Designing, Testing, and Characterizing Temperature Distributions of an Optical Oven

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Abstract

In order to find the center point focused on by a high-power light source capable of reaching 1200℃, a thermocouple is attached to a mechanism containing three motors, one for each axis. It is then instructed using code to systematically move to a new position while recording the temperature of that position until all points are exhausted. From there, it generates a diagram of all recorded temperatures, granting an estimate at where the focal point may rest. This focal point is then used to heat objects, ultimately becoming an experimental process testing the temperature distribution and utility of the light while involving a metal sample. Using indium, we determined that the light source was capable of melting samples of about 5mm by 5mm and that this area was small enough to face the full effects of the concentrated light.

Introduction & Purpose

The goal of this experiment is to test the capabilities of a high power, high temperature light source regarding the size of its hot spot as well as the hot spot temperature. The size of the hotspot will be used to select samples of the right size in the future. Verifying the utility of the light source will assist my mentor, as if the light proves useful, he plans to use it to heat samples for his future experiments that concern the use of x-rays to measure materials relative to temperature (see figure 1). Our setup takes advantage of ellipsoid focusing, concentrating the light by encasing it in a reflective ellipsoid into one, high-temperature focus point where our measurements would take place. Additionally, as assembly is part of the process, creating and refining a functional setup is yet another skill learned in the grand scheme of scientific experimentation.

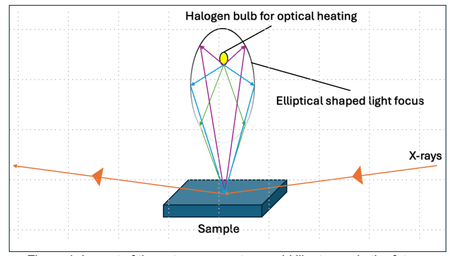

Figure 1: Layout of the setup my mentor would like to use in the future

Experimental Setup

The commercially available light source is a 750W infrared halogen bulb, capable of reaching 1200°C. It is powered by an 1000W DC power supply, and we facilitated cooling airflow within the light source in order o prevent structural materials from overheating. To find the high-temperature focus point, we attached a type-K thermocouple to a temperature reading device (Moxa), in addition to connecting three motors to a Newport (ESP 302) motion controller, allowing it to move about 26 x-points, 21 y-points and 13 z-points. Using these components, we created a software using Python which allowed the motor to move about these locations, with the temperature reading device giving an output measured by the thermocouple at every individual location. Following a full scan, the software would generate a comprehensive, color-coded visual outlining the spatial distribution of the light source about the measured locations (Figure 3). From these scans, we could roughly find the point of interest where we could place samples spanning about 5mm by 5mm, we could raise the temperature by increasing the power to the bulb, and we could draw a connection between the power transmitted and the temperature of an object heated by the light source.

As this experiment called for extensive use of a very bright, very high-temperature light source, navigating safety protocols was a vital portion of the process. From assembling the necessary components of the project with care, to moving the location of the experiment to have easier access to airflow, to submitting Safety Approval Forms, actions were made with safety taken fully into account. In order to address the light's brightness, the setup was covered during heating and a prosilica GT microscope was connected to a computer so that we could monitor the sample outside the light's line of sight as we increased the temperature.

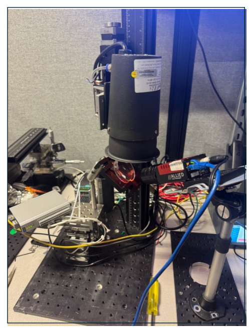
Figure 2: Photo of the workspace, ready for testing with an indium sample set up.

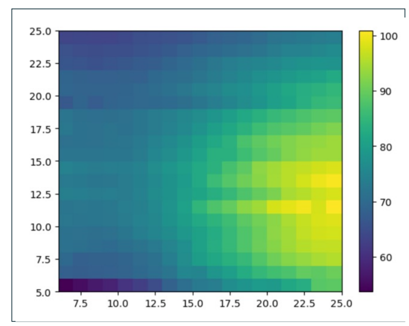

Figure 3: Color-coded temperature distribution visual of a 2D scan (x, y)

Results

In our test with indium, It was difficult to visually pinpoint an exact wattage that resulted in the sample melting, however, notable changes in texture took place. Figures 4, 5, and 6 depict the phases our test. Moving chronologically, Figure 4 was prior to heating, Figure 5 was taken at the first sign of physical change, with roughly 250W powering the light, and Figure 6 was after the temperature had been brought back down. Past the melting point, the sample's surface became noticeably smooth, yet retained its shape even after extensive raising of the temperature to above 500W of power input. The shape retention was due to surface tension, which would keep the shape of the metal seemingly spherical well after its melting point.

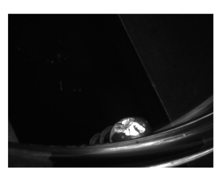
Figure 4: Indium prior to heating

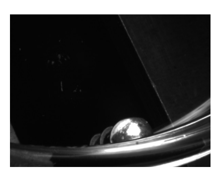
Figure 5: Indium during heating (~50V, ~5A, ~250W power)

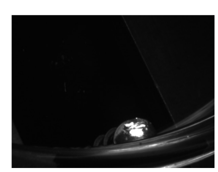
Figure 6: Indium after being heated

Conclusion

Based on our tests, we were able to conclude that while the light source can heat samples, it may not be the most effective method. For one, around 250W of its full 750W capacity needed to be used on indium for any changes to be visible, a metal with a melting point of 156.6℃. The light's hotspot seemed to be large enough for the tested 5mm by 5mm samples, as changes were observed throughout the entire sample rather than a visible area. Additionally, we discovered that while there is a positive relationship between the thermocouple-recorded and actual temperatures, there is an observable offset, which we think is caused by some of the the light being reflected away from the shiny thermocouple

Acknowledgements

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