ATOMIC OXYGEN DAMAGE CHARACTERIZATION BY PHOTOTHERMAL SCANNING

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ABSTRACT

In this paper we use a photothermal imaging technique to characterize the damage caused to an imperfectly coated gold-coated Kapton sample exposed to successively increased fluences of atomic oxygen in a laboratory atomic source.

INTRODUCTION

One major problem associated with the flight of low Earth orbit (LEO) spacecraft is the damage caused to various materials by bombardment with atomic oxygen (AO). AO will readily oxidize materials with high erosion yield coefficients, such as polyimide Kapton, epoxy graphite, and Mylar. Materials with low erosion yield coefficients such as aluminum, gold, and SiO_2 may be used as barrier coatings to prevent damage to the more vulnerable underlying materials mentioned above (ref. 1). However, manufacturing defects in the barrier coatings such as scratches and pin holes act as sites where the AO can attack the substrate, and may cause undercutting of the protective layer (ref. 2).

Photothermal imaging of solids is a powerful technique which has been applied to numerous problems involving the characterization of surface and subsurface, cracks inclusions, and delamination in materials (ref. 3, 4). We have used this method to produce photothermal images of a gold-coated Kapton sample at various stages of its exposure to AO in a laboratory AO source. The gold layer was deliberately scratched prior to exposure of the sample, and the resultant damage around this site imaged photothermally.

PHOTOTHERMAL IMAGING APPARATUS

A diagram of the apparatus is given in Figure 1.

In order to produce a photothermal image, a modulated and localized heat source is required which is used to create thermal waves in the sample. In our system, we have used an argon ion laser as a heat source whose beam is focused by means of a microscope objective onto the sample to be scanned. The laser was operated on a wavelength of 488 nm in order to optimize the absorption in the gold (≈63 percent at this wavelength) and thus generates "thermal waves" within the sample being illuminated.

The depth to which the thermal waves penetrate the sample μ_s is given by:

$$\mu_s = \left(\frac{\alpha_s}{\pi f}\right)^{1/2} ,$$

where α_s is the thermal diffusivity of the material to be investigated, and f is the modulation frequency of the laser light.

The value of μ_s and, hence, the penetration depth may be changed by altering the modulation frequency.

Associated with the thermal waves are acoustic waves which are stresses generated in the sample due to the thermal waves and which penetrate the whole sample and are detected by a piezoelectric transducer coupled to the rear side of the sample. The voltage produced by the transducer, which depends on the magnitude of these waves, is then amplified and detected by a lock-in amplifier (Stanford SR530). The lock-in amplifier gives a reading of the magnitude of the photothermal signal detected, together with its phase shift with respect to the light modulation. The sample together with its piezodetector was mounted upon two orthogonal translation stages and raster scanned beneath the focused laser beam of diameter ≈2.5 μm in steps of 3 μm. The power density of the focused laser beam was kept below the damage threshold of the sample.

The thermal waves traveling into the bulk of the sample are reflected and scattered by regions of differing thermal properties within the sample. The photothermal signal, therefore, depends upon these imperfections, and hence gives the imaging capability of this technique.

In order to produce a subsurface image, the X–Y scans consisting of 75 by 75 data points for both the signal and its phase lag were recorded across a small area of the sample. The photothermal signal is sensitive to surface optical features which have differing optical absorption. However, the phase lag is much less sensitive to surface features and is a better measure of subsurface features especially delaminations (ref. 5). We have, therefore, concentrated upon the phase measurements in the results given in this paper.

SAMPLE EXPOSURE

A 1- by 3-cm, 130-μm thick Kapton sample was vacuum coated with 40 nm of gold and an area of 1 by 1 cm selected. A strip of the gold about 35-μm wide and extending from one side of the sample to the other was removed with a thin metal probe to expose the Kapton substrate beneath it. The sample was then mounted in a laboratory AO apparatus similar to the design described by Neely (ref. 6) and exposed to an AO flux of $\approx 1.5\times10^{17}$ atoms/cm^2/s at a temperature of 200 °C.

The sample was exposed to AO for four successive exposure times, with cumulative fluences of:

(i) 8.3×10^{20} atoms/cm^2

(ii) 17×10^{20} atoms/cm^2

(iii) 25×10^{20} atoms/cm^2

(iv) 50×10^{20} atoms/cm^2.

The sample was scanned photothermally before and after each exposure.

RESULTS

Five photothermal scans of the area containing the exposed Kapton, each comprising 75 by 75 data points were obtained giving a photothermal image 220 by 220 μm in area. The photothermal signal was detected by a piezotransducer on the Kapton surface remote from the gold. An imperfection in the gold/Kapton interface, such as delamination, which would introduce an air layer between the gold and Kapton substrate will scatter the thermal waves before they are detected, modifying the photothermal phase, since this is in effect the delay in generation of the photothermal signal with respect to the modulation frequency, hence making the scan sensitive to subsurface imperfections. The data were represented in false colors in the images of the scans, using Unimap 2000, Uniras A/S (ref. 7).

A modulation frequency of 3 kHz was chosen for all the scans which correspond to a thermal wave probe depth of ≈3.2 μm into the Kapton. Photothermal images of the phase lag of the signal are shown in Figure 2. These images show undercutting and delamination around the bare Kapton section of the sample. A greater phase lag is seen in the scans for the areas in which the gold is no longer in contact with the Kapton. As the sample becomes progressively more damaged, the area around the scratch area is seen to widen and the associated phase lag becomes greater.

Further photothermal analysis, performed in Swansea, will concentrate on coated samples that are scanned while inside the AO apparatus so that the progressive damage may be characterized in situ and in real time.

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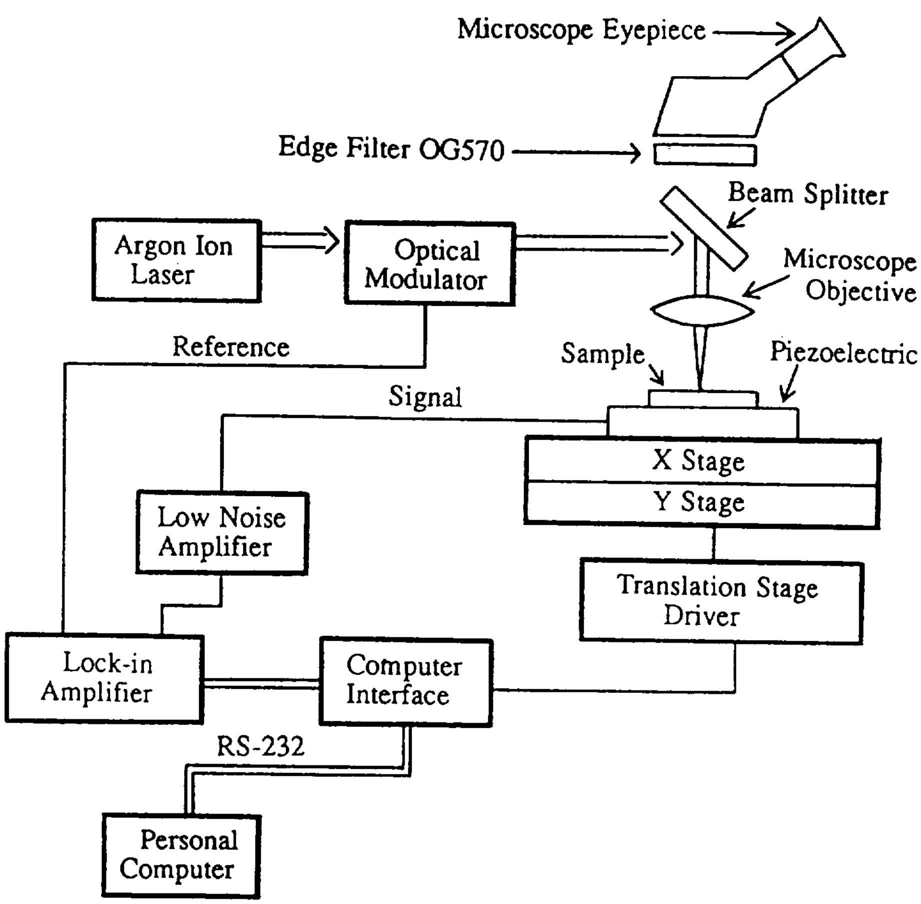


Figure 1. Diagram of photothermal imaging apparatus.

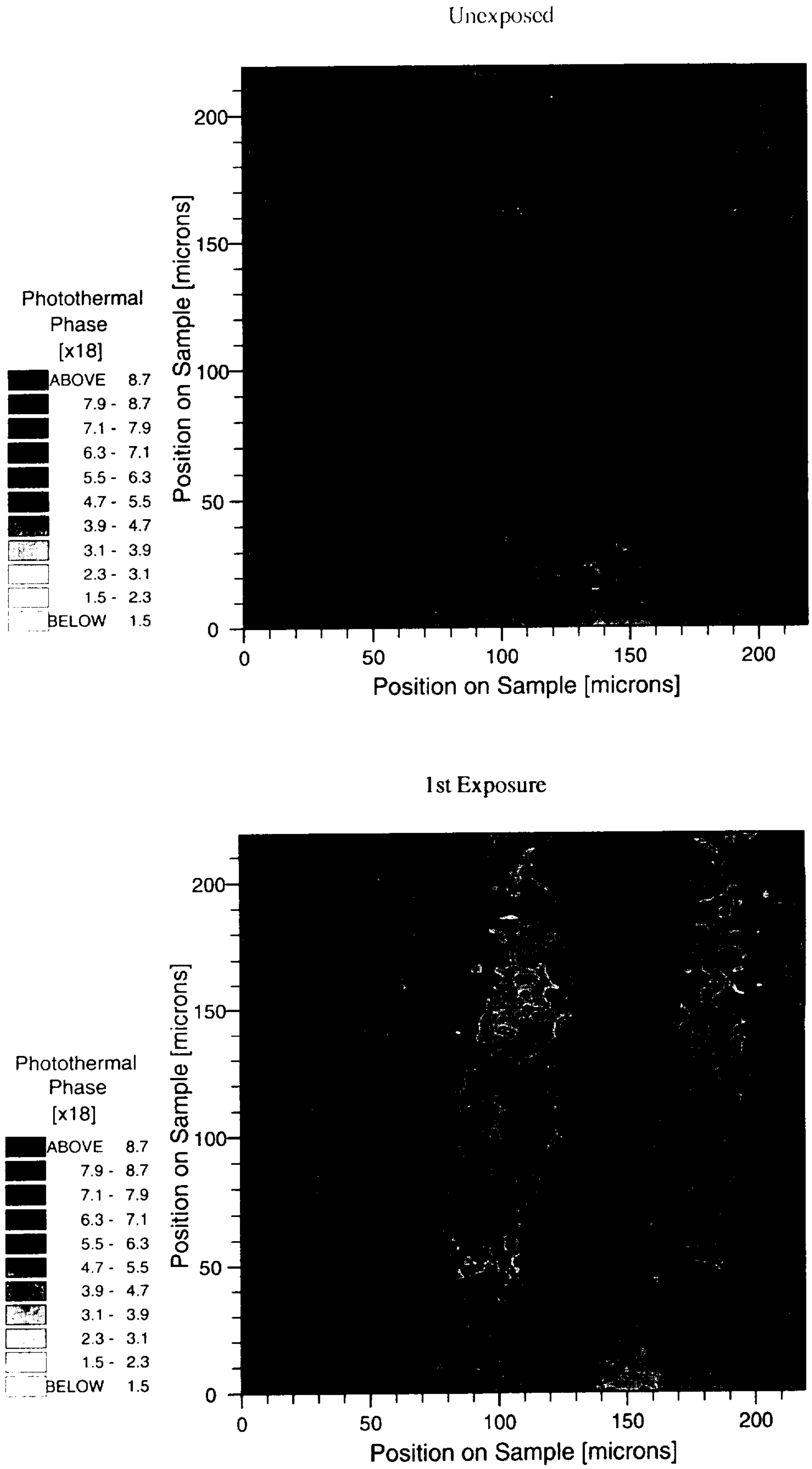
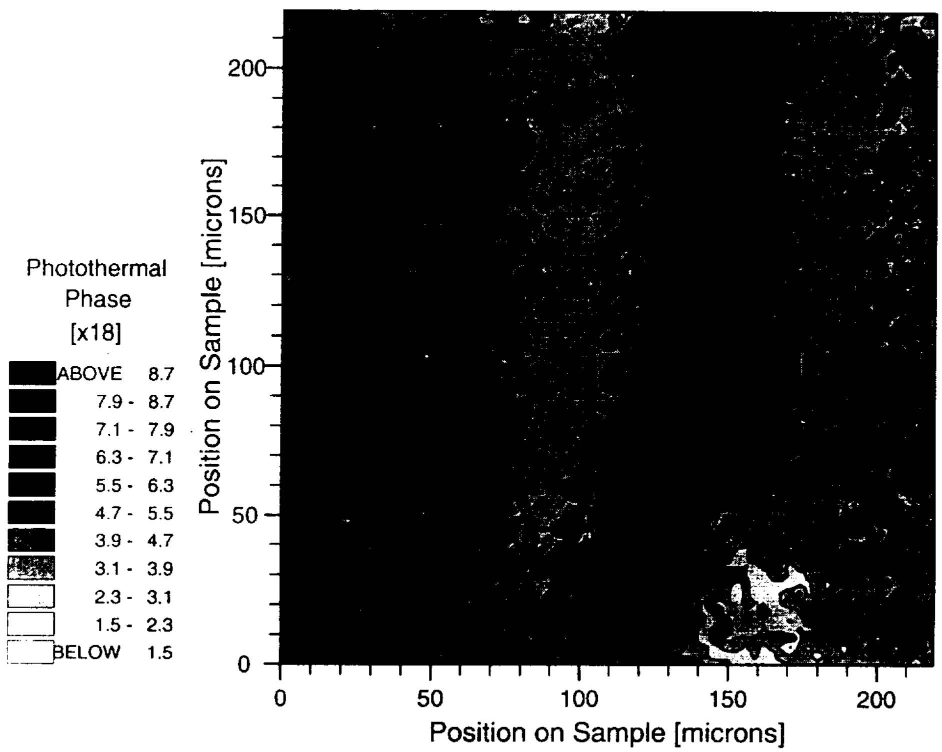


Figure 2. Photothermal phase images for cumulative AO exposures of gold-coated Kapton.

2nd Exposure



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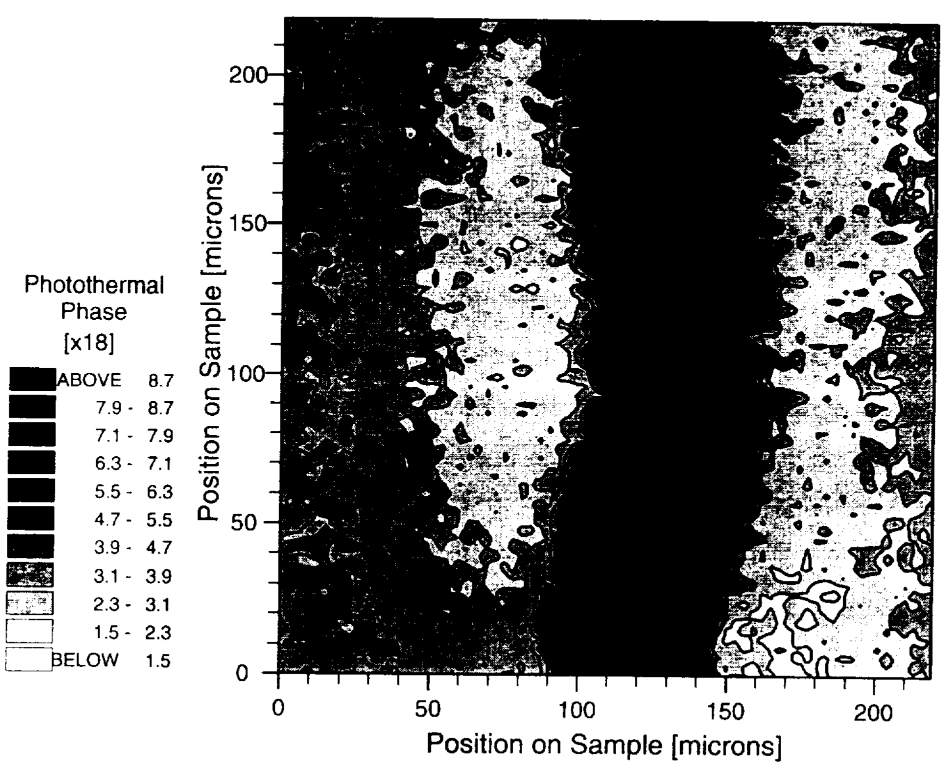

Figure 2. Photothermal phase images for cumulative AO exposures of gold-coated Kapton (continued).

4th Exposure

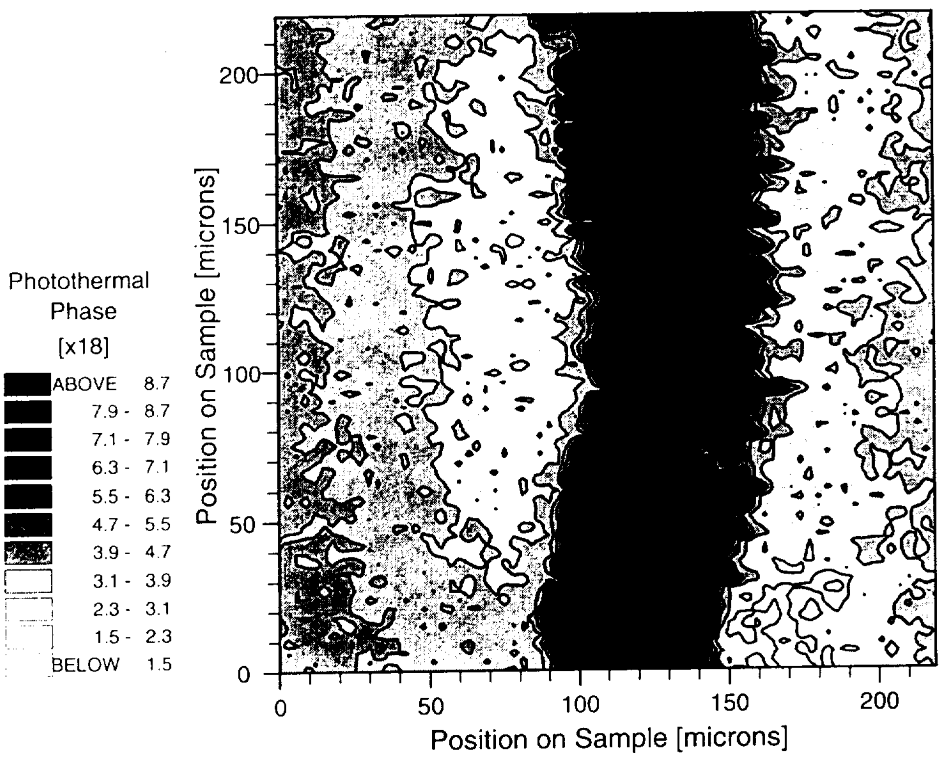

Figure 2. Photothermal phase images for cumulative AO exposures of gold-coated Kapton (continued).

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