Consultative Committee for Photometry and Radiometry (CCPR)

25th Meeting (on-line 10-11 May 2022)

CCPR member report on activities in radiometry and photometry since the last CCPR meeting (2019)

Reply from: **National Research Council Canada**

Delegate:

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1. Summarize the recent progress in your laboratory with respect to measurement standards, research projects, and metrology services to fulfill the demands of customers in:

   (a) broad-band radiometric quantities:

   (b) spectral radiometric quantities:

Haze capability development

The feasibility of carrying out measurements of transmission haze on one of NRC's existing integrating sphere-based reference instrument has been investigated. As part of this work, an uncertainty budget was developed. The impacts of sample-induced changes in sphere throughput and of variations in the reflectance of the sphere interior were considered.

Modeling fluorescence reemission in the one-dimensional radiative transfer problem

A model of radiative transport in fluorescent, scattering media that accounts for fluorescence reabsorption and reemission effects was developed. The model was studied in a simplified one-dimensional geometry using the P3 approximation. Potential applications include modelling the optical properties of fluorescent white standards and remote phosphor modules used in solid state lighting. See publication in question 7.

Update on NRC's new absolute diffuse reflectance scale

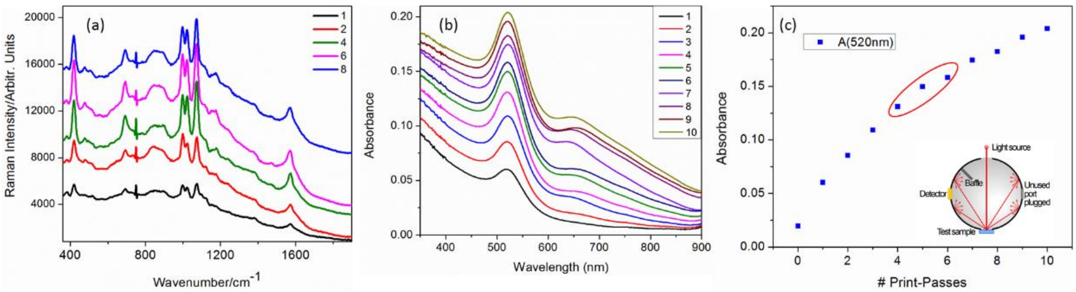
Work continues on NRC's new absolute diffuse reflectometer. This instrument employs the modified Sharp-Little method to realize an absolute diffuse reflectance scale in a d:0 geometry. Current research and development activity is focussed on characterizing and correcting for the homogeneity of the integrating sphere interior surface. The system is being used for NRC's participation in the CCPR K5 comparison which is underway.

Improvement of the NRC Calibration Service for Infrared Wavenumber Standards

A center of mass analysis was carried out on NRC polystyrene transmission standards to improve the determination of the absorption minima of the standards. This method was also compared with several other numerical methods commonly employed for determining the positions of minima. An automated sample positioning apparatus has been implemented to reduce measurement disturbances associated with sample insertion and removal. This apparatus allowed accurate determinations to be made of measurement repeatability and specimen uniformity.

Advances in Nanomaterials Optical Properties:

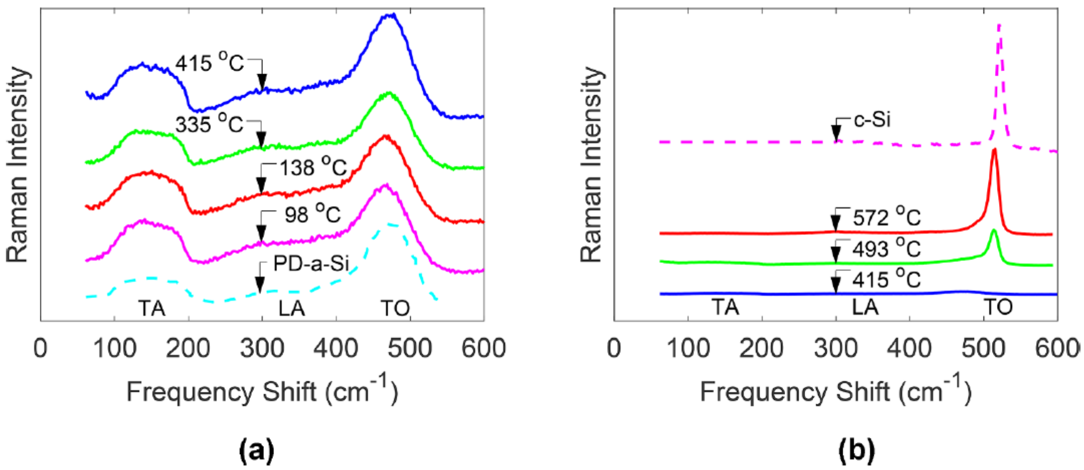
Diffuse reflectance of plasmonic surface enhanced Raman scattering (SERS) sensors – NRC has developed inkjet-printing process for the fabrication of paper SERS sensors for chemical analysis. Diffuse transmittance and reflectance measurements are currently underway to determine the localized surface plasmon resonance (LSPR) absorption of the paper SERS sensor. These measurements will provide a quantitative measurement analysis of the SERS sensors. Preliminary results are summarized in peer reviewed publications. (see bibliographic references in question 7)



Raman spectra of Inkjet-printed SERS sensors with various printing passes. (b) Diffuse Reflectance spectra of paper sensors after the indicated numbers of printing passes (c). The maximum absorbance of the 520 nm LSPR peak for the sensors plotted against the number of printing passes. The Inset shows the integrating sphere setup used for diffuse reflectance measurement.

Optical Properties of II-VI Quantum Structures – In collaboration with Sichuan University (China), NRC has been carrying out analysis of the UV optical absorption and photoluminescence data of novel II-VI semiconductor clusters and quantum dots (QDs). QDs reaction pathway, growth mechanisms, pre-cursor fragmentation and their applications in macular degeneration were studied. These results were outlined in peer reviewed publications. (see bibliographic references in question 7)

Optical Properties of CVD Grown Si Thin Film – In collaboration with University of British Colombia, NRC has carried out Raman, photoluminescence, spectral reflectance measurements of Si thin film grown at temperatures ranging from 98 °C to 572 °C by ultra-high-vacuum evaporation on fused quartz substrates. The crystallinity, order and the spectral dependence of the refractive index in thin silicon films were investigated in these series of studies. It was found that the maximum of the refractive index increases in response to increasing order as confirmed by the Raman spectroscopy. This series of studies were published in peer review papers. (see bibliographic references in question 7)



Raman spectra of the thin Si films grown at lower temperature (a) as compared to spectra obtained from the films grown at much higher temperature (b). Note the sharper TO phonon mode and much less pronounced TA and LA phonon modes indicative of higher crystallinity order.

(c) photometric quantities:

Updates on the NRC Photometry Activities

NRC is adapting its photometric calibration capabilities to provide calibrations for LED sources of luminous intensity and total luminous flux. These will be calibrated by transfer from calibrated NRC incandescent standards with corrections for the spectral mismatch. We have purchased the LED standard lamps developed by PTB and NIM for the CCPR WG-KC TG4 pilot comparison of luminous intensity and total luminous flux using LED sources as comparison artefacts.

We are developing our facilities for the calibration of UV meters and UV sources, such as the UV meters and the UV LEDs that are used in germicidal applications. We have purchased a UV-C radiometer and are evaluating various UV LEDs as test sources.

(d) other area(s) relevant to CCPR:

Few-Photon Metrology Capability

NRC has established a free-space single-photon detector calibration system for silicon single-photon avalanche diode (SPAD) efficiency measurements at 850 nm. This apparatus was tested in collaboration with NIST by comparing efficiency measurements of a SPAD on the calibration systems at NIST and at NRC. Presently, NRC-developed solid-state on-demand single-photon sources based on III-V semiconductor quantum dots are being implemented in metrology applications including investigating the possibility of using these sources as absolute standard single-photon sources and in the development and standardization of single-photon source performance metrics (i.e. source efficiency, single-photon purity, etc.) and measurement procedures.

Pilot of CCPR-K3.2014

NRC is the pilot for this comparison of Luminous Intensity using lamps as the transfer standards. Draft A was reviewed and approved by the participants in 2020-October. The draft B report was reviewed by CCPR WG-KC from 2020-October to 2021-April, including one revision. The Draft B-2 was approved by the CCPR WG-KC on 2021-April-02 and by the CCPR on 2021-November-30.

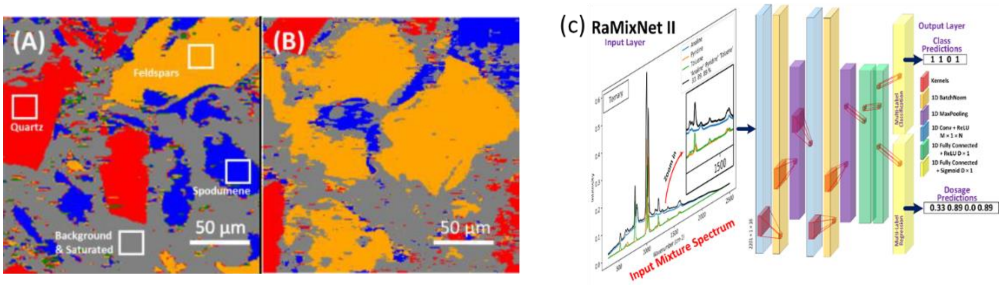
CCPR-K4.2017

NRC is participating in the CCPR-K4.2017 comparison of Total Luminous Flux. We have completed the first set (pre-NMIJ) and second set (post-NMIJ) of measurements on the travel lamps and submitted our report to the pilot, NMIJ.

CCPR WG-KC TG4 pilot comparison of luminous intensity and total luminous flux using LED sources as comparison artefacts. We have purchased the LED luminous intensity standards developed by PTB and the LED total luminous flux sources developed by NIM with the intention of participating in these pilot comparisons.

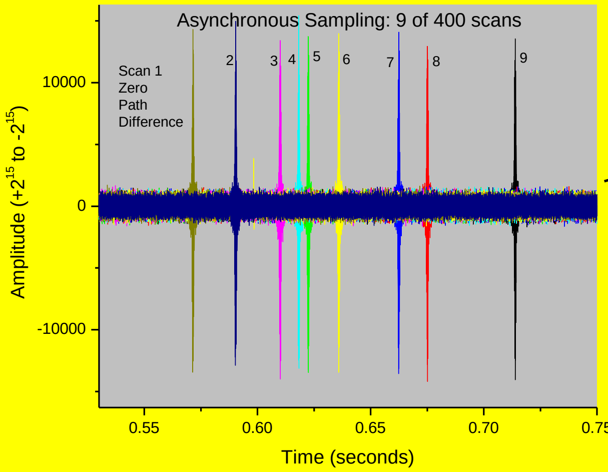
Prototype of Digital Calibration Certificate for Spectral Regular Transmittance Factor Calibration – NRC has developed a prototype DCC for its spectral regular transmittance (UV-Vis range) calibration certificate. These digital documents provide annotated calibration data and metadata in XML to support machine-readability. A human-readable version of the certificate is also generated allowing for easy integration into current workflows. We have partially automated the generation of both machine-readable and human-readable reports, with future development to focus on streamlining the generation process and extending DCCs to other calibrations. We have followed the XML Schema provided by PTB, but also investigated alternative formats for the effective communication of spectral data.

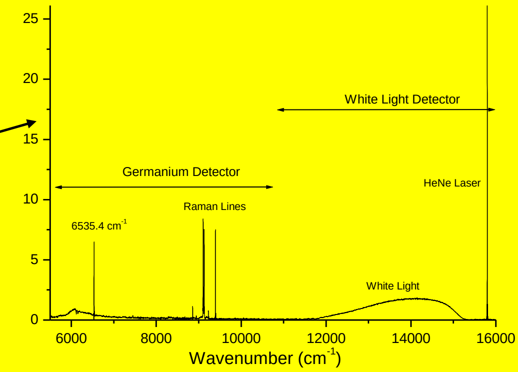
Big Data and Machine Learning for Spectral and Hyperspectral Analysis – NRC has explored and developed a number of deep learning/machine learning architecture based on the Convolutional Neural Network (CNN) to carry out complex spectral classification and spectral pattern recognitions. Machine learning was applied to Raman spectral data analysis and spectral identification. We have used the deep learning model to extract unique spectral features and using a neural network classifier to compare the features of an unknown sample against those extracted from the spectra in the spectral library and subsequently improve the spectral identification of multi-component mixture compounds. For hyperspectral data cube, we have applied similar supervised convolutional neural network for spectral image classification/segmentation to improve dimensionality reduction and classifier identification in hyperspectral images. Results are summarized in peer reviewed proceeding and Journal publications. (see bibliographic references in question 7)



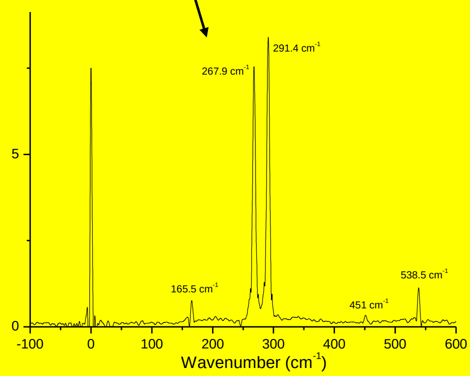
(A) Hyperspectral Raman image used as a training set for the convolutional neural network (CNN). (B). A hyperspectral Raman image classified based on the CNN model trained with dataset from (A). (c) A schematic depiction of the CNN structure for quantitative analysis of multi-component mixtures of Raman spectral data set

Asynchronous Sampling in FTIR – While leading to large data sets, asynchronous sampling in FTIR has several advantages over traditional methods with regard to hardware simplification and improved post-acquisition data processing. In the difficult measurement of FT Raman highlighted, the data was acquired in 400 separate scans of the Michelson interferometer in a FTIR spectrometer. Sampling is done uniformly in time and is converted to uniform path difference increments in software through interpolation using the simultaneously sampled HeNe laser fringes. The scans are then synchronized with respect to path difference and zero path difference, again numerically. In this process it is possible to eliminate artifacts such as the cosmic ray transients seen in the ultra-sensitive germanium PIN detectors necessary for infrared Raman spectroscopy. In the present case the software reduces a 100 Mbyte data set containing the interferogram waveforms to a single spectrum, obtained by applying a Fourier transform to the coadded synchronized interferograms also processed in software with numerical filtering, apodization, phase correction, and transient removal. By processing individually each interferogram, one is able to obtain the best possible coadded data set and hence the optimum infrared spectrum.





These figures show the effect of converting interferogram (IGM) waveform data into a spectrum. Above are shown nine of the 400 IGMs collected in a Raman experiment for which the sample was GaAs. Note the raw IGMs are not synchronized in path difference or zero path difference. The synchronization of the IGMs is performed by processing the data during and after the measurement. The overall spectrum is shown in the upper right panel. Two detectors operating in separated parts of the spectrum were used, germanium for the Raman signal and silicon for the white light/laser signals. The lower right panel contains the downshifted Raman spectrum for the phonons in GaAs at frequencies relative to the Rayleigh line originally at 9394.8 cm^{-1}.



2. What work in PR has been/will be terminated in your laboratory, if any, in the past /future few years? Please explain the reasons and provide the name of the institution if it has been/will be substituted by a DI or accredited laboratory.

   None

3. Summarize the Capacity Building and Knowledge Transfer activities undertaken by your institute in photometry and radiometry (courses, training, …):

   None offered in this period

4. Summarize the research projects currently performed within a collaboration with one or more NMIs or Dis (name of the project, participants):

   Project Name: Advanced Quantum Photonics Measurements in Support of Standards for Next Generation Telecommunications Technologies
   Participants: NRC, University of Colorado and NIST
   Description: Development of first generation quantum sources and detectors for future telecommunications standards by the direct SI traceable measurement of the optical power emitted from an NRC quantum dot source using a NIST developed faint light optical sensor.

5. Are there any other research projects where you might be looking for collaborators from other NMIs or are there studies that might be suitable for collaboration or coordination between NMIs?

   - We are interested in collaborating with other NMIs involved in the R&D areas of optical properties of novel quantum/nanomaterials, the development of Raman spectroscopy standards, and single-photon source performance metrics.
   - We are interested in collaborating with other NMIs involved in validating new colour and appearance measurement scales, e.g. transmittance
   - We are interested in measurement comparisons with other NMIs involved in high-accuracy measurement of the optical properties of fluorescent materials. Quantities of interest include total radiance factor, bispectral luminescent radiance factor, and quantum efficiency.
   - We are interested in comparing our infrared wavenumber and transmittance standards as well as our infrared diffuse reflectance measurement capability with other NMIs.

6. Have you got any other information to place before the CCPR in advance of its next meeting?

   None

7. Bibliography of radiometry and photometry papers of your laboratory since the last CCPR (September 2019):

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