NIST Measurement Services that support Optoelectronics

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Abstract

The National Institute of Standards and Technology (NIST) offers a variety of hundreds of measurement services to its customers as a part of it's core mission. These services include reference data, reference materials, and physical measurements and calibrations.

NIST's work includes:

- maintaining primary standards,
- developing new and improved measurement methods,
- assisting industry, as a neutral party, to standardize on appropriate measurement methods,
- calibrating measurement devices and instruments, and
- providing reference materials, artifact standards, so that others may calibrate their own instruments.

Optoelectronics combines optics and electronics and the applications of this industry impact our daily lives. The fields of computing, communication, entertainment, education, health care and transportation rely on this technology. Military applications include imaging, sensors, communication, and command and control.

Components of lasers, image sensors, optical fibers, and optical storage discs represent the enabling portion of the $1.5 Trillion global information industry. In the United States, we export an estimated $27B of telecommunications components and equipment annually. Measurement science plays an important role in characterizing and verifying the performance of the equipment and materials currently available, it advances the performance of the next generation equipment and systems, and it facilitates the commerce of telecom products.

In the area of optoelectronic metrology, NIST has been developing measurement technology for laser power for nearly 40 years. Since the 1970s, NIST has been developing measurement technology for optical fiber communications and assisting with the development of measurement standards. NIST has Standard Reference Materials for integrated optic components, optical data storage, and semiconductor lasers and LED's under development. Recently, researchers at NIST

have been characterizing color and other electroluminescent properties of LED's and have made some measurement services available for LED's.

Historically, NIST has provided radiometric calibrations. Part of the suite of radiometric measurements that NIST provides includes photometry and detector responsivity, both of which support the optoelectronics industry.

This paper will provide an overview of the suite of optics-based measurement services that NIST currently offers to support the optoelectronics community. The Electronics and Photonics Technology funding through the NIST Advanced Technology Program will be briefly discussed. The emphasis, however, will be on the measurement services provided through the Physics Laboratory's Optical Technology Division and the Electronics and Electrical Engineering Laboratory's Optoelectronics Division.

INTRODUCTION

NIST is the national metrology institute (NMI) for the United States. With headquarters located in Gaithersburg, Maryland and an additional facility located in Boulder, Colorado, NIST provides its customers with traceability to the International System of Units (SI). The measurement and standards infrastructure is a complex system of technical activities that serves as the basis for conformity in the marketplace. It also facilitates the development and exchange of technical information in research, product development, and manufacturing.

NIST’s support of the measurement and standards infrastructure includes:

- realizing the SI units,
- participating in international intercomparisions with other NMI’s,
- maintaining primary standards,
- developing new and improved measurement methods,
- assisting industry, as a neutral party, to standardize on appropriate measurement methods,
- calibrating measurement devices and instruments, and
- providing reference materials, artifact standards, so others can calibrate their own instruments. [1]

Measurement science plays an important role in characterizing and verifying the performance of optoelectronics currently available, it advances the performance of future optoelectronics, and it enables the commerce of optoelectronic products.

In the United States, factory sales of telecommunications equipment represent an estimated $73B marketplace. It is the underpinning of the $600B domestic telecommunications market (equipment and services) with optics being the preferred technology for the transmission of data, voice, and video information. [2] Flat panel displays, fiber and cable, and sources and detectors constitute 72% of the worldwide revenues for optoelectronic components. [3]

OPTOELECTRONIC CALIBRATIONS, MEASUREMENTS, AND CERTIFIED MATERIALS AT NIST

In the area of optoelectronic metrology, NIST has been developing measurement technology for lasers for nearly 40 years. NIST calibrates laser power meters and basic solid state photodiodes. Since the 1970s, NIST has developed measurement technology for optical fiber communications and assisted with measurement standards development. Artifact standards, certified reference materials -- NIST Standard Reference Materials (SRMs) -- are used to control dimensions in the manufacture of optical fibers and to calibrate much of the instrumentation used in the field. NIST provides wavelength standards to assist in developing the most advanced wavelength division multiplexed (WDM) communication systems, chromatic and polarization dispersion standards that relate to the capacity of a fiber, and dimensional standards that relate to the connection of fibers. NIST is developing Standard Reference Materials for integrated optic components, optical data storage, and semiconductor lasers and LEDs.[4]

Since 1967, the Optoelectronics Division of the Electronics and Electrical Engineering Laboratory (EEEL) and its predecessor organizations have been providing calibrations of detectors and power meters used to determine the output power or energy of lasers. Historically, these calibrations are based on a family of electrically calibrated laser calorimeters in which the temperature rise resulting from absorbed optical power or energy is compared to that caused by dissipated electrical power or energy. These measurements are traceable to SI units through electrical standards: voltage and resistance. [5]

More recently suites of cryogenic radiometers are the primary standard for the detector-based metrology scale at NIST, and they form the basis for many of the calibration services supporting the optoelectronics industry. Cryogenic radiometers, with their intrinsic uncertainties of 0.02% ($k = 2$) [6], improve the radiometric measurement accuracy of the Nation. Cryogenic radiometry is the basis for the radiometric measurement chain and is used to maintain the scales of spectral radiance and irradiance, optical fiber power, and absolute detector responsivity.

For nearly 70 years, the Optical Technology Division of the Physics Laboratory (PL) and its predecessor organizations has provided radiometric calibrations. The broad suite of radiometric measurements offered by NIST includes photometric and detector responsivity, both of which support the optoelectronics industry.

The Optical Technology Division at NIST is responsible for the realization of the SI base unit, the candela. The candela represents a unit of measure of the brightness of a light source as observed by the human eye. The unit of luminous intensity, the candela, is maintained on a set of well-characterized, appropriately filtered detectors. This detector method provides a direct link between a cryogenic radiometer and the candela as an alternate method of transferring this unit to calibration customers. NIST has realized the candela using standard detectors constructed to emulate the International Commission on Illumination (CIE) spectral luminous efficiency function for photopic vision. The uncertainty in determining the candela value is 0.4 %. [7]

Photometry, the science of measuring light with the response function of an average human observer, is an activity that is integral to the detector characterization efforts in the Optical Technology Division. The detector-based candela is the basis for other photometric units. The luminous flux scale (lumen) and the luminance scale (candela per square meter) have been realized based on the detector-based candela. Various calibration services are available for luminous intensity, total luminous flux, illuminance, luminance, and color temperature. SP 250-37 outlines further details of the NIST photometric calibration. [8]

A calibration facility has been developed in the Optical Technology Division to address the need for high accuracy color measurements of displays, including those for military applications. Calibration services are planned for colorimeters and spectroradiometers, tailored to display measurements. A reference spectroradiometer is being used to measure chromaticity and lumininance of CRT and LCD displays. [9]

The Optical Technology Division routinely characterizes spectral power responsivity of photodetectors. Primarily working with Silicon (Si), Germanium (Ge), and Indium Gallium Arsenide (InGaAs) detectors, characterizations are offered in the Ultraviolet, Visible, and Near Infrared (NIR) spectral regions. For further details about the NIST spectroradiometric detector measurement services refer to SP 250-41. [10]

The Optoelectronics Division, in some cases in collaboration with the Precision Engineering Division of the Manufacturing Engineering Laboratory (MEL), provides a variety of Standard Reference Materials for the optoelectronics industry. See tables 1 and 2. A Standard Reference Material (SRM) is a certified reference material, which means that one or more of its property values are certified by a technically valid procedure, accompanied by or traceable to a certificate [11] or other documentation which NIST issues.

Table 1 provides an overview of Standard Reference Materials that are made available by the Optoelectronics Division. SRMs 2520, 2521, 2522, and 2523 were developed in collaboration with the Precision Engineering Division of the MEL at NIST.

SRM No.	Name	Description
2513	Mode Field Diameter Standard for Single-Mode Fiber	Optical fiber specimen with cleaved end and calibrated mode field diameter
2517	Wavelength Reference Absorption Cell-Acetylene (12C2H2)	Molecular gas absorption cell with numerous absorption lines in the 1510 nm to 1540 nm region
2519	Wavelength Reference Absorption Cell-Hydrogen Cyanide (H13CN)	Molecular gas absorption cell with numerous absorption lines in the 1530 nm to 1560 nm region
2520	Optical Fiber Diameter Standard	Optical fiber specimen with cladding diameter values known to approximately ± 40 nm
2522	Pin Gauge Standard for	Wire used to size bores of connector

	Optical Fiber Ferrules	ferrules; diameter known to approximately ± 40 nm
2523	Optical Fiber Ferrule Geometry Standard	Ceramic connector ferrule with specified outside diameter and roundness
2524	Optical Fiber Chromatic Dispersion Standard	Approximately 10 km of optical fiber with zero-dispersion wavelength known to approximately ± 0.08 nm
2525	Optical Retardance Standard	Nominally 90 degree retarder with retardance known to approximately ± 0.1 degree

Table 1 SRMs available for Optoelectronics

Table 2 provides an overview of Standard Reference Materials that currently under development by the Optoelectronics Division. [12]

SRM No.	Name	Description
2514	Wavelength Calibration Reference for 1560 nm to 1595 nm	Fiber-coupled molecular gas absorption cell
2515	Wavelength Calibration Reference for 1595 nm to 1630 nm	Fiber-coupled molecular gas absorption cell
2518	Polarization Mode Dispersion Standard	Device with stable and known value of polarization mode dispersion which simulates optical fiber
2521	Optical Fiber Coating Diameter	Glass specimen with refractive index approximating that of polymer coating and diameter known to approximately ± 0.1 µm

Table 2 SRMs that are under development for Optoelectronics

OPTOELECTRONIC RESEARCH: NIST'S ROLE

Research constitutes a large and diverse set of activities at NIST. In particular, eighteen Technical Divisions in six of the NIST Measurement and Standards Laboratories support optoelectronics. The following list provides examples of a few projects that represent NIST research that benefits optoelectronic industries:

- Electro-optic-based electrical waveform measurements,
- Electro-optical measurement of surface charge,
- Optical current transducers for electric utility applications,
- Wide-bandgap semiconductors for short-wavelength photonic devices,
- Optoelectronic crystals,
- Nanometrology for compound semiconductor materials and processes,
- Photonic electromagnetic field probes,

- Magnetic materials characterization with near-field optics,
- Characterization of fiber and discrete components,
- EUV and VUV optics and detector characterizations,
- Hybrid-optical pattern recognition and neural networks,
- Volume holographic storage,
- Light emitting polymers, and
- Ferroelectric oxide thin films for photonics. [13]

The goal of NIST's Advanced Technology Program (ATP) is to benefit the U.S. economy by cost-sharing research with industry to foster new, innovative technologies. The ATP invests in risky, challenging technologies that have the potential for a big pay-off for the nation's economy. By reducing the early-stage R&D risks for individual companies, the ATP enables industry to pursue promising technologies which otherwise would be ignored or developed too slowly to compete in rapidly changing world markets. Over 100 projects have been funded through ATP's Electronics and Photonics Technology Office. Electronics and Photonics ATP funding represents $387M, combined with the matching industry funding that totals nearly $800M. [14]

CONCLUSION

NIST has a long and diverse history of supporting the optoelectronics industry and the telecommunications sector. Providing metrology and research that drives the measurement science, NIST will continue to fill a vital role enabling the technology and commerce of the global marketplace that thrives on optoelectronics.

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[3] Components Revenues, OIDA, http://www.oida.org/comprev.html

[4] Ray Kammer, Former Director of NIST, Remarks at the Optoelectronics Industry Development Association Meeting, October 2, 1998 http://www.nist.gov/speeches/oida.htm

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[10] Larason, T. C., Bruce, S. S., and Parr, A. C., NIST Measurement Services, Spectroradiometric Detector Measurements: Parts 1 and 2, Special Publication 250-41, February 1999.

[11] American National Standard for Calibration -- Calibration Laboratories and Measuring and Test Equipment -- General Requirements, ANSI/NCSL Z540-1-1994, National Conference of Standards Laboratories International 1800 30th Street, Suite 305B, Boulder, Colorado 80301.

[12] Tables 1 and 2 were created from information found at http://www.boulder.nist.gov/div815/NEWsrms.htm and http://ts.nist.gov/srm

[13] Optoelectronics at NIST, NISTIR 5054, September 1996.

[14] Advanced Technology Program Electronics and Photonics Technology Office website http://www.atp.nist.gov/epto/