# Wavefront Year for Analyzing aNd Testing in 2021 (Wyant-2021)

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## ABSTRACT

Wavefront sensors are applied for wavefront measurement, which is the basis for analyzing and testing optical systems. SPIE (OP300) 2021 is a special year for Tribute to Professor James C. Wyant who has great contributions and services to the fields of optical metrology and optics education, including the science and application of interferometry. This paper focuses mainly on recalling some interesting stories related to Prof. Wyant.

**Key Words**: Wavefront sensor, tribute to Prof. Wyant, optical metrology, laser interferometer

A laser interferometer is one of the typical wavefront sensors. It is used not only to measure the wavefront in reflection, but also in transmission. This paper covers three main stories: the change of wavefront sensor, distance learning program, and "role transition".

## 1. CHANGE FROM POINT SENSOR TO WAVEFRONT SENSOR

### 1.1 A key person

It seems that every 12th year of my life, i.e. my big year, some special things would happen, for example in my first big year when I was a 12-year old boy, two of my gouache paintings were published in a local daily newspaper; in my second big year when I was 24-year old, I got my master degree in optical engineering from Changchun Institute of Optics and Fine Mechanics, which is currently known as Changchun University of Science and Technology (CUST). My third big year was no exception. In 1997, I obtained my Ph.D. in optical engineering under the guidance of Professor Hans Tiziani from the University of Stuttgart (US) and my research field changed from point sensor to wavefront sensor. A reason for this change is that my Ph.D. study at US was focusing on heterodyne interferometers for distance measurement[1], but WYKO's main products were Fizeau interferometers for measuring surface shapes. The change was not done without a special person — Dr. James C. Wyant (Figure 1) who was both a professor of Optical Sciences Center (OSC), University of Arizona (UA), and a Chairman of WYKO Corp. In fact, before coming to Tucson, I have even read a lot of his papers and worshipped his contribution to optical metrology and education.

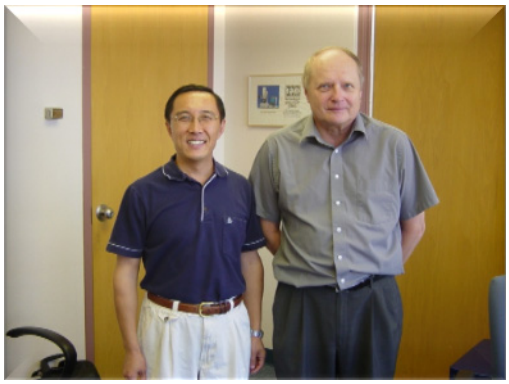

Figure 1 Prof. James Wyant (right), Dean of OSC and Chairman of WYKO Corp and Prof. Sen Han (left)

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edited by Virendra N. Mahajan, Daewook Kim, Proc. of SPIE Vol. 11813, 118130P
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### 1.2 Meeting for the first time

On June 16, 1997, our family wanted to leave Stuttgart, Germany for Arizona in the United States. This international travel was not a family vacation, but instead work for Boss Wyant's company. The entire travel costs were taken care of by Boss Wyant. When the front door of international Tucson Airport was opened, waves of heat crashed into my face. My immediate reaction was how I would live here and Tucson is so different from Stuttgart. After three months, I touched my head and realized I am still alive. In addition, I found that Tucson's sky is always deep blue. Tucson is a city that is really good for optics development. I see why people call it the Optical Valley.

Boss Wyant drove his "big truck" to pick us up. Unfortunately, we didn't have so much stuff for the "big truck". Finally, he rented a medium-sized car for us. When I worked at WYKO on the first day, some colleagues told me that Boss Wyant said we hired an Optical Doctor. He had an Asian face and spoke English with a very strong German accent. After our first meeting, Boss Wyant's "big truck" left a "big" impression on me, and my Asian face and German accent gave him one as well.

Even till now, I still ask myself two questions: (1) Should I have brought some equipment and furniture from Germany, otherwise, why would Boss Wyant use his "big truck" to pick us up? (2) Does Boss Wyant like German accents, otherwise, why didn't I have an interview for this job opening?

### 1.3 Typical wavefront sensors

There are two main wavefront sensors - one of them is Hartmann sensor and the other one is laser interferometers. Prof. Wyant has published many papers related to phase shifting techniques and his WYKO has designed and manufactured many interferometer products for high-end application markets. In addition, based on these fundamental phase shifting techniques, H&L Instruments has developed a new wavefront sensor.


Figure 2 Prof. Wyant (left) and Prof. Han (right) visited the customer's lab

The world's first 24" phase shifting interferometer was made by WYKO in 1997. At that time, it was the digital interferometer with the largest aperture[2,3]. Figure 2 shows Prof. Wyant and Prof. Han visiting the customer's lab of the 24" interferometer in China in 2000. Before shipment, it was located in WYKO's lab in 1997 (Figure 3).


Figure 3 24" interferometer at WYKO's lab


Figure 4 1.06um high accurate interferometer for LIGO project

The 1.06um highly-accurate interferometer[4] showed in figure 4 was designed and manufactured to measure super-smooth optics for the Laser Interferometer Gravitational-Wave Observatory (LIGO) in 1998. LIGO project is supported technically by Caltech and MIT. At the end of acceptance testing for the 1.06um interferometer, Caltech assessed "RMS 1nm was successfully obtained by the 1.06um interferometer". In 2017, three scientists obtained the Nobel Prize. But at that time, Prof. Wyant worked at 4D Technology. "He ran too fast and I couldn't catch up."

The multi-wavelength interferometer for wavefront testing was designed by H&L Instruments. It mainly focuses on solving the wavefront measurement in transmission when the design wavelength of a transmission system under testing is different from the testing wavelength in a standard laser interferometer. A simulation result was done by using both a design wavelength and three testing wavelengths[5]. The wavefront shape generated by calculating the real system at the design wavelength of λ=400nm is shown in Figure 5. The generated shape uses Zernike coefficients and is calculated with the Conrady-Zernike formula from three wavelengths (600nm, 630nm, 660nm), shown in Figure 6[6]. Their values of Peak to Valley (PV) are 0.4454λ and 0.4444 λ (λ =400nm), respectively.

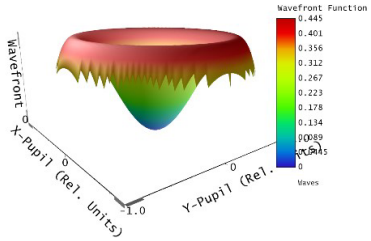


Figure 5 Wavefront shape with PV 0.4454λ from a design wavelength of 400nm.

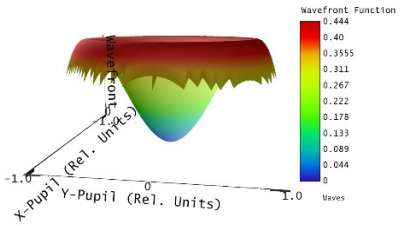


Figure 6 Wavefront shape with PV 0.4444λ from the three wavelengths of 600nm, 630nm, 660nm.

The interferometer layout is given in Figure 7[7] where five wavelengths are used, including 473nm, 532nm, 632.8nm, 721nm, 1064nm. Experimental results are followed as Figure 8[7].

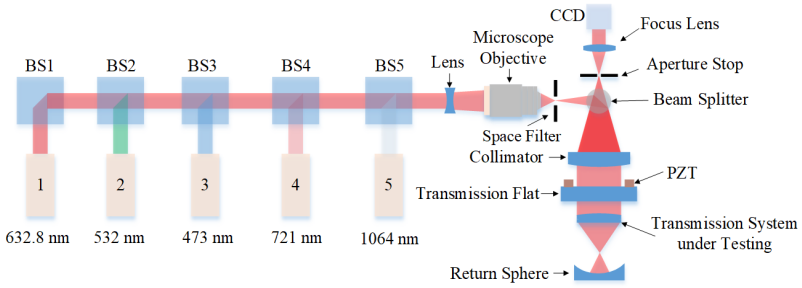


Figure 7 Layout of a multi-wavelength interferometer

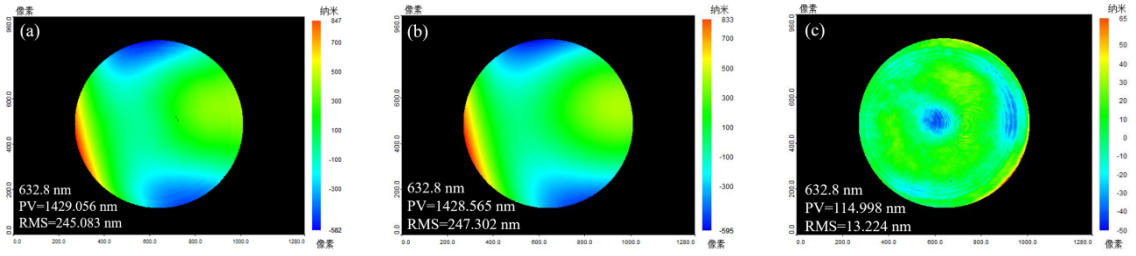


Figure 8 Real measurement results for the design wavelength of 632.8nm: (a) PV=1429.056nm and RMS=245.083nm using the testing wavelength of 632.8nm which is the same as the design wavelength, (b) PV=1428.565nm and RMS=247.302nm using the three testing wavelengths of 473nm, 532nm and 1064nm, (c) difference between (a) and (b) which is a residual error with PV=114.998nm and RMS=13.224nm.

The multi-wavelength interferometer may be used as a new method for analysing and testing the transmission wavefront.

## 2. DISTANCE LEARNING PROGRAM FROM OSC TO CUST

Changchun is an original city for optics in China, Tucson is an optical valley in the United States; Changchun University of Science and Technology has a College of Optical Engineering, the University of Arizona has an Optical Sciences Center. This background made bilateral cooperation inevitable. The Distance Learning Program (DLP) from OSC was a great bridge to connect both parties. Thus, the DLP was introduced from OSC to CUST.


Figure 9 Prof. Wyant (middle), Prof. Greivenkamp (left) and Prof. Han at the DLP introduction

Prof. Huiling Jiang who was the President of CUST in 2005 met Prof. Wyant, Prof. John Greivenkamp, and Prof. Jose Sasian at CUST (Figure 9). The photo shown in Figure 10 was taken in front of the CUST main building.


Figure 10 Photo was taken after the DLP introduction with Prof. James Wyant (left 5), Prof. John Greivenkamp (left 4), Prof. Jose Sasian (left 3), Prof. Huiling Jiang (right 5), and Prof. Sen Han (right 4).

After 4 years, Prof. Huadong Yu, who was the President of CUST in 2009, was making a return visit to OSC (Figure 11). Prof. Wyant met Prof. Yu and other professors from CUST. There were also many other

activities, including a seminar, meetings with the UA Vice President and other management teams, and a barbecue (Figure 12).

Figure 11 Prof James Wyant met Prof Huadong Yu, CUST President at UA in 2009

Figure 12 Other activities in Tucson in 2009

## 3. TRANSITION FROM A PROFESSOR TO A "NEW KING"

It is well known that Prof. Wyant has visited many places and made probably thousands of presentations because he is a very famous professor in optical metrology and optical education.

### 3.1 Professor role

Prof. Wyant was invited to attend the first Advanced Optical Manufacturing and Testing Technologies (AOMATT) in 2000 in Chengdu as a conference chair and a plenary speaker (Figure 13). Prof Li Yang organized and hosted this conference. SPIE supported publishing the first proceeding for AOMATT-2000 and other proceedings (Figure 14).

Figure 13 Prof James Wyant, Prof. Li Yang, and Prof. Harvey Pollicove (from right)


Figure 14 First and Proceedings of SPIE for AOMATT-2000 and others

This International Commission for Optics (ICO) gathered many famous professors and scientists. Prof Wyant attended it in Changchun in 2005 (Figure 15). As shown in the photo, at that time, cell phones were normally hung on belts.

Figure 15 Dr. Phil Stahl (SPIE President in 2014), Prof. John Greivenkamp (SPIE President in 2020), Prof. Jose Sasian, Prof. Malgorzata Kujawinska (SPIE President in 2005), a friend of Prof. Wyant, Prof. James Wyant and Prof. Sen Han (from left to right)

This training class on writing research papers was organized by both the Optical Society of America (OSA) and Chinese Laser Press (CLP) in Shanghai in 2012. Prof. Wyant was invited as a speaker (Figure 16) and asked me to translate from English to Chinese.

Figure 16 Prof. James Wyant was teaching a training on writing research papers.

### 3.2 New role

In 2012, there was a tour plan to see a 1000+-year-old town near Shanghai — Zhouzhuang. It was raining, but Zhouzhuang's scenery was still beautiful. Its main features are small bridges and water (Figure 17).

Figure 17 Prof. James Wyant was taking some nice photos.

Prof. Wyant liked them. He walked on stone streets and bridges until he was really tired, then sat down to take a rest (Figure 18). Prof. Wyant was thinking of what to do next. Just at that time, a tour guide said a former King sat down at that exact spot many years ago. Now it can be his turn to take that position. Thus, Prof. Wyant had this new role and the old town had a "NEW KING". In this travel, he smoothly and successfully transited himself from the professor to the "NEW KING" (Figure 19).

Figure 18 Prof James Wyant walked on a bridge and a stone road and then sat down with Prof. Sen Han.

Figure 19 Prof. James Wyant became a "NEW KING" for the old town.

## 4. SUMMARY

This paper summarized the wavefront measurements which are related to Prof. James Wyant's contribution to optical metrology and optical education. Prof. Wyant is both a great professor and a successful businessman.

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