# 10.6 Micron Interferometry and Beyond

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**ABSTRACT**

As the first graduate student coming from Korea at the Optical Sciences Center 0n January 1976, I was quite fascinated by the genuine “Openness” and “Diversities” not only in the surroundings of Tucson, but also among the people and programs at OSC. Under the guidance of Dr. James C. Wyant, various long-wavelength interferometric systems were developed using 10.6 micron CO2 laser for testing large optics, IR transmitting optics, rough surfaces, etc. This presentation describes some of the early developments in optical testing and measurements in real-time, high-speed interferometry and profiling technologies with some anecdotes.

## 1. INTRODUCTION

It is great honor and privilege to be part of this tribute to Dr. James C. Wyant. This presentation is to honor and thank him by recollecting some of the earlier works and later experiences under and with him as my teacher, advisor and colleague. Entering into the Graduate Programs at the Optical Sciences Center (now Wyant College of Optical Sciences), University of Arizona in January 1976, I was quite excited and humbled by the various fascinating courses, research projects, and unique facilities. Also, the open, supportive, vibrant, and pleasant atmosphere among faculties, staffs, and students has been inspirational and encouraging. Watching the magical works of Master Opticians, and the dark silhouettes of the routine low-flying U-2s over the campus against the backdrop of cobalt blue desert sky were additional fun memories. The initial task assigned to me as a graduate assistant was to manually locate the center of fringes for series of hard copy interferograms using a scanning microdensitometer. Having taken all the classes taught by Dr. Wyant and other related courses, I had an opportunity to ask him to be my dissertation advisor, and had become a part of his dynamic group of students.

## 2. INFRARED POINT DIFFRACTION INTERFEROMETER (IRPDI)

There were growing needs for design, fabrication, and testing of IR materials, metal optics, and other non-conventional small and large modern optical components and systems. With Dr. Wyant’s suggestion and guidance, I took the projects to expand and convert the conventional visible interferometry to the infrared wavelength region using a 10.6micron CO2 laser.

The well-known and simple nature of the Smartt Point Diffraction Interferometer(1) was considered as a good start to demonstrate these conversions (Fig. 1). First, various sizes of spherical micro-balloons were placed on polished surface of thin 1-inch diameter silicon wafer substrates using the tip of fine needles from cacti abundant in the UA campus ground. Then gold thin film was vacuum-coated on the wafers in upside-down position. Good number of micro-balloons were survived and gently blown away leaving pinholes of different sizes for spherical reference wavefronts. Optimum combinations of pinhole size vs IR transmittance were selected with respect to the size of the point diffraction patterns of the test optics for self-referenced interferograms of different contrasts. (Fig. 2).(2)

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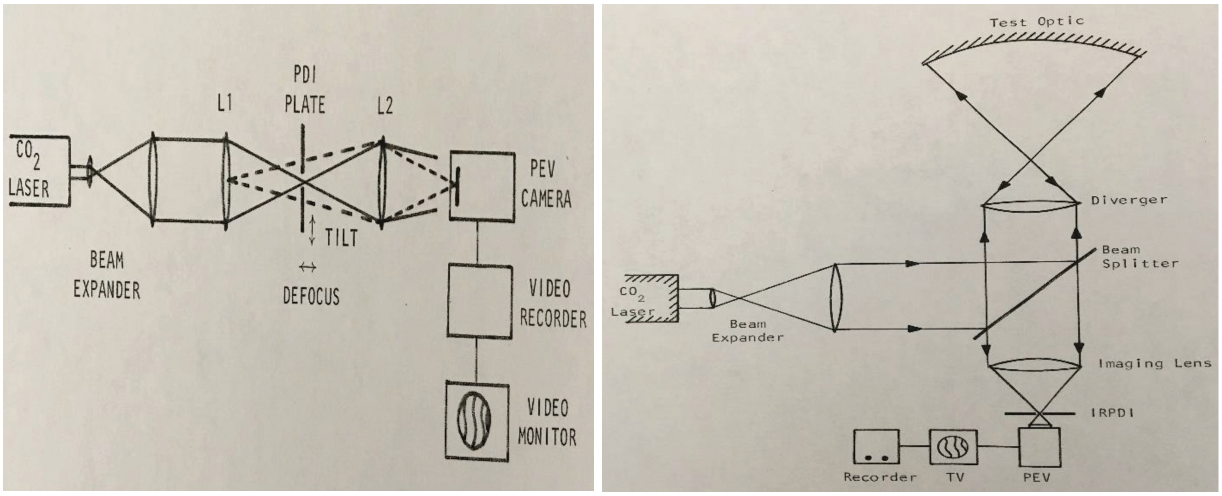



(a) (b)

Fig. 1. Infrared Point Diffraction Interferometer (IRPDI). (a) Transmitting Optics, (b) Reflecting Optics

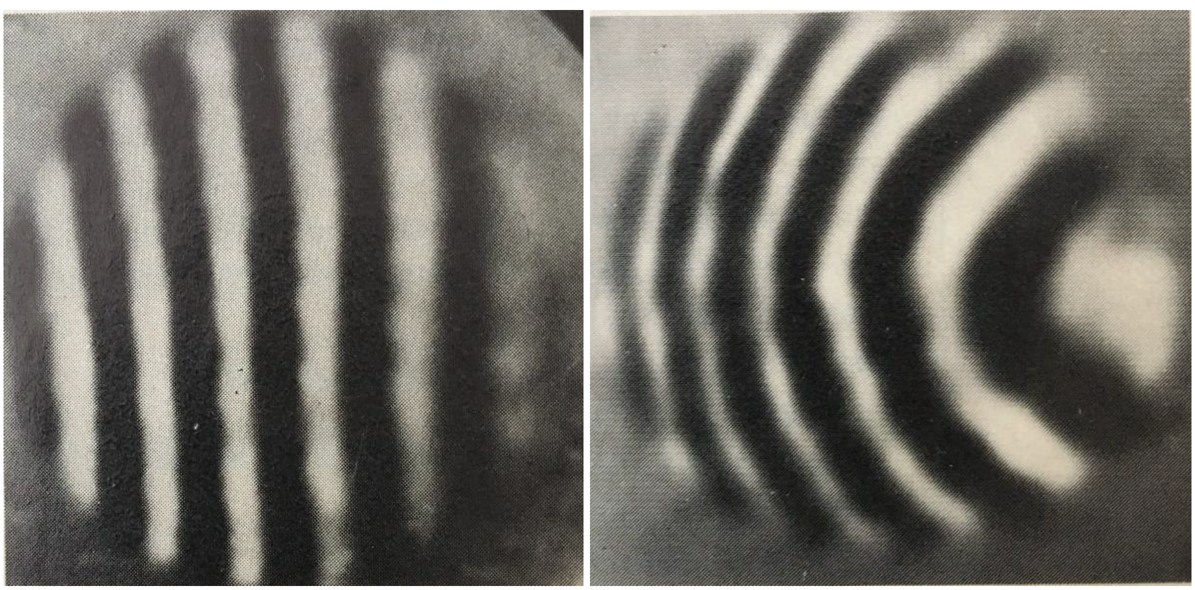
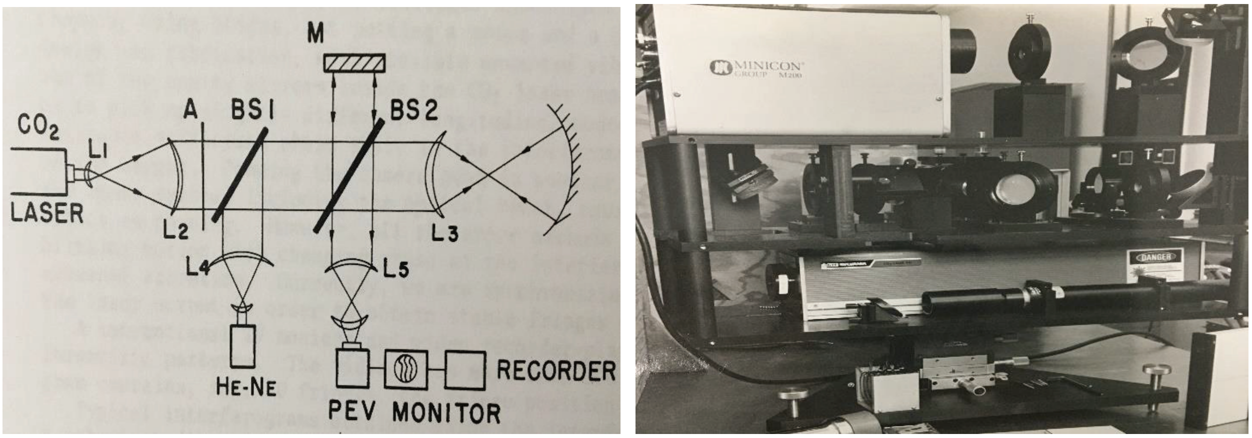


Fig. 2. IRPDI Interferograms for F/6 Germanium Lens

## 3. IR LASER UNEQUAL-PATH INTERFEROMETER (IRLUPI)

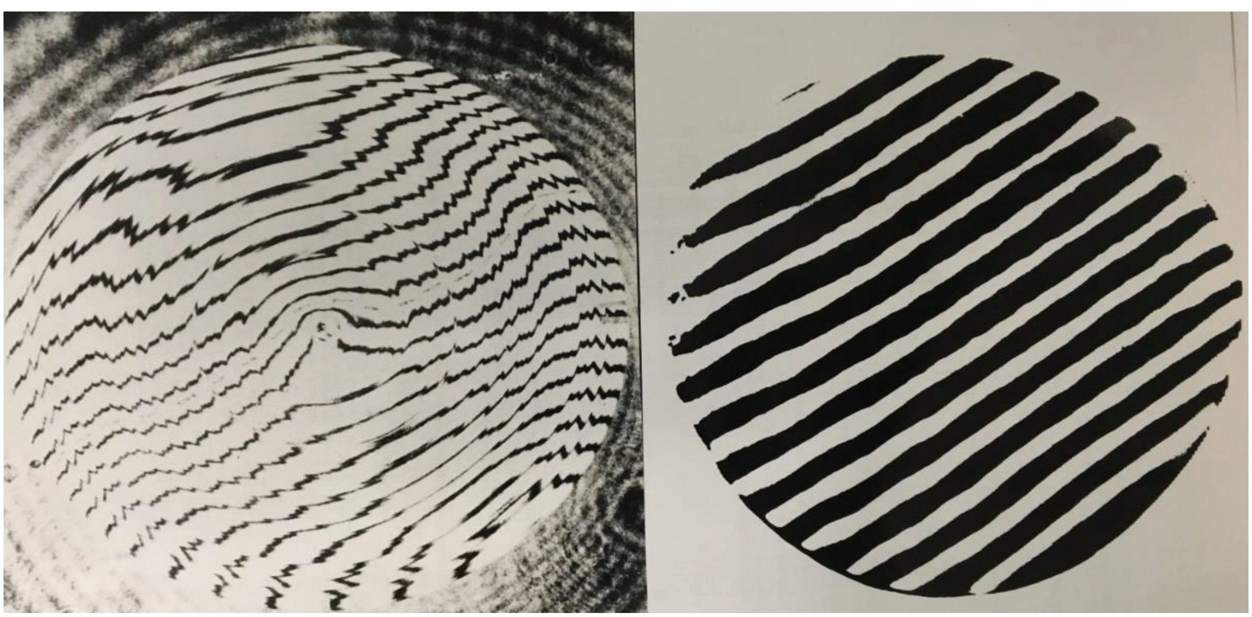
The next project was to convert the Laser Unequal-Path Interferometer (LPUPI) applied for testing of diamond-turned metal optics for high-energy laser systems, Computer Generate Holograms (CGH), and fabrication of large off-axis aspheric mirrors. (Fig. 3)




(a) (b)

Fig. 3. IR Twyman-Green Interferometry. (a) Schematic with He-Ne Alignment Laser, (b) Prototype

A prototype system was constructed on a tripod base with a heavy-duty Klinger XYZ micro-stage. A 3W water-cooled CO2 laser was configured with germanium lenses. A He-Ne laser was added for visible alignment with ZnSe optics. CaF plates were used as attenuators for the Magnavox Pyroelectric vidicon with a video tape recorder for later playbacks. Fig. 4, Fig. 5 show the interferograms demonstrating remarkable differences between visible and IR wavelengths for a diamond-turned metal flat and a segment of off-axis aspheric aluminum mirror, respectively.(3)



(a) (b)

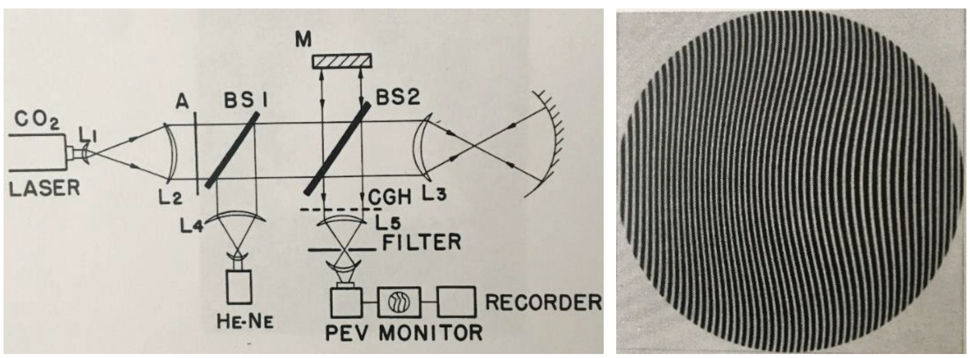
Fig. 4. Interferograms of a diamond-turned Metal Flat, (a) at 0.6328 micron, (b) at 10.6 micron

(a) (b)

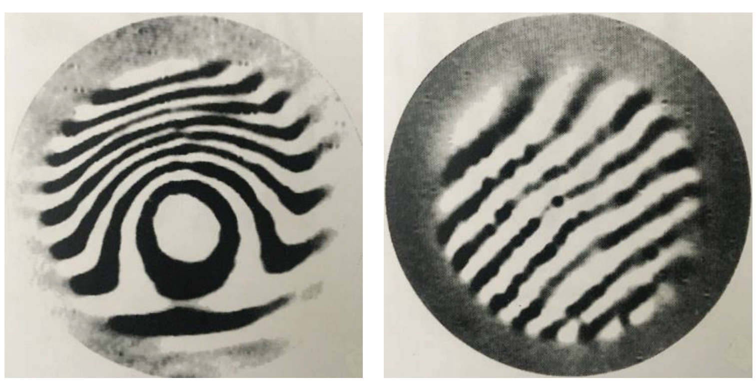
Fig. 5. Interferograms of a diamond-turned Off-Axis Aspherics, (a) at 0.6328 micron, (b) at 10.6 micron

## 4. IRLUPI WITH IR COMPUTER GENERATED HOLOGRM (IRCGH)

CGH has been used as a means of nondestructive null testing of optics with severe departures from the "ideal" reference surfaces or wavefronts if master optics may not be available for making a real test plate hologram. Fig. 6 shows the schematics of IRLUPI-CGH Interferometer and test results for an elliptical mirror.(3)




(a) (b)



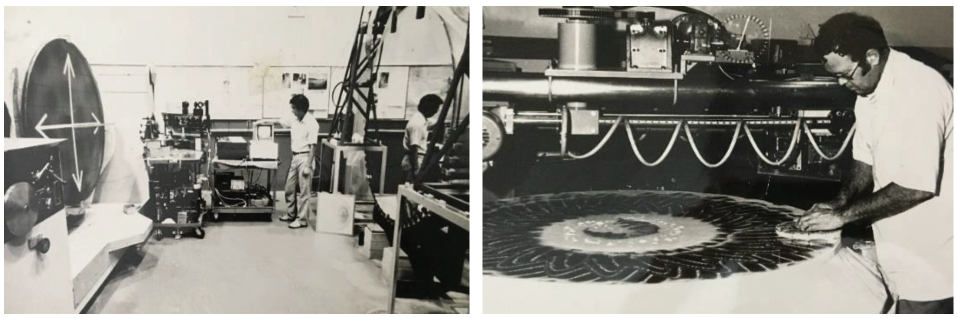
(c) (d)

Fig. 6. (a) Schematics of IRLUPI-CGH, (b) IRCGH silicon test plate, (c) Interferogram w/o IRCGH Plate

(d) Interferogram w/IRCGH Plate

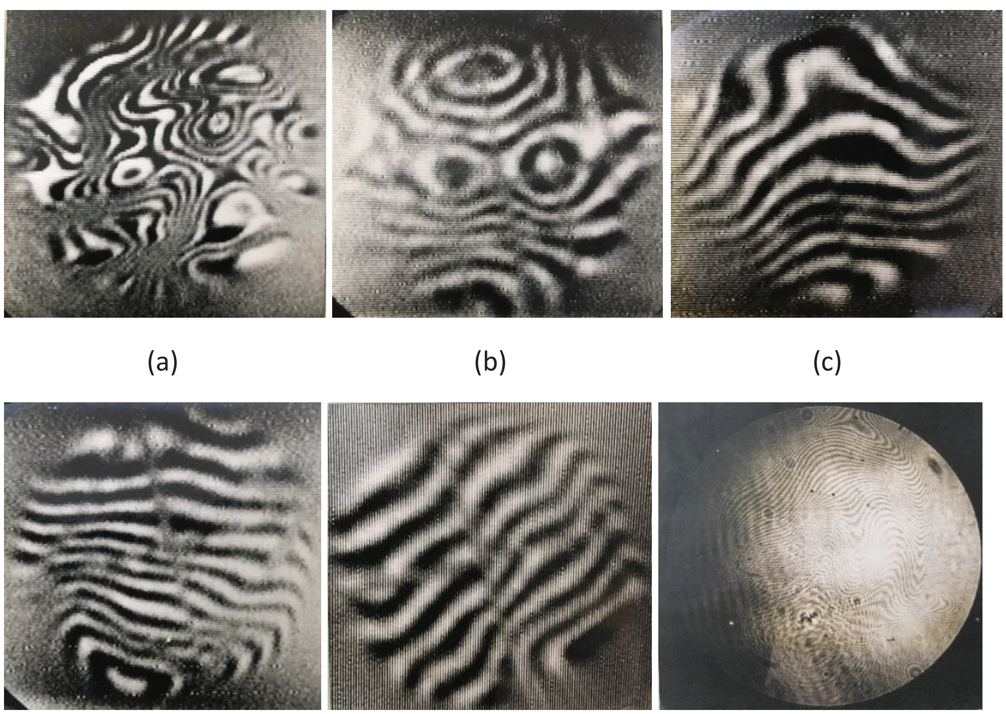
## 5. IRLUPI FOR FABRICATION AND TESTING OF LARGE OFF-AXIS PARABOLA

The effectiveness of IRLUPI was well demonstrated through the fabrication and testing cycles of 60-in diameter off-axis parabolic primary mirror during the grinding stages by providing interferograms of the rough surface of the primary mirror at each cycle. Fig. 7 shows, (a) the primary mirror with fiducial marks, IRLUPI and the 90-in reference flat mirror, and (b) polishing of 60-in off-axis parabola. Fig. 8. shows examples of IRLUPI interferograms during the progressive grinding stages, and the He-Ne laser interferogram of the polished surface which still shows dense fringes indicating still large departures from the final surface figure. This enhanced testing capability had some contribution for the project to save time and budget.(4)



(a) (b)

Fig. 7. (a) IRLUPI Testing Elements, and (b) Fabrication of 60-in off-axis parabola



(a) (b) (c)

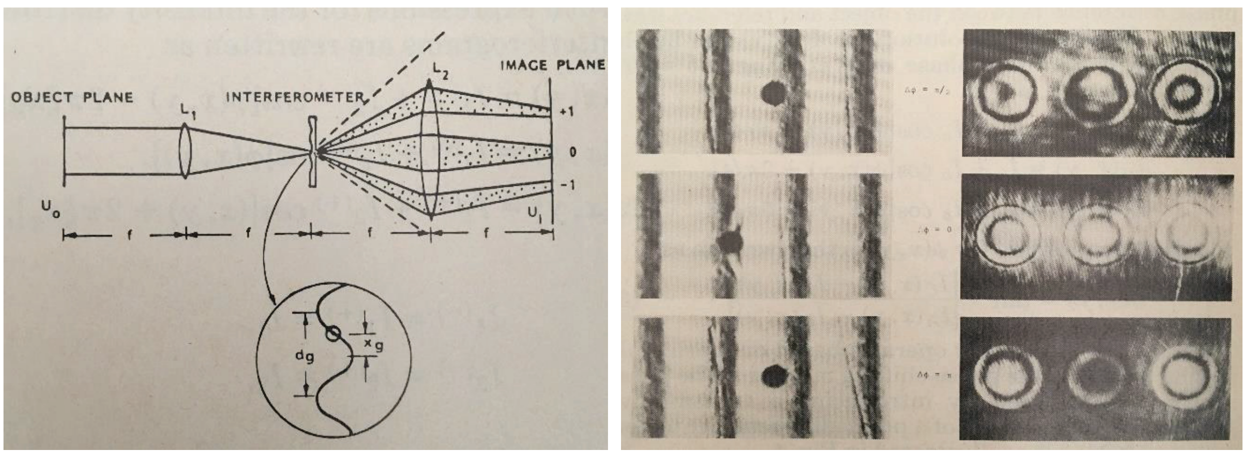
(d) (e) (f)

Fig. 8. (a)-(e) Progressive IRLUPI Interferograms of grinding stage, and (f) Visible Interferogram of Initial polishing stage.

## 6. SIMULTANEOUS PHASE-SHIFTED INTERFEROMETRY

The post-graduate activities at the Lockheed Martin were involved with the development of advanced real-time interferometry for optical testing, wavefront sensing, diagnostics, and control of the large-aperture optical systems, high-speed optical phenomena, high-power laser systems, and 3-D surface profiles of diverse subjects for both ground and space applications.

One of the simplest methods for implementing the “Phase-Shifting” to the interferograms instantaneously or simultaneously was to introduce pinholes to grating substrates resulting a Phase-Shifted Smartt Point Diffraction Interferometer (PSPDI). Fig. 9. shows (a) the schematic, and (b) the phase-shited interferograms at 90, 0, and 180 degrees respectively.

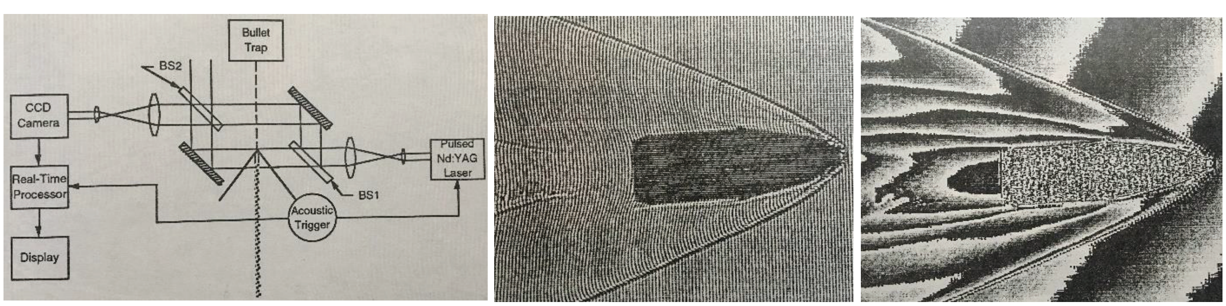



(a) (b)

Fig. 9. Phase-Shifted PDI, (a) Schematic, and (b) Interferograms at 90, 0 and 180-degree Phase Shift.

## 7. PULSED LASER INTERFEROMETRY

The pulsed laser interferometry was applied to the high-speed optical phenomena by introducing large amount of tilt fringes coupled with high resolution digital arrays for phase measurement. Fig. 10. Shows (a) schematics, and (b) interference pattern with large tilts, and (c) phase-unwrapped density distribution.

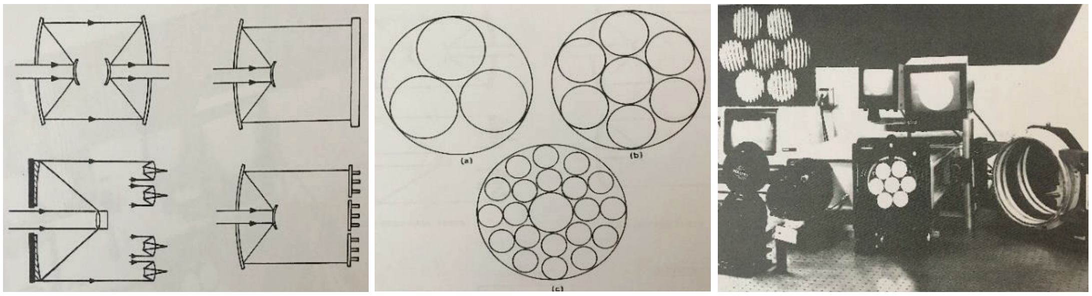



(a) (b) (c)

Fig. 10. Pulsed Laser Interferometry, (a) Schematics, (b) Interferogram, (c) Unwrapped Phase Map.

## 8. MULTIPLE SUBAPERTURE OPTICAL TESTING

Theoretical analysis and experimental feasibility were demonstrated for the use of subaperture test optics to evaluate the performance of advanced lightweight large optical systems as shown in Fig. 11.



(a) (b) (c)

Fig. 11. Subaperture Optical Testing, (a) Configuration, (b) Array Geometry, (c) Experimental Setup

## 9. FRINGE PROJECTION INTERFEROMETRY FOR 3-D PROFILING AND STEP-GAP MEASUREMENTS

The automated fringe projection interferometry was found to be quite effective time and cost saving tool for versatile 3-D profiling of objects with various sizes, shapes and surface conditions in civil and defense applications. Special contributions were recognized for the step-gap sensor system for the inspection and installation of the heat-shield tiles on the Space Shuttles after each flight. The traditional tools for these tasks were to manually use gauges for gaps, and dial indicators for steps, and rulers for recession. These were very time-consuming and inaccurate considering the large number of different tiles (over 25,000) which required nearly 75,000 total measurements for each orbiter turnaround.

## 10. TANGENTIAL CAREER SHIFT TO COMMERCIAL SATELLITE IMAGING INDUSTRY.

The end of "cold war" era in early 90's opened up unique opportunities to commercialize some of the previously restricted technologies for public use. Space Imaging LLC was formed by Lockheed Martin with other international partners for global operation and distribution of high spatial resolution digital satellite imageries. Regional partners were selected at the strategic locations that operate ground receiving and processing facilities to provide continuing coverages of the earth for wide ranges of users in government and private sectors. Fig. 12. shows examples with dramatic evolution of the quality of satellite imageries.

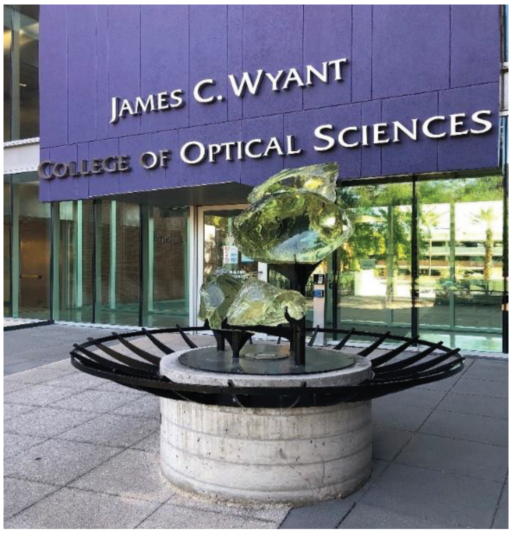

(a) (b)

Fig. 12. Satellite Imageries, (a) Low Resolution Black & White, and (b) High Resolution Multispectral

## 11. ACKNOWLEDGEMENT

I would like to thank SPIE leadership, especially Conference Chairs, Dr. V. N. Mahajan and Dr. D. W. Kim for organizing this special Tribute to Dr. James C. Wyant for honoring and appreciating him and his multi-faceted, extraordinary works and contributions in the Optical Metrology, Education and Industry.

I thank him deeply for taking me on as one of his students and has supported me personally and professionally in many ways over the years. Wishing him many blessings and good health!

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