and hence, the size of each speckle is determined by the lens system in the interferometer. Since the minimum deconvolution area of a given diffuse surface is \( \sim \lambda \), the number of scatterers responsible for the speckle field is approximately of the order of \((d_0/\lambda)^2\) where \(d_0\) is the beam waist at the surface. Assuming that the incident polarization is not changed by scattering, the complex amplitude at the Wollaston prism can be written as

\[ E_{sc}^P (x,y,z) = a_p (x,y,z) \exp [-i\delta(x,y,z)]. \]  

(11)

This can be represented as a vector in a complex plane as shown in Figure 3. This complex amplitude which contains all the information about the spatial structure of the P polarized light is actually the sum of a large number \(N\) of components which represent the light received.
\[ E_{p}^{sc}(x,y,z) = \left( \frac{1}{\sqrt{N}} \right) \sum_{n=1}^{N} a_n \exp(-i\phi_n) \]

**FIGURE 3. ADDITION OF RANDOM PHASOR AMPLITUDES.**
from the vicinity of each point of the illuminated diffuse surface. Thus the phasor amplitude of the speckled field at the Wollaston can be written as:

\[
E_{p}^{sc} = \frac{1}{\sqrt{N}} \sum_{n=1}^{N} a_n \exp(-i \delta_n) \tag{12}
\]

As in the previous case, the electric field at the detector plane is

\[
E_{\text{sig}} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \begin{bmatrix} E_s e^{i \delta_x} \\ \frac{1}{\sqrt{N}} \sum_{n=1}^{N} a_n \exp(-i \delta_n) \end{bmatrix} \tag{13}
\]

Following the same analysis as before the signal from detector A and B can be written as:

\[
S_A = a_s^2 + \frac{1}{N} \sum_{n=1}^{N} a_n^2 + \frac{1}{N} \left[ \sum_{j=1}^{N-1} a_j e^{i \delta_j} \cdot \sum_{n=j+1}^{N} a_n e^{-i \delta_n} + \sum_{j=1}^{N-1} a_j e^{-i \delta_j} \cdot \sum_{n=j+1}^{N} a_n e^{i \delta_n} \right] + \left[ \frac{a_s}{\sqrt{N}} e^{i(\delta_x + \gamma)} \sum_{n=1}^{N} a_n e^{-i \delta_n} \sum_{n=1}^{N} a_n e^{i \delta_n} \right] \tag{14}
\]

and
The first two terms in (14) and (15) represent the signal dc level and the third term represents the speckle pattern. The fourth term, which is of special interest to our studies represents the interactions of speckles with the reference beam. It can be rewritten as:

\[
S_b = a_s^2 + \frac{1}{N} \sum_{n=1}^{N} a_n^2 + \left[ \frac{1}{N} \sum_{l=1}^{N-1} a_l e^{i\delta_l} + \sum_{n=1}^{N} a_n e^{-i\delta_n} \right] + \left[ a_s e^{i(\delta_x + \gamma)} + \frac{a_s}{\sqrt{N}} e^{i(\delta_x + \gamma)} \cdot \sum_{n=1}^{N} a_n e^{-i\delta_n} \right]
\]

The cosine term in (16) then can be written as:

\[
2 \frac{a_s}{\sqrt{N}} \sum_{n=1}^{N} a_n \cos \left[ (\delta_x - \bar{\delta}_n) + \gamma \right]
\]

As is evident from the cosine term, achieving phase quadrature condition in the presence of speckle field is not a trivial matter. For large phase excursions of \(\delta_n\), fringe visibility will be totally lost. However, if the illuminated spot on the diffuse surface is kept small, say of the order of a few microns, the probability for abrupt change in surface roughness features within the spot can be extremely small (<<1). This is especially true when the surface is eroding and the erosion rate is small. In such a case, one may be justified in assuming the scattered radiation to have minimum spread in its spatial phase information. The cosine term in (16) then can be written as:

\[
\cos \left[ (\delta_x - \bar{\delta}) + \gamma \right]
\]
the surface feature heights. Under this condition, phase quadrature may still be achieved, however, fringe visibility will be reduced.

In the next section we present some experimental results that substantiate the above assumption.

2.1.2 DIP Interferometry Calibration and Measurement

The interferometer was calibrated using a mirror like surface and a diffuse surface. The object was mounted on a translation stage that had a sensitivity of 0.25 μm. Figure 4 gives the plot between the distance the object was moved against the voltage applied to the Pockel's cell for quadrature condition. Calibration points for both mirror and diffuse surfaces lie close to one another supporting the assumption that for small d₀, spread in εₙ is minimum. The calibration curve was generated using a laser spot size of 19 μm. Efforts are underway to reduce the focal spot size to 5 μm. If successful, this would further validate our assumption.

2.1.3 Spatial Resolution

The spatial resolution of the interferometer is limited by the size of the focal spot on the target surface. This is at least two orders of magnitude better than what can be achieved with a mechanical profilometer.

2.1.4 DIP Interferometer Sensitivity

Since the translation stage on which the objects were mounted had only a resolution of 0.25 μm, we had to resort to indirect methods to
Figure 4. Calibration of the Diffuse Point Differential Interferometer
determine the sensitivity of the interferometer. The methods used involved measuring path length variation induced in the object beam as a result of temperature variation in the air near the surface. A temperature controlled boundary layer was used for that purpose (3) and Figure 5 shows the response of the interferometer to the thermally induced pathlength change. From the curve one can see that the interferometer is capable of responding to a temperature change of 1°C. Since this change corresponded to a path length variation of 0.002 μm. The sensitivity of the DiP interferometer can be taken to be 0.002 μm. (3)

2.1.5 Measurements on Diffuse Surface

After the interferometer was calibrated and its sensitivity determined, measurements were done on three cam surfaces which have already been profiled using a mechanical profilometer. Figures 6-8 compare the profilometer trace against that obtained using the interferometer. The rms values from both measurements were then compared to check the applicability of DiP interferometry to surface profiling. The rms values agree to within ± 5% indicating that diffuse point interferometer can indeed be a viable, noncontact, surface characterization tool.

All the measurements that we have carried out so far are on machined surfaces and not on eroded ones. Since the aim of the program is to look at those surfaces that have been subjected to erosion, we designed and built a system that is capable of producing surface erosion through electrical discharge. This will be detailed in the following section.
Figure 5. Laser Interferometer Signal rms as a Function of Temperature Fluctuation for Both the Reflecting Mirror and the Scattering Surface
Figure 6a. Injector Lobe Surface Profile After Grinding Process Using Diffuse Point Differential Interferometry. Surface Height rms Value = .645μm

Figure 6b. Injector Lobe Surface Profile After Grinding Process Using a Mechanical Stylus. Surface Height rms Value = .652μm
**Figure 7a.** Cam Surface Profile after Polishing Process Using Diffuse Point Differential Interferometry. Surface Height rms Value = .262 μm

**Figure 7b.** Cam Surface Profile After Polishing Process Using a Mechanical Stylus. Surface Height rms Value = .259μm
Figure 8a. Cam Surface Profile After Etching Process Using Diffuse Point Differential Interferometry. Surface Height rms Value = 0.290μm

Figure 8b. Cam Surface Profile After Etching Process Using a Mechanical Stylus. Surface Height rms Value = 0.293μm
2.2 **Surface Erosion Through Electrical Discharge**

Surface electrical erosion occurs when a surface is exposed to an energetic plasma. For the present experiment, a simple glow discharge was assembled. The discharge is maintained inside an aluminum vacuum chamber which can be pumped down to about $1 \times 10^{-3}$ torr of pressure. A schematic diagram of the chamber is shown in Figure 9 (Photograph of the chamber in Figure 1b). Two high voltage feed throughs are used to apply the needed voltage to the electrodes. The anode is attached to a push-pull feedthrough and can be moved perpendicular to the cathode. This degree of freedom is required to have optical access to the cathode surface that is to be profiled using the DiP interferometer.

The cathode is mounted such that it can be moved along the beam direction. This movement allows for varying gap distance between the copper electrodes.

The chamber is pumped down using a Varian mechanical pump Model SD-90 and then flushed with Argon gas half a dozen times. After pumping out residual gases, Ar gas is let into the chamber at 1-2 torr pressure. The temperature of the cathode when the discharge is on is monitored with a thermocouple kept in contact with the cathode (not shown in the figure). The electrodes are energized using a 1KV, 15 mA power supply. The resulting glow discharge was characterized under static and dynamic flow conditions. The pertinent parameters of the discharge are listed in Tables 1 and 2. For voltages beyond $V_{\text{max}}$, the discharge becomes unstable and erratic. Figures 10 and 11 give the discharge current as a function of electrode separation. As can be seen
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**Figure 9. Legends**
Figure 9a. Top View of the Vacuum Chamber.
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<td>325</td>
<td>0.25</td>
<td>&gt;10</td>
</tr>
<tr>
<td>15</td>
<td>1 TORR</td>
<td>350</td>
<td>230</td>
<td>320</td>
<td>0.19</td>
<td>2.68</td>
</tr>
<tr>
<td></td>
<td>2 TORR</td>
<td>450</td>
<td>230</td>
<td>328</td>
<td>0.25</td>
<td>&gt;10</td>
</tr>
<tr>
<td>20</td>
<td>1 TORR</td>
<td>380</td>
<td>240</td>
<td>335</td>
<td>0.16</td>
<td>3.82</td>
</tr>
<tr>
<td></td>
<td>2 TORR</td>
<td>500</td>
<td>240</td>
<td>303</td>
<td>0.4</td>
<td>&gt;10</td>
</tr>
</tbody>
</table>

$V_B$: Breakdown voltage

$V_{MIN}$: Minimum voltage required to sustain a glow discharge

$V_{MAX}$: Maximum voltage that can maintain a stable discharge
### TABLE 2 DISCHARGE PARAMETERS UNDER STATIC FLOW

<table>
<thead>
<tr>
<th>ELECTRODE GAP (mm)</th>
<th>PRESSURE</th>
<th>$V_B$ (volts)</th>
<th>$V_{MIN}$ (volts)</th>
<th>$V_{MAX}$ (volts)</th>
<th>$I_{MIN}$ (mA)</th>
<th>$I_{MAX}$ (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>1 TORR</td>
<td>350</td>
<td>235</td>
<td>300</td>
<td>0.15</td>
<td>3.38</td>
</tr>
<tr>
<td></td>
<td>2 TORR</td>
<td>400</td>
<td>270</td>
<td>320</td>
<td>0.2</td>
<td>4.02</td>
</tr>
<tr>
<td>10</td>
<td>1 TORR</td>
<td>390</td>
<td>285</td>
<td>360</td>
<td>0.18</td>
<td>3.22</td>
</tr>
<tr>
<td></td>
<td>2 TORR</td>
<td>470</td>
<td>300</td>
<td>410</td>
<td>0.2</td>
<td>10</td>
</tr>
<tr>
<td>15</td>
<td>1 TORR</td>
<td>450</td>
<td>265</td>
<td>350</td>
<td>0.2</td>
<td>3.61</td>
</tr>
<tr>
<td></td>
<td>2 TORR</td>
<td>460</td>
<td>310</td>
<td>410</td>
<td>0.2</td>
<td>6.9</td>
</tr>
<tr>
<td>20</td>
<td>1 TORR</td>
<td>450</td>
<td>250</td>
<td>370</td>
<td>0.17</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>2 TORR</td>
<td>490</td>
<td>340</td>
<td>410</td>
<td>0.23</td>
<td>3.96</td>
</tr>
</tbody>
</table>

$V_B$ Breakdown voltage  
$V_{MIN}$ Minimum voltage required to sustain a glow discharge  
$V_{MAX}$ Maximum voltage that can maintain a stable discharge
Figure 10. Discharge Current vs. Gap Separation Under Dynamic Flow Condition.
Figure 11. Discharge Current vs. Electrode Separation Under Static Flow Condition.
from the curves, higher discharge currents are attainable at 2 torr pressure and that accelerates surface erosion. However, the electrodes get heated up at a faster rate and the ensuing thermal expansion may be undesirable for holography work. At 1 torr pressure, the discharge current does not exceed 5 mm A. Hence, it will be more appropriate to use 1 torr as the working pressure.

Working under static conditions, we found that the pressure was slowly but steadily increasing due to micro leaks in the chambers. This eventually lead to the destabilization and discoloration of the glow discharge. However, under dynamic condition, i.e., with a steady flow of Ar gas, a well stabilized glow discharge could be sustained for periods longer than 16 hours. Since the required flow rate is only of the order of few milliliters/minute, we prefer the latter.

2.3 Holographic Interferometry

Real time holographic interferometry (HI) has been carried out on an eroded cathode surface. Unwanted fringes generated by thermal expansion of the cathode prevented us from having high current glow discharge. However, low current, glow discharge could be sustained over long periods without any serious thermal expansion problem. Holograms of the surface were made before and after the discharge. At sixteen hours, 1.2 mA discharge generated four interference fringes indicating that the cathode surface had eroded through 2 μ. A detailed analysis of this study along with our on going work with sandwich holography will be reported later.
3.0 SIGNIFICANT ACCOMPLISHMENTS

The most significant achievement in this program so far is the understanding and development of the Diffuse Point Interferometer. This in conjunction with the vacuum chamber, where controlled surface erosion is possible brings us closer to the program objective of developing an optical technique that can nonintrusively monitor surface erosion. Also the preliminary results from the holographic interferometer study shows that HI can detect overall surface recession of the order of \( \lambda \). These achievements are itemized below.

Specifically, the following tasks were achieved:

1. A test chamber with sufficient optical access and complete control of the electrode location has been designed, constructed and tested.

2. Performance evaluation of the test chamber was achieved experimentally. Characterization of the discharges as a function of electrodes voltage, current, chamber pressure and electrode gap were performed under static 2 dynamic flow conditions.

3. Established the DiP as a viable technique for measuring diffuse surface profiles with a sensitivity of 0.002 \( \mu \).

4. Established holographic interferometry as an alternative candidate to DiP for surface erosion monitoring.

5. Use holographic interferometry to obtain detailed surface profile of eroded electrodes.
4.0 PROPOSED EFFORTS FOR THE SECOND YEAR

- Generate eroded surfaces under various discharge conditions.
- Apply DiP interferometry to profile the surfaces
- Apply sandwich holography to study surfaces when at high temperatures
- Study more than one cathode material
5.0 REFERENCES


6.0 TECHNICAL ARTICLE IN PREPARATION

"Surface Topography Using Diffuse Point Differential Interferometry", to be submitted to Applied Optics.
LIST OF PERSONNEL ASSOCIATED WITH THE PROGRAM

The scientists involved in this program are Dr. K. A. Arunkumar, Dr. M. Azzazy, Dr. J. D. Trolinger. The resume's of these persons along with their lists of publications are given below.

DR. K. A. ARUNKUMAR

University of Kerala (India) B.Sc. (1969), Physics
University of Kerala (India) M.Sc. (1971), Solid State Physics
I.I.T. (Madras, India) Ph.D. (1976), Magneto-optics
University of Hull (England) Ph.D. (1979), Applied Physics

Dr. Arunkumar is a physicist with interests in optics, lasers, application of lasers, spectroscopy, holography and fiber optics. He has been involved in the design and development of optical instrumentation for application in the fields of magneto-optics, electro-optics, surface analysis, plasma diagnostics and other high technology areas.

Dr. Arunkumar joined Spectron Development Laboratories, Inc. (SDL) in December of 1984 and is involved in their optical design and inspection programs involving holography. He is also associated with preposing and design fiber-optic based sensors and optical instrumentations.

Before joining SDL, Dr. Arunkumar was with Apollo Lasers Inc., an Allied company, as their Senior Design Engineer. There he was in charge of design and development of new solid state scientific laser systems.

From 1979 to his joining Apollo Lasers, he had been associated with the University of Kentucky where he worked as Assistant Research Professor. There he developed the technique for measuring Normal Unenhanced Raman Scattering (NURS) from very low polarizability molecules adsorbed on surfaces. His invention, capable of altering the temporal characteristics of a pulsed laser, is currently patent pending.

Dr. Arunkumar is listed in Who's Who in the World, Personalities of America, and Who's Who in Frontier Science and Technology. He has also been appointed as an Adjunct Assistant Professor at the University of Kentucky.

86-2439-03/48
CURRENT ACTIVITIES:

Dr. Arunkumar is currently working in the Optics Technology group with optical design and inspection programs for Spectron Development Laboratories, Inc.

PROFESSIONAL SOCIETY AFFILIATIONS:

American Physical Society
Optical Society of America

PATENTS:


"Fiber-Optic Magnetic Field Sensor" - Patent Pending.

PUBLICATIONS:


"Raman Studies of Oxygen on Ni (111)", presented at the International Conference on Phase Transitions on Surfaces, p. 57, Orono, Maine, August, 1981.

"Low Frequency Raman Spectra of CO adsorbed on Ni (110)", presented at the Washington Meeting of the APS in April, 1982.

"Raman Band Shapes from CO adsorbed on Ni (111), Ni (110) and Ni (100)", in Spectral Line Shape, Vol. 2, p. 625, 1983. Published by Walter de Gruyter & Company, Berlin, New York.
"Raman Spectra of Acetone on Ni (100) and Ni (111)", presented at the APS meeting in Philadelphia in November 1982.

"Low-Frequency Raman Spectrum of CO Adsorbed on Ni (111)", presented at the general meeting of APS in April 1983.


"Can Atomic Scale Roughness Features Contribute to Surface Enhanced Raman Scattering?", submitted.


"Holographic Interferometry Technique to Detect Defects in Printed Circuit Boards," to be presented at the SPIE Conference in San Diego, August 1986.


"Holographic Inspection of Printed Circuit Boards" - Submitted to Wright-Patterson Air Force Base, 1986.

Dr. Medhat Azzazy
Scientist

Cairo University, Egypt: B.S. (1975), Mechanical Engineering
Cairo University, Egypt: M.S. (1977), Mechanical Engineering
University of California, Berkeley: Ph.D. (1982), Mechanical Engineering

Dr. Azzazy's responsibilities at Spectron Development Laboratories, Inc., (SDL) include research in the areas of combustion and combustion diagnostics. His current responsibilities include particle and spectroscopic measurements in flames and theoretical investigations in combustion. He was involved in the temperature measurements of pulverized coal combustion and the characterization of soot particles during the combustion of broad specification gas turbine fuels. He is also involved in developing a resonant holography technique and its applications to turbulent reactive flows.

While at the University of California, Berkeley, Dr. Azzazy conducted extensive research on the experimental and theoretical aspects of turbulent premixed flames.

Dr. Azzazy has developed the method of Laser Induced Fluorescence spectroscopy (LIFS) and then applied it to measure the number density of the hydroxyl radical in Turbulent Premixed Flames. Also he has applied the method of Rayleigh scattering to measure the gas density in the same flame. He has also developed a statistical theory for turbulent flame propagation using a PDF transport equation. The theory was further extrapolated to accommodate for the chemical kinetics.

During the period of 1972 to 1981, Dr. Azzazy has held several assignments in industry and at the University. Dr. Azzazy has participated in the investigations of steel heat treatment (Voest Iron and Steel, Austria) and the operation of electric power plants (Electricite et gas de France). Also, he has conducted heat transfer computations for cable
de France). Also, he has conducted heat transfer computations for cable car gripping under different loading conditions (City of San Francisco). Dr. Azzazy also participated in designing and teaching undergraduate courses in thermal systems (San Francisco State University) and fluid mechanics and aerodynamics (Cairo University, Egypt).

A list of publications is given below.

**PUBLICATIONS:**


TECHNICAL REPORTS:


"Notes on Particle Sizing Techniques," Short Course Notes, SDL NO. 83-61029, July. (1983)


DR. J.D. TROLINGER  VICE PRESIDENT AND R&D DIRECTOR

University of Tennessee:  B. S. (1963), Engineering Physics
Louisiana State University:  M. S. (1967), Physics
University of Tennessee:  Ph.D. (1967), Physics

Dr. Trolinger is an applied physicist with special interest in the application of lasers, optical instrumentation, and optical data processing and holography.
Dr. Trolinger joined SDL in May 1975 and is Chief Scientist. His work primarily involves the development and application of optical instrumentation for particle field analysis, flow diagnostics and non-destructive evaluation. His experience includes the development and use of instrumentation for studies in high energy chemical lasers, internal combustion engines, wind tunnels, gun ranges, meteorological facilities, plasma diagnostics, ships, aircraft and manufacturing facilities.

Prior to joining SDL, Dr. Trolinger was Manager of the Science Applications, Inc. (SAI) Optics and Acoustics Applications Laboratory wherein he was responsible for technical direction of programs related to laser instrumentation, coherent and incoherent optical data processing and acoustical imagery. During this time, he developed and implemented the first airborne holocamera system for use in cloud particle measurement. The system was flown successfully in Guam, Kwajalein, and Wallops Island testing.

Prior to joining SAI, he was a member of the technical staff of Arnold Research Organization, Inc. (ARO) at the USAF Arnold Engineering Development Center (AEDC). He headed the ARO, Inc. Laser Applications Committee. He and his team developed and fielded over twenty different laser systems for applications in the AEDC ground test facilities.

He has served as a consultant to the NATO Advisory Group for Aerospace Research and Development and currently acts as an Editorial Advisor for "Lasers and Applications", a monthly periodical. He was an associate professor (part time) in the department of physics, University of Tennessee, where he taught coherent optics and electro-magnetic theory.

A partial list of Dr. Trolinger's publications follows:

PUBLICATIONS:

Periodical Literature


Other Publications


AGARDography in Progress.

8.0 PAPER PRESENTED AT MEETINGS, CONFERENCES, SEMINARS, ETC.

The results of our work had not been reported in any meeting.
9.0 NEW DISCOVERIES, INVENTIONS OR PATENT DISCLOSURES AT SPECIFIC APPLICATION STEMMING FROM THE RESEARCH EFFORT

The DiP interferometer developed can be applied to surface measurements where high accuracy is needed. We are looking at the possibility of patenting this interferometer.
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