The quest for a robust sensor for the OH radical
Case study 2024

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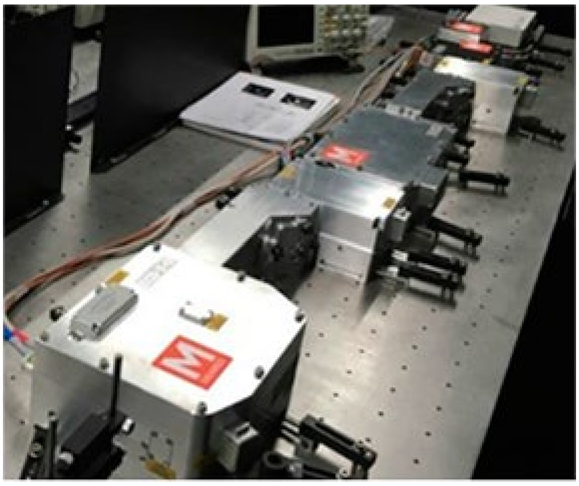
Building the next generation of carbonless combustion devices requires detailed knowledge of the underlying thermochemical processes powering them. The Spearrin Lab at UCLA is focused on developing optical sensors to probe the fundamental physics within these high temperature and pressure environments. A key species which participates in all hydrogen-containing combustion is the hydroxyl (OH) radical and Nick Kuenning, a fifth-year PhD student under Professor Mitchell Spearrin, is developing a simple and robust way to measure OH in a combustion environment. The Spearrin Lab is using a 19µm wavelength laser supplied by the American vendor RPMC lasers and its French manufacturer mirSense, enabling this novel technique opening many new sensing opportunities for combustion researchers.

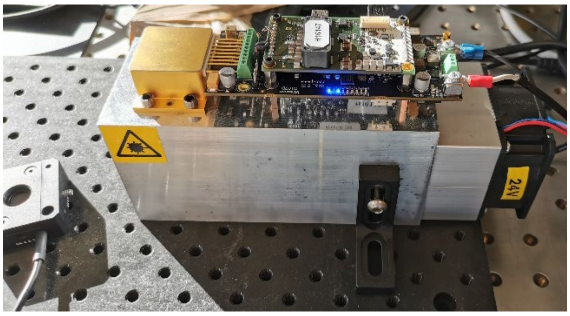
Originally from Los Angeles, Nick did both his undergraduate and master's degree at UCLA and is currently working to finish his PhD thesis in the coming year. What he likes about UCLA is the wealth of knowledge and resources within the school. With over 4,000 students in the engineering school, no matter what problem he has there is always someone nearby who can help. Intra-school collaboration is an extremely valuable resource aiding the scientific work of the lab. The Spearrin Lab is a diagnostics group inside the engineering school meaning the group's research spans from fundamental science, like probing individual molecular absorbance transitions inside a shock tube, all the way up to building and testing their own rocket engines. This unique ability to straddle both fundamental and applied science is linked to Prof. Spearrin's many different interests and today, the lab has projects in aerospace, clean energy, planetary science, and fire science. For example, the lab has also worked on designing a spectrometer to measure water on the moon and is collaborating with fire fighters to reduce their exposure to toxic species.

Accurate OH measurements are a growing need in combustion research, but existing sensor architectures are challenging to make economic, compact, and robust. The need for robust OH sensors is amplified in the global effort to decarbonize combustion. Many species, such as CO and CO_2, have robust, high-speed laser absorption sensors targeting their fundamental vibrational bands in the mid-infrared; however, certain species like OH do not have a favorable vibrational spectrum, complicating sensing in the mid-infrared. Sensors targeting OH have been developed in the near- to mid-infrared but the weak transitions require complex measurement techniques which are prone to biases in the harsh environments of combustion devices. UV sensors at 310nm wavelength have been successfully used to obtain fast and sensitive measurements but UV light sources are difficult to rapidly tune, leading to the possibility of measurement biases in harsh environments. Additionally, they typically require much higher powers which can result in increased cost and size when compared to semiconductor lasers available in the infrared. Importantly, the fact that UV sources generate high energy short wavelength light creates safety issues that complicate usability.

A picture of the Spearrin lab at UCLA c. 2024. On the left we see the long metallic shock tube that can create combustion environments (high pressure and high temperature explosions recreated inside the tube chamber). The shock tube is an essential tool for scientists who want to carry out combustion diagnostics in the lab.

The key finding of the Spearrin Lab is that the rotational spectra of many hydrides is stronger than their mid-infrared vibrational spectra and that these rotational spectra can be accessed with emerging far-infrared semiconductor lasers. Now it is possible to sense OH with an extremely compact light source targeting rotational absorption transitions of comparable strength to those in the UV. The Spearrin Lab used a 19µm compact QCL to measure OH at high temperatures and elevated pressures and published their results this year in the prestigious “Proceeding of the Combustion Institute” [1]. The primary advantage of these semiconductor sources is the ability to rapidly tune the wavelength of the light at microsecond rates. By rapidly turning the laser, the shape of an absorption transition is measured, rather than just the magnitude, enabling correction for the mechanical vibrations and interfering species common in combustion environments. The long wavelength also has inherent safety advantages that allows for ease of use in many applications.





The volume of a UV light source is at least two orders of magnitude higher than the volume of a QCL light source. Left is a typical setup for a 310nm UV light source from M:Squared (a huge table-top instrument with several optical components like a pump laser) and right is a HHL-packaged QCL with its driver and air cooling fan. The HHL package is the size of a matchbox.

Now that the sensor has been demonstrated, Nick will be focused on increasing the temporal resolution of the OH sensor from 10’s of microseconds to the 1 microsecond attainable with mid-infrared QCLs, further improving OH sensing capabilities in high temperature combustion environments. Additionally, Nick will begin measuring the rotational spectra of many more species, further demonstrating the advantages of the far-infrared domain for sensitive gas sensing. After his PhD, Nick plans to continue working with the Spearrin Lab as a research engineer developing laser-based optical diagnostics.

[1] Nicholas M. Kuenning, Nicolas Q. Minesi, Brett A. Honaker, R. Mitchell Spearrin,*THz rotational absorption spectroscopy of the hydroxyl radical at high temperatures using a quantum-cascade laser*, Proceedings of the Combustion Institute, Volume 40, Issues 1–4, 2024, 105480, ISSN 1540-7489, https://doi.org/10.1016/j.proci.2024.105480.