PROSPECTS OF MEASURING THE TEMPERATURE OF A BACTERIAL SOLITARY WAVE WITH NITROGEN VACANCY CENTERS

B.R. Slezak, H. Salman, M.V. Gurudev Dutt
Department of Physics and Astronomy, University of Pittsburgh

**Motivation**
- We hypothesize that bacteria traveling in a high density packet will raise the temperature of their local environment.
- Traditional temperature sensors (e.g., thermocouple) suffer due to size constraints of the wave packet (~250µ) and sensitivity.
- A nano-diamond provides a sensitive temperature sensor, with nano-scale footprint, that can be completely immersed in the packet.

**Background**
- The amino acid glycine is an attractant detected by the chemoreceptor Tsr.
- Above a certain critical bacterial density, the glycine excreted by bacteria is produced in large enough quantities to attract nearby bacteria, providing a positive feedback mechanism for amplification of local density increase.
- Bacteria in nutrient rich medium are loaded into microfluidic channels fabricated in polydimethyl-siloxane (PDMS).
- Once the packet has formed, the collection of bacteria will deplete the local nutrients; they then sense the chemical gradient of nutrients and move toward higher nutrient density.

**Sensor**
- **Nitrogen Vacancy (NV) Center in (Nano) Diamond**
  - Optical polarization and readout of electron spin state at room temperature.
  - Spin manipulation in microwave (GHz) range.
  - S=1 ground state Hamiltonian sensitive to absolute temperature.

\[ \tilde{H}_{gs} = D(T) \tilde{S}_z^2 \]

with \( D(T) \approx 2.87 \text{GHz} \) and \( \frac{\partial D}{\partial T} \approx -77 \text{ kHz/K} \)

**Measurement Scheme**
- \( D(T) \) can be determined by finding the peak of a Photoluminescence VS MW frequency scan.
- Determining \( D(T) \) from a full frequency scan is difficult due to restrictions on switching time, noise, overall PL fluctuations, and a large linewidth compared to the frequency shift.
- Choosing four points symmetrically around the peak and modulating the frequency at a fast rate improves signal to noise and removes noise from small fluctuations (BIB below) [2].

\[
\begin{align*}
C_1 &\approx C_0 + \frac{\partial C_0}{\partial T} \frac{\delta T}{\delta T} \\
C_2 &\approx C_0 - \frac{\partial C_0}{\partial T} \left( -\delta T + \frac{\delta T}{\delta T} \right) \\
C_3 &\approx C_0 - \frac{\partial C_0}{\partial T} \left( -\delta T - \frac{\delta T}{\delta T} \right) \\
C_4 &\approx C_0 + \frac{\partial C_0}{\partial T} \frac{\delta T}{\delta T}
\end{align*}
\]

**Calibration**
- Measurement calibrated by increasing sample temperature via a thermo-electric cooler.
- Temperature measured independently via thermocouple located on sample.
- Sample used was 100nm diamonds dispersed on Silicon.

**Future**
- Perform the full experiment.
- Apply nano-diamond sensing techniques to other bacterial phenomena (temperature, magnetic, or electric field sensing).

**References**

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[1] Figure: spatial profile and evolution of bacterial wave packet. Insert: photographs of the bacteria filled channels at 3 minute intervals.