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TITLE: LASER IGNITION STUDIES

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INTRODUCTION

The goal of this work is to study the details of laser induced ignition and combustion of high-temperature condensed-phase exothermic reactions. In this work high-speed photography (HSP) and real-time optical pyrometry have been combined to provide a diagnostic tool with a 1 ms temporal resolution for studying laser ignition and combustion wave propagation.

Previous experiments have involved the use of HSP for studying combustion wave propagation (1). Real-time pyrometry studies of the ignition process have also been performed previously. The present paper describes how HSP has been expanded to include three-view split-frame photography to allow the ignition and combustion processes to be recorded and studied simultaneuosly.

EXPERIMENTAL

A schematic representation of the experimental apparatus is shown in Fig. 1. The laser shutter (LS) was triggered by a NAC model E-10 high speed camera (framing speed used = 1000 f/sec). Radiation from a Helios HF-DF laser (DF mode, 3.8 um, 100 watt nominal pwr.) was focussed by a 350 mm focal length CaF_2 lens, entered the sample chamber through a saphire window, and impinged on the front surface of the pellet. The laser spot diameter at the pellet front surface was nominally 1 mm. The sample chamber (10^{-2} Torr accessible vacuum) was backfilled with 10 Torr of argon to minimize soiling of the windows by material vaporizing from the heated pellet.

Six mirrors were arranged as shown in Fig. 2 to allow simultaneous photography of the sample pellet front, side, and back surfaces. Three mirrors (M1, M2, M3) in the bottom of the sample chamber reflected images of the pellet to three nesting mirrors outside the sample chamber. The high-speed camera was positioned to view the images from the nesting mirrors. The axis of the camera optics was situated perpendicular to the plane of the apparatus diagrammed in Fig. 2. The mirrors showing the front and side surfaces of the pellet were fixed while the back-view mirrors were adjustable to allow viewing of pellets having different lengths. The focal depth of field of the camera optics was 40 thousandths of an inch.

In conjunction with the split-image photography, three pyrometers (see Fig. 1) were used to obtain temperature measurements of the front, side, and back surfaces of the pellet. An IRCON two-color pyrometer (P1) was aimed at the back surface, and two Thermogauge single-color photodiode pyrometers (P2, P3) were aimed at the front and side surfaces, respectively. A pyrometer (P3) used a germanium detector and provided accurate temperature measurement above 900K. Pyrometer P2 used a silicon detector and provided accurate temperature measurement above 1900K. Pyrometer P2 was focused to view a spot size approximately 1.1 mm in diameter, centered on the laser spot. A Scientech power meter (PM) was used to monitor the laser power, and an integrating sphere (IS) was used to determine the occurrence of laser burn through. The data from these diagnostics were acquired and stored using an IBM PC computer. Data acquisition by the computer was initiated 500 ms prior to the opening of the laser shutter.

The samples were cylindrical pellets ranging in size from 1/16" dia. X 1/8" l. to 1/4" dia. X 1/2" l. The pellets consisted of a stoichiometric mixture of the powdered reagents (-325 mesh) and were formed by uniaxial pressing at either 10,000 or 20,000 psi. The reagents were obtained from ALPHA VENTRON and were used as received from the supplier. Fig. 3 shows the mount used to hold the sample pellet. The sample holding ring was attached to a three axis micrometer-screw translation stage. Six 3 mil dia. tungsten support wires were the only material in contact with the pellet. Thermal loss through the tungsten wires was calculated to be less than 2 watts. Thirty-four pellets, which included mixtures of Ti+C, Zr+C, Hf+C, and the respective diboride analogs, were laser ignited, the ignition and combustion processes filmed, and real-time pyrometry data obtained.

RESULTS AND CONCLUSIONS

Results of the high-speed photography and pyrometry are currently being analyzed to obtain kinetic and temperature data for the laser ignition and combustion processes. These will be published at a later date. However, we have made a number of qualitative observations which will be discussed here.

The films indicated that laser ignition did not occur immediately and that ignition did not occur on the pellet surface as was expected. Rather, there appeared to be an ignition induction period and ignition may have occurred inside the pellet. As the laser impinged on the pellet surface, a substantial part of the pellet heated to glowing with no ignition occurring. The laser-heated volume of the pellet can be envisioned as having a hemispherical geometry. The cooler part of the pellet outside the hemisphere acts as a heat sink so that heat is conducted out of the laser heated region. The rate of heat flow out of the hemisphere is governed by the complex thermal conductivity properties of the pellet and is determined by some inverse function of the temperature of the surrounding heat sink. The heat sink eventually reaches a temperature where the rate of heat conduction out of the hemisphere equals the rate of laser heating. Additional laser heating provides the necessary thermal energy for the reactants to achieve ignition

For a pellet having dimensions much larger than the laser spot diameter, heat conduction out of the laser heated volume should be isotropic. However, dimensions of the pellets studied in this work were only an order of magnitude larger than the laser spot size. It is clear from the high-speed photography that the thermal conductivity in the pellets is anisotropic. For pellets where the length-to-diameter ratio (l/d) is greater than one, heat flow appears to be in the axial direction. For pellets where $l/d<1$ the heat flow appears to be radial. For example, we observed that in pellets having a wafer geometry ($l/d<1$), the back surface temperature almost reached that of the front surface and heat flow occurred in the radial direction just before ignition. On the other hand, for pellets having a cylindrical geometry, the surface temperature on the side of the pellet (near the laser heated end) almost reached that of the front surface and heat flow was in the axial direction before ignition occurred.

Another interesting effect observed in the films concerns the propagation of the combustion wave in pellets having $l/d>1$. The back surface image showed the appearance of a hot spot in the center of that surface before the combustion wave reached the end of the pellet. The hot spot grew in size as the combustion wave neared the end of the pellet. It appeared that the combustion wave front may have had a conical geometry. The conical shape of the wave front may be an artifact due to either the pellet geometry or the shape of the laser beam. Two explanations for the conical shape of the combustion wave may be proposed. The first is that radiant heat loss at the pellet surface decreases the velocity of the combustion wave relative to the velocity at the center of the pellet. A second explanation concerns the degree of anisotropic heat flow in the pellet as a result of continued laser irradiation. The laser may impart a momentum to the axial heat flow in the pellet and this may enhance the combustion wave velocity in the vicinity of the laser heated region.

In all experiments conducted to date the laser continued to impinge on the sample until combustion was complete. Experiments are currently being designed where laser heating will be stopped at the onset of ignition.

It is clear that HSP in conjunction with optical pyrometry provides an excellent diagnostic technique for studying SHS reactions. Coupling these two techniques provides accurate real-time temperature measurements as well as excellent temporal and spatial information on the kinetics of ignition and combustion wave propagation in SHS reactions.

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FIGURES

(1) Schematic diagram of the apparatus used to obtain split-frame high-speed photography of SHS reactions in laser-ignited pellets.

(2) Optics diagram showing the mirror configuration used to perform split-frame photography. The axis of the camera optics was positioned perpendicular to the plane containing the nesting mirrors.

(3) Side view diagram of the sample pellet mount. A portion of the sample holding ring was removed to permit HSP of the combustion wave propagation along the axis of the pellet.

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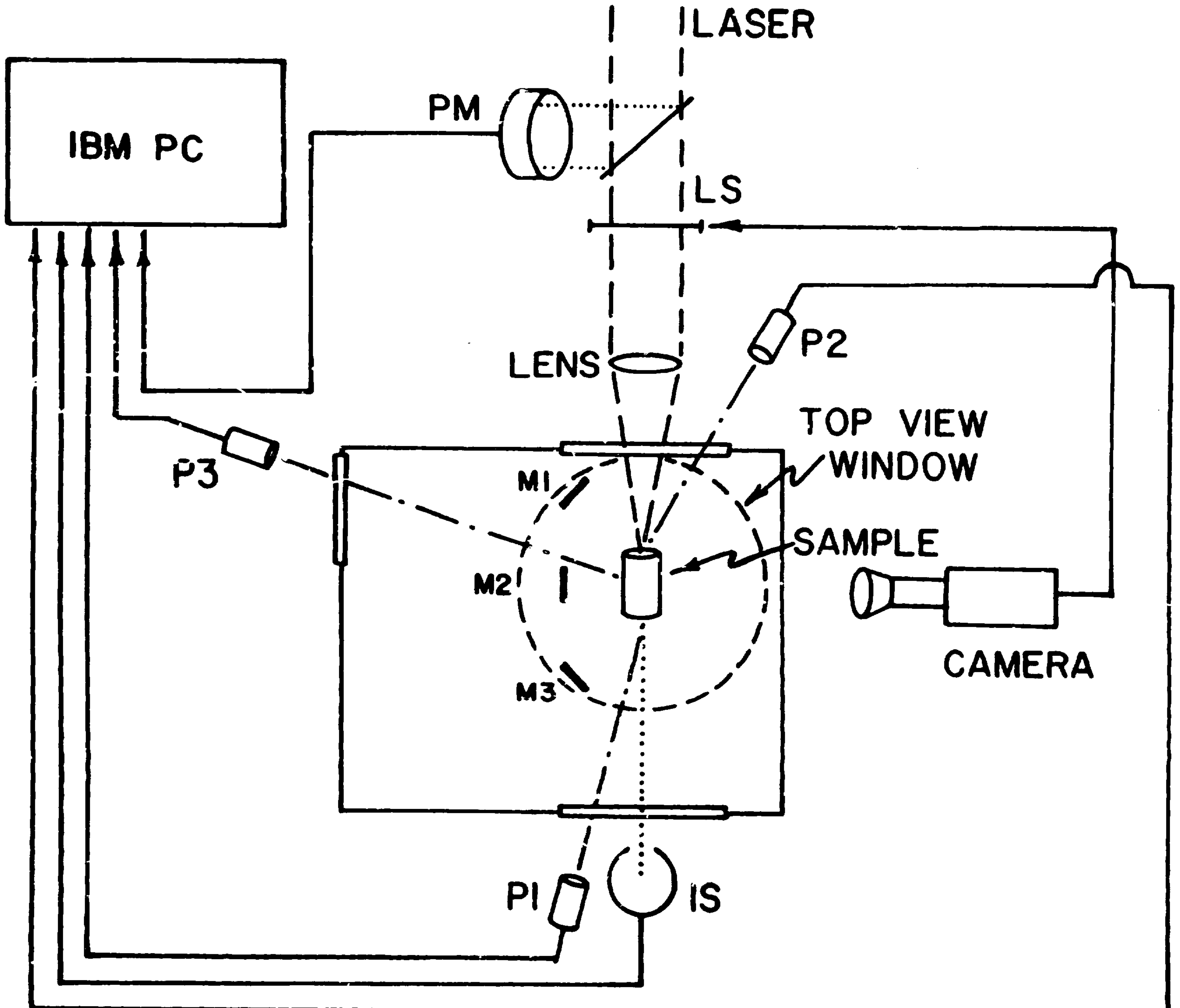
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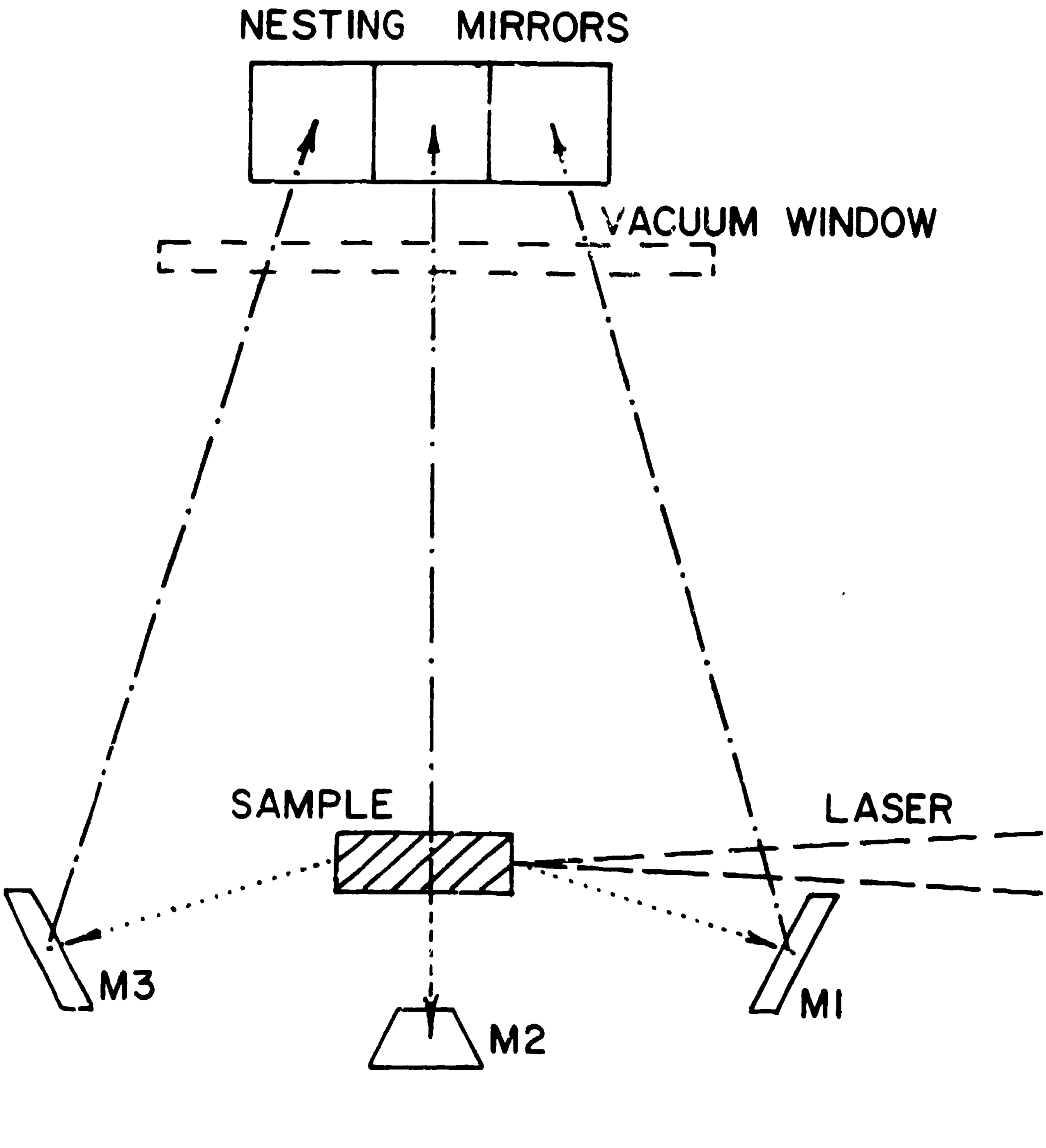
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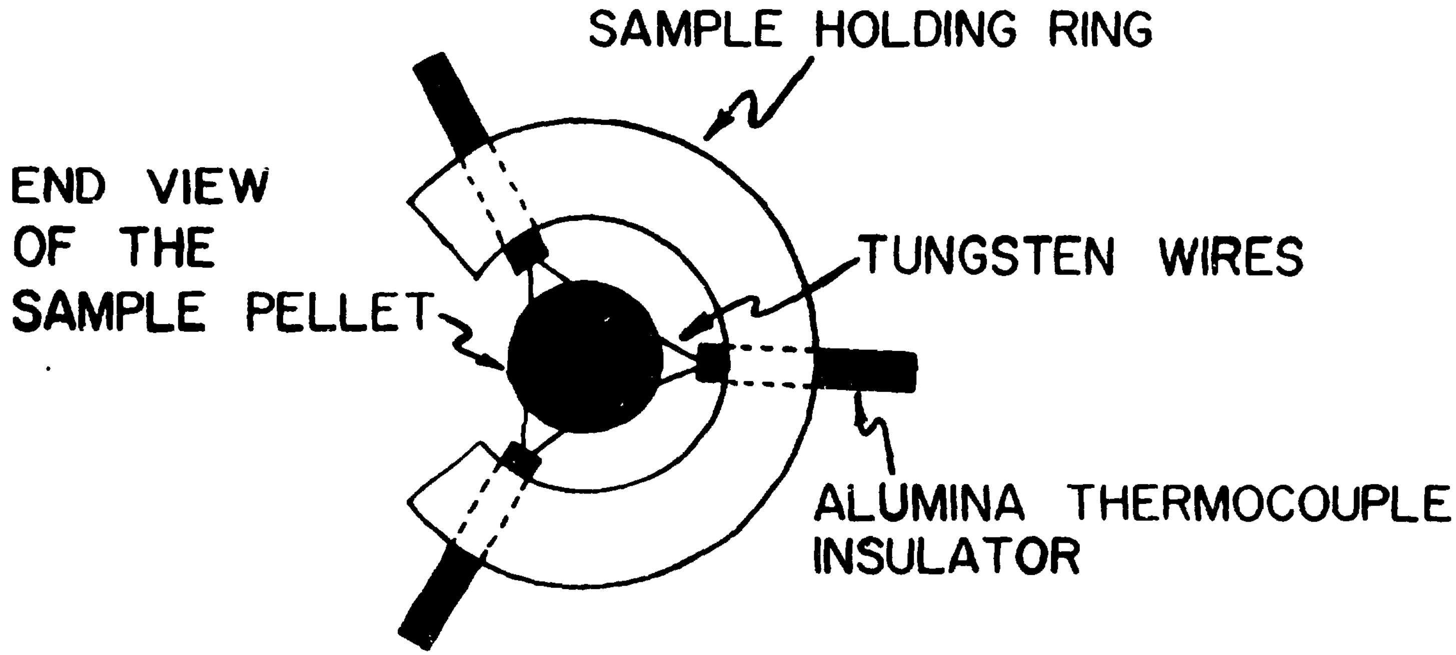
SAMPLE HOLDING RING
END VIEW
OF THE
SAMPLE PELLET
TUNGSTEN WIRES
ALUMINA THERMOCOUPLE
INSULATOR