A Simple, Real-Time Method for Measuring Firebrand Heat Flux using Semiconductor Devices

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Problem Statement

This project evaluated the use of semiconductor devices as sensors for measuring the heat flux of incoming firebrands. Firebrands are burning wooden particles that detach from burning trees during wildfires as a result of buoyancy and wind force. Wind carries firebrands far from the fire line where they can land on structures or other wildland fuels. The brands can transfer heat to the fuel and start spot ignition which can consequently, become a developed fire if not addressed. Therefore, it is important to characterize firebrands and their capability to transfer heat for spot ignition. Developing responsive and accurate sensors to measure the heat flux received from firebrands is a critical need for assessing and analyzing the fire risk presented by firebrands.

Concept

- Use a thermoelectric generator (TEG) to create a voltage based on the differential temperature between the hot side to the cold side of the TEG.
- Chose this concept due to fast response between heat flux and voltage output as well as the high sensitivity of the TEG.

Objectives

- Build a semiconductor-based device that can accurately detect heat flux of a firebrand
- Create device that produces voltage response proportional to heat flux
- Interface device with LabView to accurately monitor the voltage response
- Create device that is easily scalable to increase detection surface area

Procedure/Data

Procedure:
1. Lead pellets of different masses were placed on a hot plate.
2. Heated pellets were placed on the TEG prototype which was connected to LabVIEW via a NI-DAQ68004.
3. First one pellet of the same mass was tested multiple times, followed by changing both the quantity and mass of the pellets.

Results:
- In the first graph, four identical tests were conducted to show the heat flux characteristics of a heated lead pellet.
- Each of the four tests produced a nearly identical voltage response, showing that the prototype can measure with high precision.
- In the second graph, five tests were conducted, each with three pellets of the same temperature.
- These tests simulate the arrival of multiple firebrands at different times and shows that the system can detect multiple firebrands.
- In the third graph, three averaged firebrand results were plotted to show the differences between small, medium and large firebrands.
- Although the small and medium firebrand averages look to have a similar impulse response, the individual firebrand tests had many different formations due to the uniqueness of how each individual firebrand burns.
- This "uniqueness" increases as the firebrand size increased, which can be seen with the large firebrand plot.

Discussion

- It is theorized that the area under the voltage-time curve (integration of the response) is proportional to heat flux.

\[
\text{Area Under the Voltage Curve} = \sum_{n=0}^{k} (M_n - Q_n)
\]

Where:
- \( n \) = Sample Number
- \( Q_n \) = Baseline Voltage Noise
- \( k \) = Final Sample
- \( M_n \) = Sample Magnitude

Future Work

- Calibrate the prototype by comparing the results to the heat flux measured from a thin skin calorimeter.

Acknowledgements

This project is funded in part by NRC Grant Number: NRC-HQ-84-16-G-0030