OSSC Optical Society of Southern California

IMAGES

Newsletter Volume 25, Number 7 WWW.OSSC.ORG April 2019

From the President

Greetings OSSC Members!

After a few attempts and several years, Dr. Hamid Hemmati arranged for us to visit Facebook at their new Northridge facility to learn about their connectivity research. This event was a little out of the way for many people, but it brought quite a few people that we have not seen in a while including Antonio Mendez who originally suggested this event.

We will be finishing out our program year with an event in El Segundo on coating technology. Rumor has it that our speaker, Wayne Rodgers will avoid the LA traffic by flying his personal plane to the event. This might be the first time a speaker has done this for the OSSC, but regardless we appreciate that he picked up the slot left open because we are delaying the JWST talk until next year. Then for our grand finale, we will be having a talk on Quantum Computing in a central location in Brea, and we hope everyone can attend the talk and welcome the new OSSC officers.

I met with the nomination committee, which is a group of past Presidents to help fill the BOD for next year and beyond. We are still looking to fill a couple of positions, and anyone can be nominated from the floor prior to or at the May meeting for any office. However, I suggest you get feedback from anyone you want to nominate. The key criteria are the ability to do the job, the desire to do the job, and the time to do the job. Many of us are working busy jobs with other commitments, so even a few extra hours per month is difficult; however, most of our members have the skills and general experience to succeed in a leadership role. Plus, for all the positions, there is an option to be mentored in that position to prepare you for the role in a future year. For those of you being shy about not having the experience, I would like to embarrass Shankar, our current Newsletter Editor. I doubt he would have put newsletter editing on his resume; however, we really had a big hole to fill, and he wanted to contribute. So he stepped in and learned how to get it done on one of the more time consuming and stressful roles. Now, he obviously leveraged his years of leadership and presentation skills; however, he developed new ones and learned more about the society by performing this stretch role. There are many of you in a similar situation, and not many companies today give their employees these types of growth opportunities.

The dates for Mirror Tech Days have been set, and they are November 5th - 7th 2019 at NGC. This may be the last year with the extra motivation to have this event as the telescope may be all packaged up by late 2020. We look forward to this excellent event and will likely be looking for student volunteers this year as in 2017. So please contact Martin Hagenbuechle, Kevin Romero, or myself if you are interested.

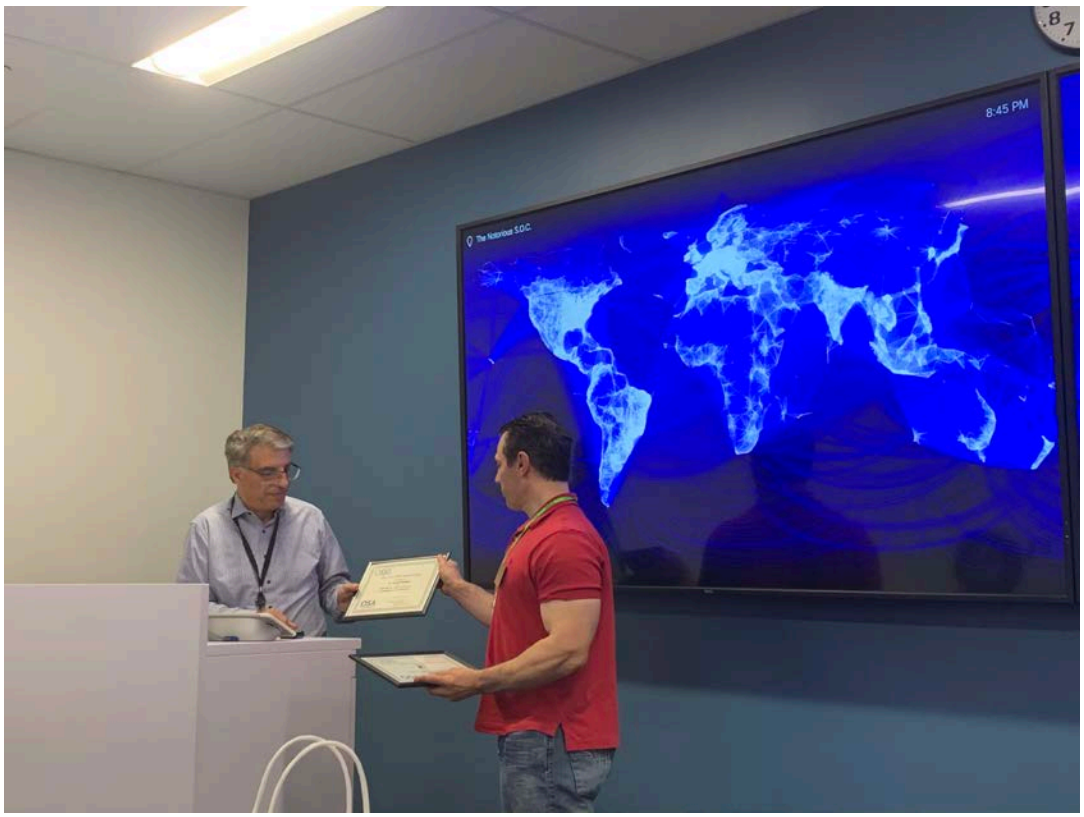
Finally, I would like to put out a special thanks to Past OSSC Presidents Bo Wang and Donn Silbermann who picked up for our Outreach Chair who moved to Seattle, along with Dr. Brian Monacelli and his students, IEEE Southern California Chair pro-tem Brian Hagerty, OSSC Members Paul Nylander and Mark Helmlinger and everyone else who helped make this a successful event.

Sincerely,
Nicholas J. Croglio Jr.
OSSC President 2018/19

From the Editor

Welcome to the April 2019 Images Newsletter!

For this issue of *Images*, OSSC Councilor Russell Rauch has provided an interesting technical article on broadband interferometry with unequal path lengths, a technique that has been patented fairly recently.



President Nicholas Croglio presenting OSSC March 2019 guest speaker Dr. Hamid Hemmati his one year OSSC Membership Certificate.

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Evolution of Optical Monitoring for Thin Film Coating

Wayne Rodgers, President, Eddy Co.

OSSC Monthly Meeting, May 8th 2019

Abstract: Multi-layer optical coatings play a key part in modern photonics, tailoring optical properties to create high-performance mirrors, low reflectivity surfaces, and wavelength or polarization dependent optics. Without such coatings, many optical systems would not be practical, or even possible. While multi-layer optical coating technology has developed tremendously since its inception in the 1940's, there are still challenges that can lead to failed designs and require optimization by trial and error.

Much of the trial and error in coating design is driven by the difficulty in accurately specifying index dispersion for each material. While index dispersion can be approximated by bulk index values or thin film measured values, for many this is insufficient to accurately design a coating without multiple iterations. What is required is an accurate estimate of index dispersion produced by a particular coating technique on a particular machine.

The IDEM system provides a unique index calibration for each material and process used in particular machine. IDEM then monitors the reflected vis/NIR spectrum (400nm-900nm), fitting the reflectivity curve derived for the layer's calibrated index dispersion and the combined dispersion of the substrate and previous layers (IDEM can track more than four layers on one witness chip), rather than monitoring a key wavelength. Additional benefits are continuous insight into system performance, and ability to restart a coating run after a system interruption. IDEM significantly increases the reliability and efficiency of creating multi-layer optical coatings, reducing lead-time and increasing cost margin.

About our speaker: Wayne's involvement in the coating industry began in 1962, working at Infra-red Industries in Carpinteria. This was followed by 4 years in the US Air Force, after which he joined the UCLA molecular beam lab, where he spent 15 years designing and building vacuum systems, spectrometers and particle detectors. During this time, Wayne's entrepreneurial spirit was awakened, and he founded the Eddy Co, and Select Coating Lab. Since its creation, the Eddy Co has been a leader in multi-layer coating technology and scientific equipment design and development.

Wednesday, May 8th, 2019

Reception: 6:00; Dinner: 7:00; Talk: 8:00

Dinner: $35 for members registered by May 2 ($40 non-members), $40 after for members ($45 non-members)

(OSSC Student Members $10 by May 2, $20 after)

The Proud Bird Food Bazaar & Event Center

11022 Aviation Blvd, Los Angeles, CA 90045

(310) 670-3093

On-line Registration: www.ossc.org or

Contact: Alex Small

Events@ossc.org, 240-672-7639

Event map on following page 4.

[The Proud Bird, 11022 Aviation Blvd., Los Angeles, CA 90045](#) Ph: (310) 670-3093

Phase Shifted Broadband Light Source Fringes

by Russell Rauch, OSSC Councilor

Summary

This article briefly describes the principle of shifting the phase of a broadband light source by periodically modulating the spectrum of the light source. The technique is described in a patent as referenced below (1), and *it allows broadband interferometry with unequal path lengths.*

Limitations of a Broadband Source

Consider a Michelson interferometer with a broadband light source, schematically illustrated in Figure 1. The fringes have maximum signal when the optical path lengths of the two arms of the interferometer are equal. Unlike a coherent source, the fringes for a broadband source in the Michelson interferometer diminish quickly as one mirror is displaced by distance h.

Suppose that an LED is used as the broadband source. Figure 2 (top) illustrates an idealized spectrum of a LED with a center wavelength 633nm and a spectral FWHM of 24 nm. The LED has a wide range of wavelengths, which causes the wavelength components of two beams of the interferometer to go out of phase with respect to one another as the light propagates --so the fringes rapidly weaken as mirror M2 is moved by distance h. Calculation of fringe intensity as a function is done by statistical time-average of the intensity of the amplitude sum of the two beams, where one beam is delayed by time $\tau = 2h/c$ (2). Figure 2 (bottom) is the calculated fringe intensity versus distance h for the LED spectrum of Figure 2 (top). An outline of the fringe calculation of Figure 2 is in the appendix below. *The short range of broadband light fringes suppresses fringe formation from nearby optical surfaces.*

Time-Separation to Enable Broadband Fringes for Unequal Arm Lengths

A method **of modulating the spectrum light source for time shifting the light** is described in the patent (1). A simplified optical schematic in Figure 3 is used to illustrate the method. Starting from the broadband source, optics L1 shape and collimate the beam, which impinges on a grating G and after lens TL produces the frequency spectrum of the LED across the length of spatial light modulator M. Thus distance along the length of the modulator is a frequency plane of the source spectrum. After modulation, the light is focused into output fiber F. *Note: This schematic is for discussion purposes only and is not an actual system!*

What kind of modulation can be used to advantage in the spatial light modulator? Suppose a cosine modulation of frequency fm (DC offset of ½) is used in in the plane of modulator:

(1) $\mathbf{Im}(f) = [\,1/2+1/2\cos(2\pi f \tau_m)\,]\,\mathbf{I}(f) = 1/2\,\mathbf{I}(f) + 1/4e^{j2\pi f \tau m}\,\mathbf{I}(f) + 1/4e^{-j2\pi f \tau m}\,\mathbf{I}(f)$,

where $\mathbf{I}(f)$ and $\mathbf{I}m(f)$ are the light source power spectra before and after modulation, respectively, and τ_m is the modulation period and $f_m = 1/\tau_m$. *Equation (1) is the type of modulation proposed in the patent.*

Spectral intensity and autocorrelation are a Fourier transform pair.[2] Transforming eqn. (1) to the time domain gives three terms (one un-shifted and two shifted):
(2) $I_m(t) = 1/2I(\tau) + 1/4I(\tau - \tau_m) + 1/4I(\tau + \tau_m)$. These terms are time autocorrelations corresponding to the terms of equation (1). See the appendix for explanation of equation (2)
If there is a difference in the path length L of the two beams of the interferometer, the fringes will be only be formed by one term since two of the terms will have large time delays. The relative phase of the test surface with respect to the reference surface is $2\pi(2L/c - \tau_m + 2h/c)$.
Adjusting fm, for $2L/c - \tau_m = 0$, gives fringes as in Figure 2 (bottom) ; alternatively*, if h = 0 and fm is varied about 2L/c, the vibrating reference optic for coherent sources can be emulated.*

In the Appendix below is an outline of the analysis behind equations (1) and (2) *for calculating the envelope of the interference fringes.* Figure 4 is an example of using the phase-shifted light source in a Fizeau interferometer.

Summary
The patent enables broadband interferometry with unequal optical path lengths. Some key features of the method are:
1. The **frequency spectrum** of a broadband light source is projected onto a spatial light modulator. Distance along the length of the modulator corresponds to optical frequency of the source.
2. **Modulation of light source spectrum by cosine modulation with a DC component** creates three components: un-shifted $\tau = 0$, shifted by $\tau = 1/fm$, and shifted by $\tau = -1/fm$. Two of the components do not create fringes since the net phase shift is large, but for one component the extra phase from unequal arm lengths is cancelled by the modulation-induced phase shift.
3. **Spurious fringes are eliminated** from surfaces are further apart than two coherence lengths.
4. **Electronic phase scanning through the surface of the test part** (by varying the modulation frequency) can eliminate the need for a vibrating reference surface.

References and Note
1. U.S. Patent 8,422,026 B2, "Spectrally Controllable Light Source in Interferometry".
2. J W Goodman*, Statistical Optics*, John Wiley,1985 Chapter 3 for Wiener-Khinchin theorem and Chapter 5 for analyzing fringes of a broadband source. Newer editions are available.
3. Note: Going from wavelength spectrum to frequency spectrum requires an additional factor of f^2; not done here for simplicity. Moreover, the LED wavelength spectrum can be quite different than a Gaussian.

Appendix
The calculation for Figure 2B is based on Goodman's book (footnote 3 above), which analyzes an interferometer intensity signal for broadband light. Referring to the interferometer of Figure 1, the two beams are summed and time-averaged as in Goodman Chapter 5.

Outline of Time Averaged Light Source Intensity
(a1) $Id(h) = \langle |(k_1u(t) + k2u(t+2h/c)|^2 \rangle$, where
Id(h) =intensity at detector; u(t) =amplitude of each beam (50 % beam splitter),
k1 & k2 =reflection at mirrors; **angular brackets denote time averaging.**

Expanding

(a2) $I_d(h) = k_1^2 \langle|u(t)|^2\rangle + k_2 \langle|u(t+2h/c)|^2\rangle + 2k_1k_2 Re\langle(u(t)u(t+2h/c)\rangle$; **(a3) Let $\tau = 2h/c$.**

The first two terms are equal $\langle|u(t)|^2\rangle = \langle u(t+2h/c)|^2\rangle$. If k1 = k2 **, after manipulation**
(a4) $I_d(h) = I_0K(1+\gamma(2h/c)*\cos(2\pi h/\lambda)+\alpha(\lambda))$, K = constant, $\alpha(\lambda)$ is a phase factor.

(a5) $\gamma(2h/c) = \gamma(\tau) = |\langle(u(t)u(t+2h/c)\rangle| / |\langle|(u(t)|^2|\rangle$ is called the **self-coherence function of the broadband source**; it is the normalized autocorrelation. Note that $\gamma(0) = 1$ and that $\gamma(\tau)$ decreases with increasing τ and that **$\gamma(\tau)$ is the envelope of the fringes in Figure 2b.** In Figure 2 a Gaussian frequency spectrum is used for illustration.

Calculating Coherence Function for a Given Light Source Spectrum

The coherence function and the frequency power spectrum have a Fourier transforms relation:
(a6) $\gamma(\tau) = \langle(u(t)u(t+\tau)\rangle = \int \mathbf{I}(f)\, e^{-j2\pi f\tau}\, df$, which is the Wiener-Khinchin theorem, where $\mathbf{I}(f)$ = spectral intensity of the light source. See Goodman Chapter 3.

Phase Shifting by Cosine Modulation

Suppose that a cosine modulation is applied to the power spectrum on RHS of eqn. (e):

(a7) $\gamma_{mod}(\tau) = \int [\,1/2+\text{cosine}(2\pi\tau_m f)\,]\, \mathbf{I}(f)\, e^{-j2\pi\tau_m f}\, df$

$= 1/2\int \mathbf{I}(f)\, e^{-j2\pi\tau f}\, df + 1/4\int \mathbf{I}(f)\, e^{-j2\pi\tau f + 2\pi f\tau_m}\, df + 1/4\int \mathbf{I}(f)\, e^{-j2\pi\tau f - 2\pi f\tau_m} df$

$= \gamma(\tau) + \gamma(\tau+\tau_m) + \gamma(\tau-\tau_m)$, where $\tau_m = 1/f_m$. Note: $\gamma_{mod}(\tau)$ corresponds to $I_m(\tau)$ in equation (2) above.

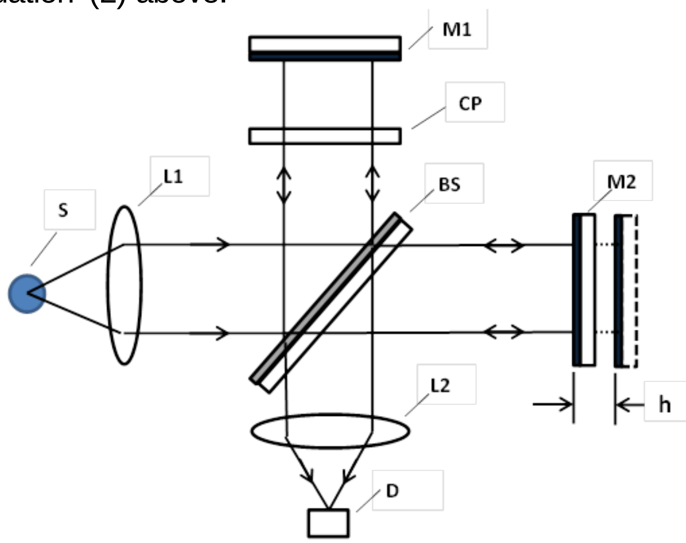


Fig. 1. Schematic of Michelson Interferometer with Broadband Source

S =LED Light source, L1 collimator , BS = 50% beam splitter, CP = compensation plate, M1 = fixed mirror, M2 = adjustable mirror, L2 = lens, D = detector.

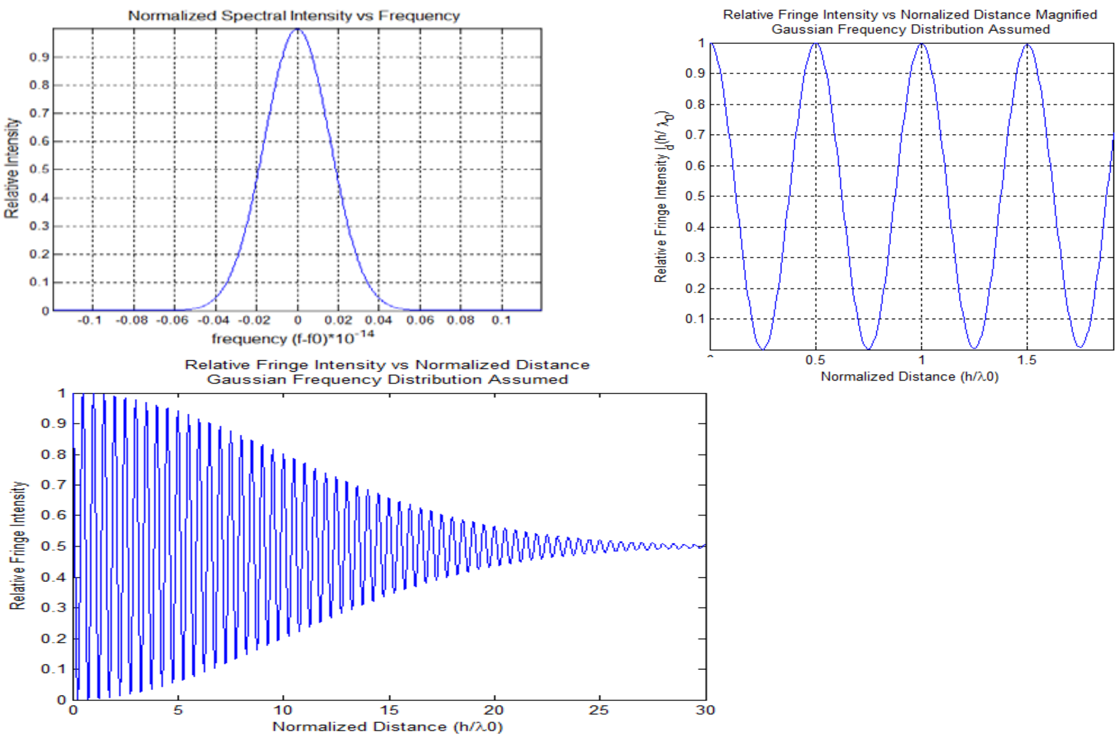


Figure 2. LED Spectrum Light and Michelson Interferometer Fringes
Above Left: Gaussian Frequency Spectrum (Peak $f_0 = 4.74 \times 10^{14}$ Hz).
Below Left: Relative Fringe intensity vs Normalized Distance h/ λ_0; magnified in right Figure.
Note: Lower Figure is symmetrical for negative h.

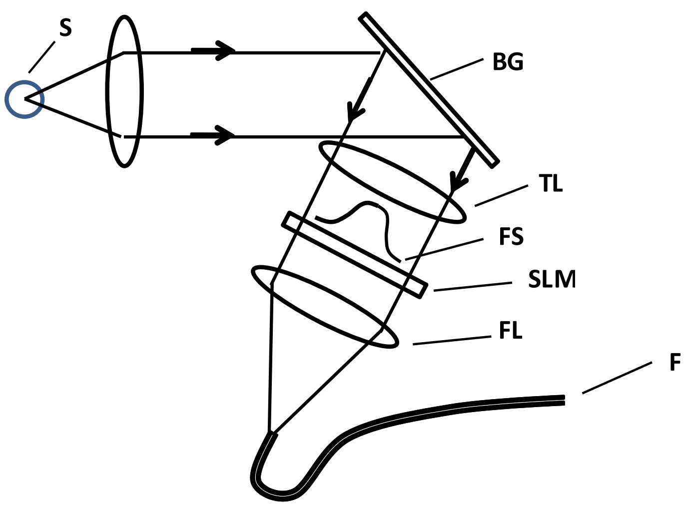


Fig. 3. Illustrative Schematic for Phase-Shifted Broadband Light Source

S = LED source, CS = collimator, BG = blazed grating, TL= transform lens,
SLM = spatial light modulator, FS = frequency spectrum at SLM, FL = focusing lens,
F = Output Fiber. Note: Distance in Plane of SLM is Proportional to Optical Frequency

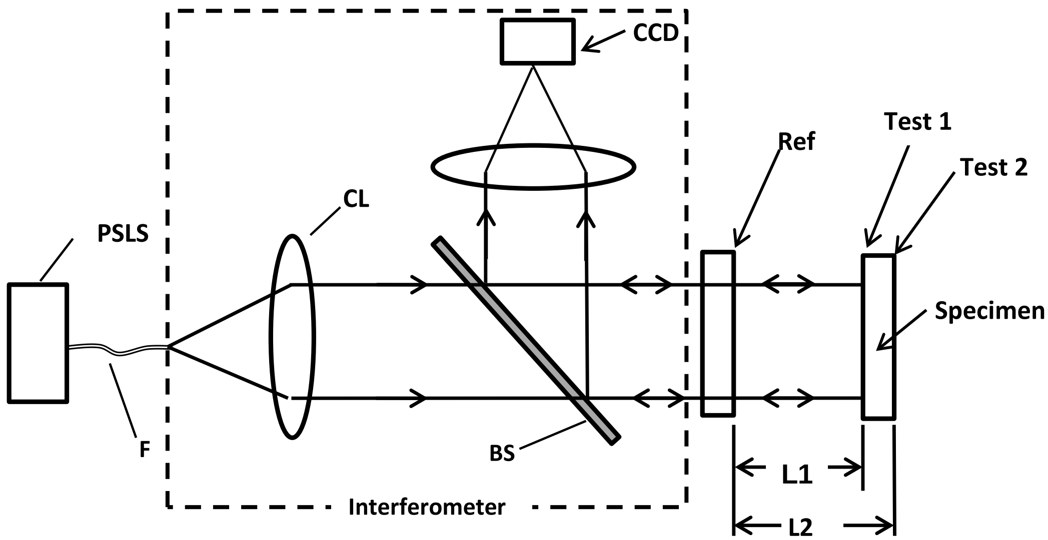


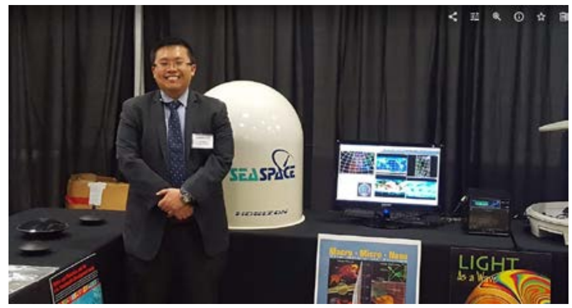
Figure 4. Fizeau Interferometer Schematic with Phase-Shifted Light Source

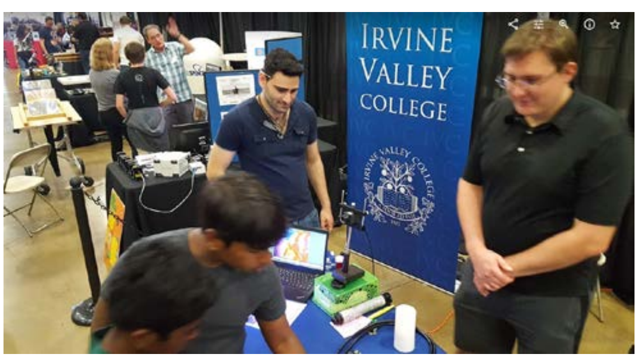
PSLS =phase-shifted light source, CL collimating lens , BS = beam splitter,
Ref=reference surface, Test1 = test surface at L1, Test2 = test surface at L2
Fringes are isolated from interference by other surfaces (if envelope of the broadband fringes is smaller than specimen width or distance to nearby optical surfaces).

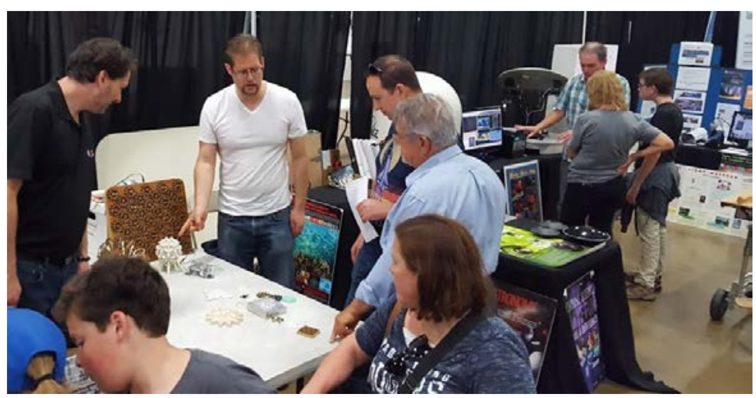
OUTREACH CORNER…

OSSC participated in the Vital Link STEM Career Leadership Conference which was held for three days from April 12th through April 14th, at the Orange County Fair Grounds in conjunction with Imaginology. This gathering is a great way of giving back to the community and getting young children to college students interested in optics.

Our thanks go out to our many volunteers including OSSC Past President & Vital Link Board Chairman Bo Wang; IVC Laser Technology Adjunct Professor Dr. Brian Monacelli and his students, IEEE Southern California Chair Pro-tem Brian Hagerty, OSSC Past President / Fellow Donn Silberman, OSSC Members Paul Nylander and Mark Helmlinger.







More photos are available on-line at the OSSC Homepage.

Outreach & Education

The OSSC is assisting local university students with OSA Student Chapters. Contact OSSC Student Chapter Liaison Alex Small if you would like to support these efforts. Currently, the following universities have on-going chapters: UC Irvine, UCLA, UC Riverside, Cal Poly Pomona, UC San Diego, Caltech.

Aim and Purpose

It is the aim and purpose of this society to increase and disseminate the knowledge of Optics and closely allied sciences, to promote the mutual interests of investigators, teachers and students in these fields, and of designers, manufacturers and users of optical instruments and allied scientific apparatus as well as those who have optics as a hobby and to encourage cooperation and establish acquaintanceship among these persons.

Speakers Bureau

The OSSC has formed a Speakers Bureau, to create a roster of individuals interested in giving talks for student chapters, OSSC meetings, and similar events. If you have something interesting to share with our local optics community, especially career-related topics of interest to students, please contact a member of the OSSC Board of Directors.

Optical Society of Southern California
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Upcoming Meetings & Events (2019)

Date	Location	Speaker	Topic
May 8 (OSSC Monthly Meeting)	The Proud Bird, 11022 Aviation Blvd., Los Angeles, CA 90045	Wayne Rodgers, President, Eddy Company	Evolution of Optical Monitoring for Thin Film Coating
June 12 (OSSC Annual Business & Monthly Meeting)	Brea Civic & Cultural Center, 1 Civic Center Cir., Brea CA 92821	Dr. Sandy Irani, UC Irvine, ICS & Dr. Jonathan Habif, USC CQIST	Quantum Computing & The National Quantum Initiative

All events subject to change without notice.

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