MODULATION OF ELECTROMAGNETIC RADIATION USING A DOT MATRIX PRINTER

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ABSTRACT

Spatial modulation of electromagnetic radiation is crucial for many optical systems. We are focused on the design of a biological instrument that relies on spatially varying infrared laser radiation for heating of aqueous solutions within an array of 1.5 µL microchambers. Such a radiative heating method is preferable to conductive and convective heating because it allows for fast heating rates at absorption wavelengths, there are no risks of incompatible materials coming into contact with the reaction, and it allows for the possibility of a disposable reaction environment. A single radiation source directed to multiple reaction chambers can reduce complexity of the overall device and also cost. We have developed an optical shutter designed to partially block radiation to a select chamber. This allows for two adjacent chambers to achieve different temperatures. Testing of the device has resulted in a direct, linear relationship between the shutter's duty cycle and the amount of radiation passing through. This device will allow us to control the temperature in two chambers heated by one source of radiation.

INTRODUCTION

Many microfluidic applications require the ability to control the temperature of tiny liquid volumes (e.g. 1-10 µL). An example of such an application is the polymerase chain reaction (PCR) in which a DNA template is amplified via a heat-stable polymerase enzyme and thermal cycling [1]-[3]. A major limitation on current PCR cyclers is the inability to run multiple thermally independent reactions simultaneously, which would require the ability to locally control the temperature in each reaction chamber during thermal cycling [4]. Critical temperatures for this reaction are in the range of 50-60°C, and adjacent chambers require temperature differences as large as 5°C.

A source of electromagnetic radiation can be blocked to locally decrease the temperature on a microfluidic chip. Therefore, we have developed an optical shutter utilizing the solenoids of a dot matrix printer. By opening and closing the shutter at a varying duty cycle, different amounts of radiation are allowed to pass through to the reaction chamber. This allows one source of radiation to control multiple temperature profiles in adjacent chambers. Our current setup is shown in Fig. 1.

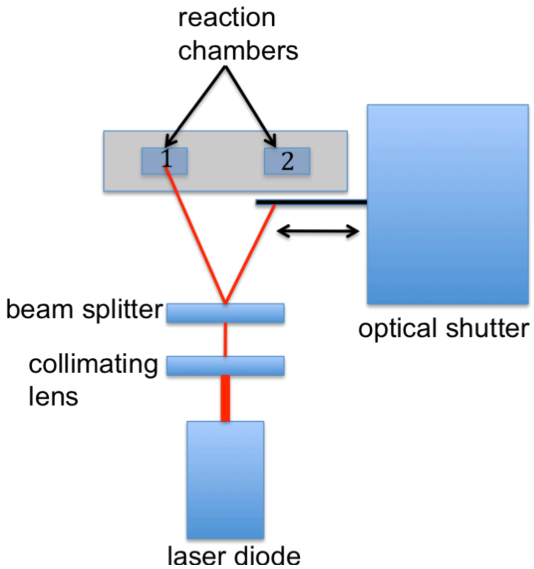

FIGURE 1. Schematic of dot matrix printer based optical shutter. Chamber 2 will have a lower temperature depending on the duty cycle at which the shutter operates. The two chambers are heated by a single source of radiation; a laser diode.

A 1450 nm laser diode is collimated and split into two beams focused on two identical 1.5 μL reaction chambers. The optical shutter is mounted directly below one of the chambers. When it is activated, the temperature of that chamber decreases based on the duty cycle at which the shutter operates.

MATERIALS AND METHODS

The challenges associated with utilizing an optical shutter on a microfluidic device are the space constraint and speed. The shutter must fit on or around the small area of the microfluidic chip but still operate at a high enough frequency to effectively control temperature. Traditional solenoids are far too large to fit into the device architecture so a dot matrix printer head is used, which has 24 individually activated miniature solenoids.

Thermocouples are inserted into both reaction chambers to monitor temperature. The temperature in each chamber is controlled with a Labview program, which has different set points for each chamber. To decrease the temperature of the blocked chamber, the program increases the duty cycle of the shutter. In this way, the temperature of the blocked chamber is less than or equal to that of the unblocked chamber.

The maximum displacement of the shutter, from a dot matrix printer [NEC, Pinwriter P2200XE] is 0.58 mm, and the minimum duty cycle that produces full displacement is 0.05 at 10 Hz. High speed video [Phantom, v9.0, Wayne, NJ] analysis has revealed the time to close the shutter as 1.841 ms, and the time to retract as 1.315 ms. The chamber width of 0.50 mm is fully blocked by this displacement, and the sufficiently low displacement time effectively makes this a digital shutter.

EXPERIMENTAL RESULTS

The shutter was characterized by measuring the amount of radiation passing through at a given duty cycle. This was done using a photodiode, which recorded intensity data through Labview. The results can be seen in Fig. 2.

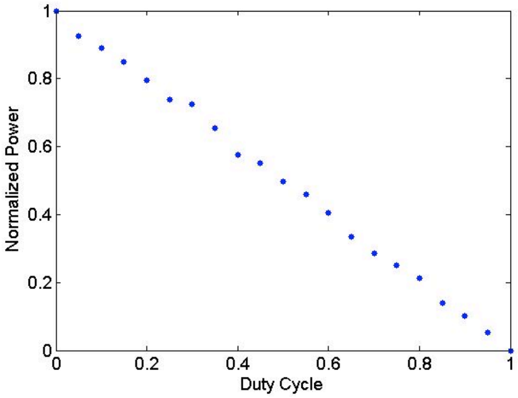

FIGURE 2. Plot of normalized power as a function of duty cycle. Data was obtained by changing the shutter duty cycle while measuring transmitted power with a photodiode.

The power was normalized based on full irradiation and no irradiation. This plot shows the linear relationship between duty cycle and power.

Decreasing the temperature in chamber 2 will lead to some temperature drop in the other chamber because of conduction. Therefore, it was important to understand what the maximum temperature difference between the chambers was at a given temperature. To achieve this, the two chambers were brought up to the same temperature, Tss. The shutter was then run at a duty cycle of 1, or fully closed. This was done for several temperatures and plotted in Fig. 3.

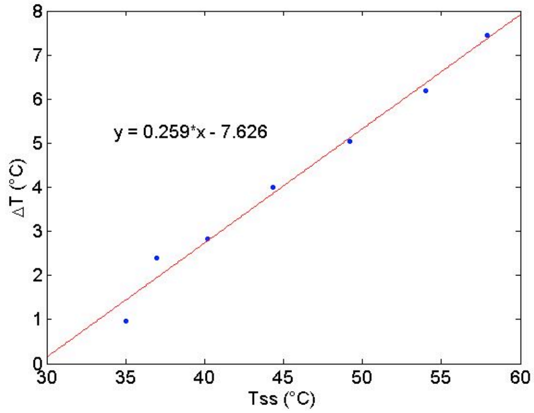

FIGURE 3. Plot of temperature difference between the chambers as a function of steady state temperature in chamber 1. The duty cycle was set to a value of 1.

The temperature in the first chamber was maintained through feedback control. As can be seen, the trend is fairly linear. These temperature differences exceed the required 5°C at Tss > 49°C.

To show that varying the duty cycle has an effect on temperature, different duty cycles were used at the same set point. This can be seen in Fig. 4.

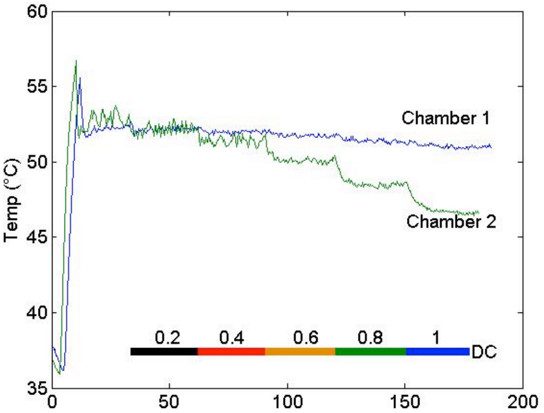

FIGURE 4. Plot of temperature in both chambers vs. time. The temperature of chamber 2 is varied by changing the shutter duty cycle.

The line on the bottom of the graph marks the duty cycle at which the shutter was operating at for that period of time. It can be seen that there are clear and distinct regions of decreased temperature at each of the different duty cycle values.

CONCLUSION

Independent temperature control in microfluidics is a useful feature in many biological applications. Achieving this with a single source of electromagnetic radiation has the added benefits of simplicity, lower cost, and a heat source that is isolated from the reaction environment. We have developed an optical shutter that is small enough to fit into a microfluidics environment yet has the speed to effectively control temperature. The power output as a function of duty cycle was plotted, and the temperature isolation between adjacent chambers was obtained. It was also shown that by varying the duty cycle, distinct temperatures could be achieved. This device will allow us to run two independent PCR reactions on the same microchip. Further scaling of our shutter could allow for up to 25 microchambers to be independently controlled from the 24 solenoids in the dot matrix printer.

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