Determining programmed characteristics for smart thermal material using topology optimization

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Introduction

- There are several mechanisms that are capable of actively or passively altering their thermal conductivity, which allows them to be used to manipulate heat transport.[1] However, the current generations of these devices can only be utilized as individual components due to their large size.
- If these mechanisms were to be made sufficiently small, they could act as the bits of a smart thermal material that can locally adjust its thermal conductivity. Such a material would have numerous thermal management applications.
- This project aims to determine the feasibility of using commercial topology optimization software to decide the characteristics to program the theoretical smart thermal material with.

Methods

- ANSYS Workbench was used for thermal analysis and topology optimization.
- Experimental setup has 3 electrical components on a PCB made of the smart material, which is used to avoid overheating the sensitive component.

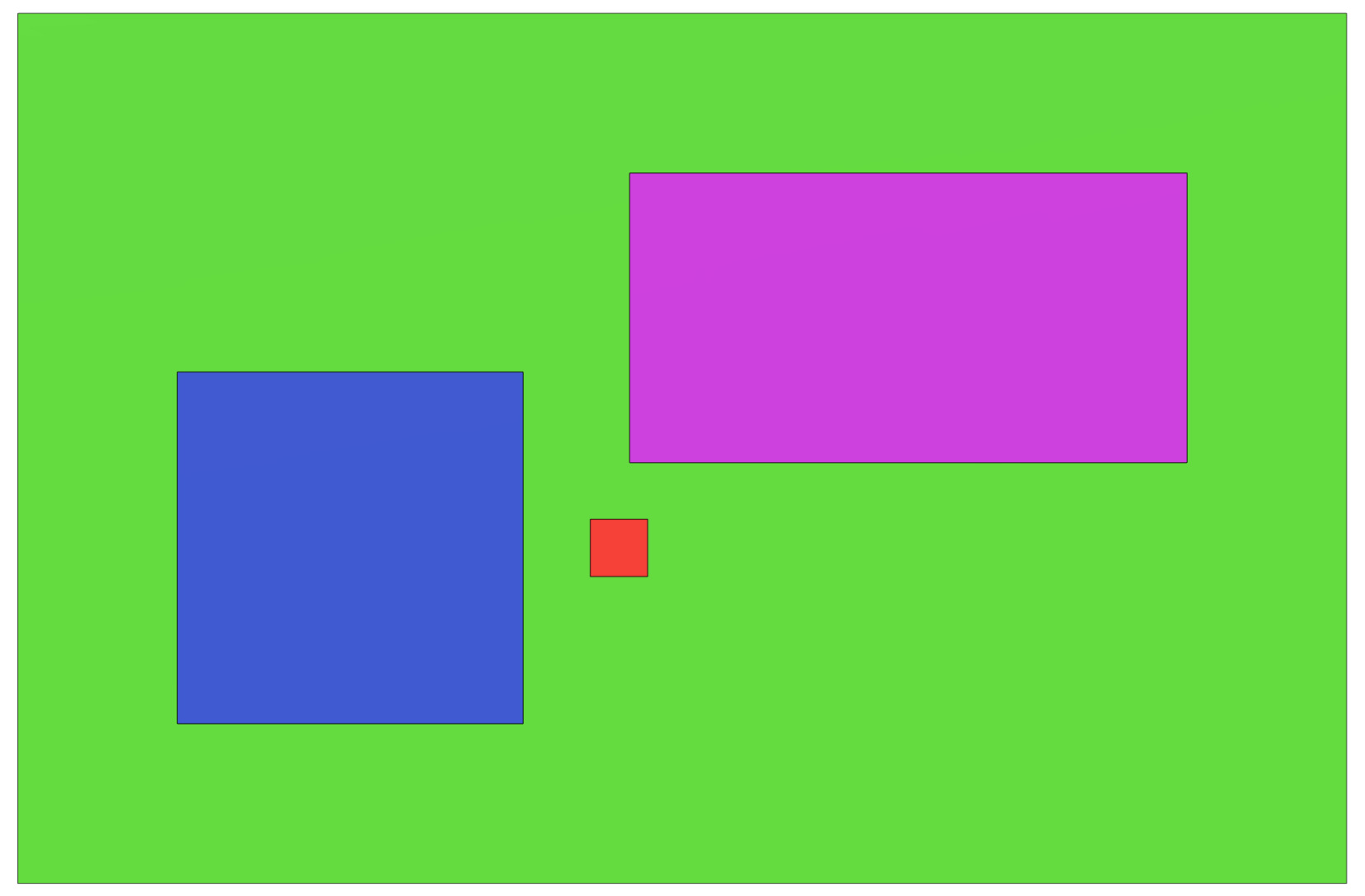

Figure 1: PCB layout

- Ambient temperature was set to 22°C.
- Natural convection from all upwards facing surfaces was set to 10 W/(m^2×K).
- PCB (Green) is 124.912 mm × 81.71 mm and has a thermal conductivity of 0.4 W/(m×K) (like FR-4). Switching ratio was set to 5.
- Diode (Red) generates 5mW of heat, and has a max operating temperature of 40°C.[2]
- Driver (Blue) generates 1.2W of heat.[3]
- Power Supply (Purple) generates 1W of heat.[4]

Results

Original:

- Maximum temperature of the diode is 49.152°C, which exceeds the max operating temperature.

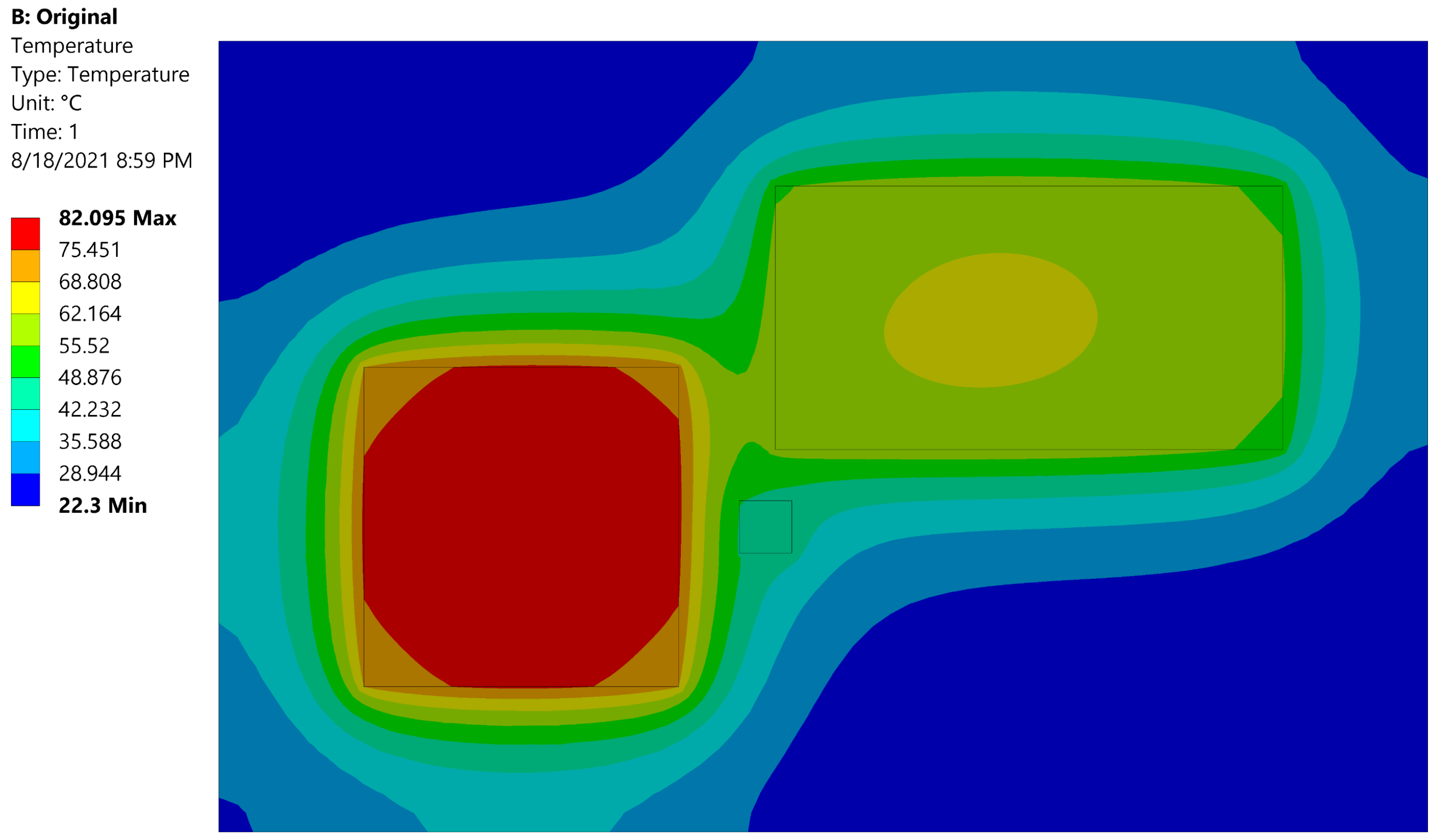

Figure 2: Temperature model of original PCB.

Optimized – No Material:

- Maximum temperature of the diode is 33.996°C, which is below the max operating temperature.
- Maximum temperature of the driver increased by 0.722°C.

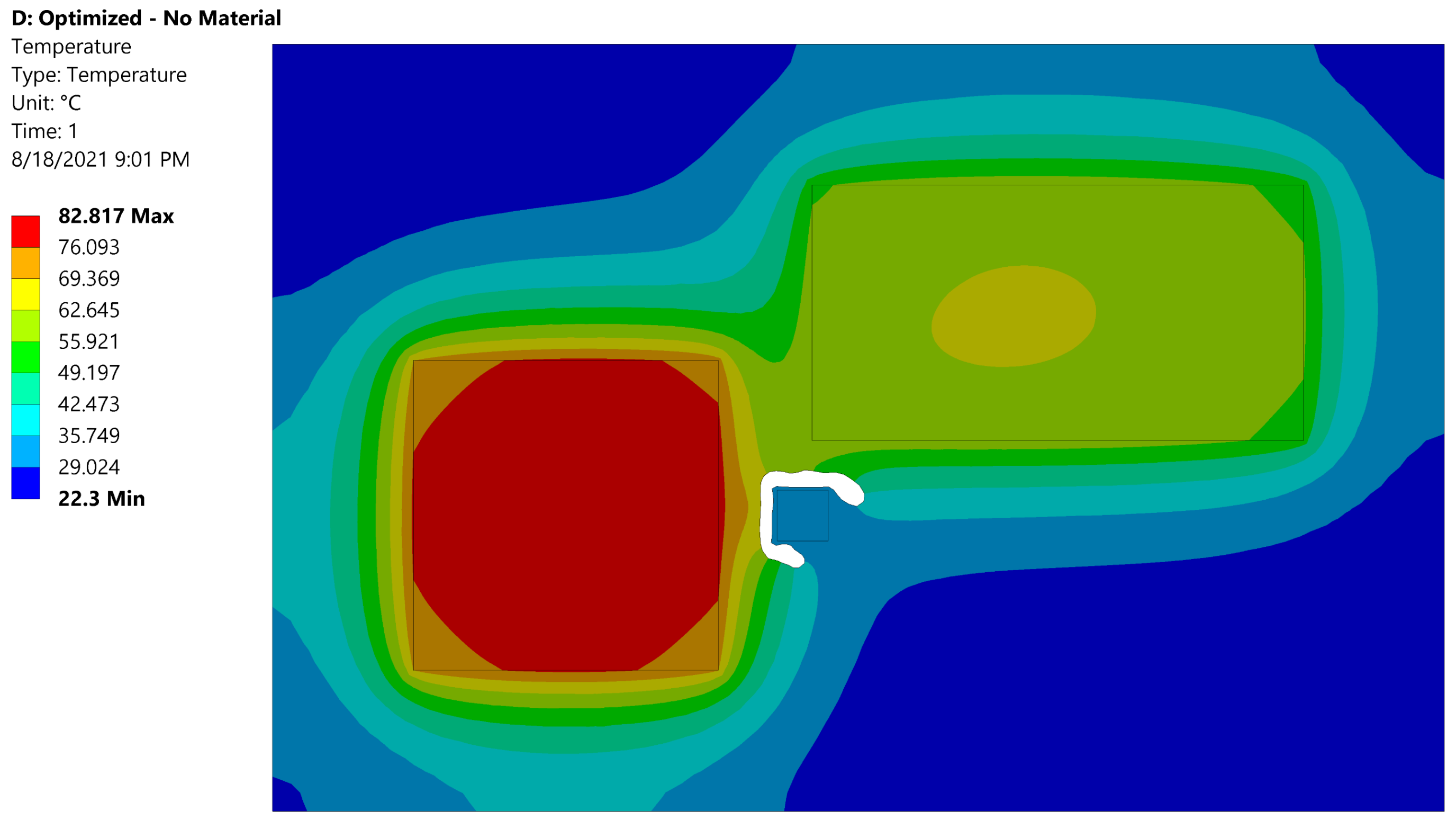

Figure 3: Temperature model of topology optimized PCB with material removed.

Optimized – Smart Material:

- Maximum temperature of the diode is 43.945°C, which exceeds the max operating temperature, but is below the original.

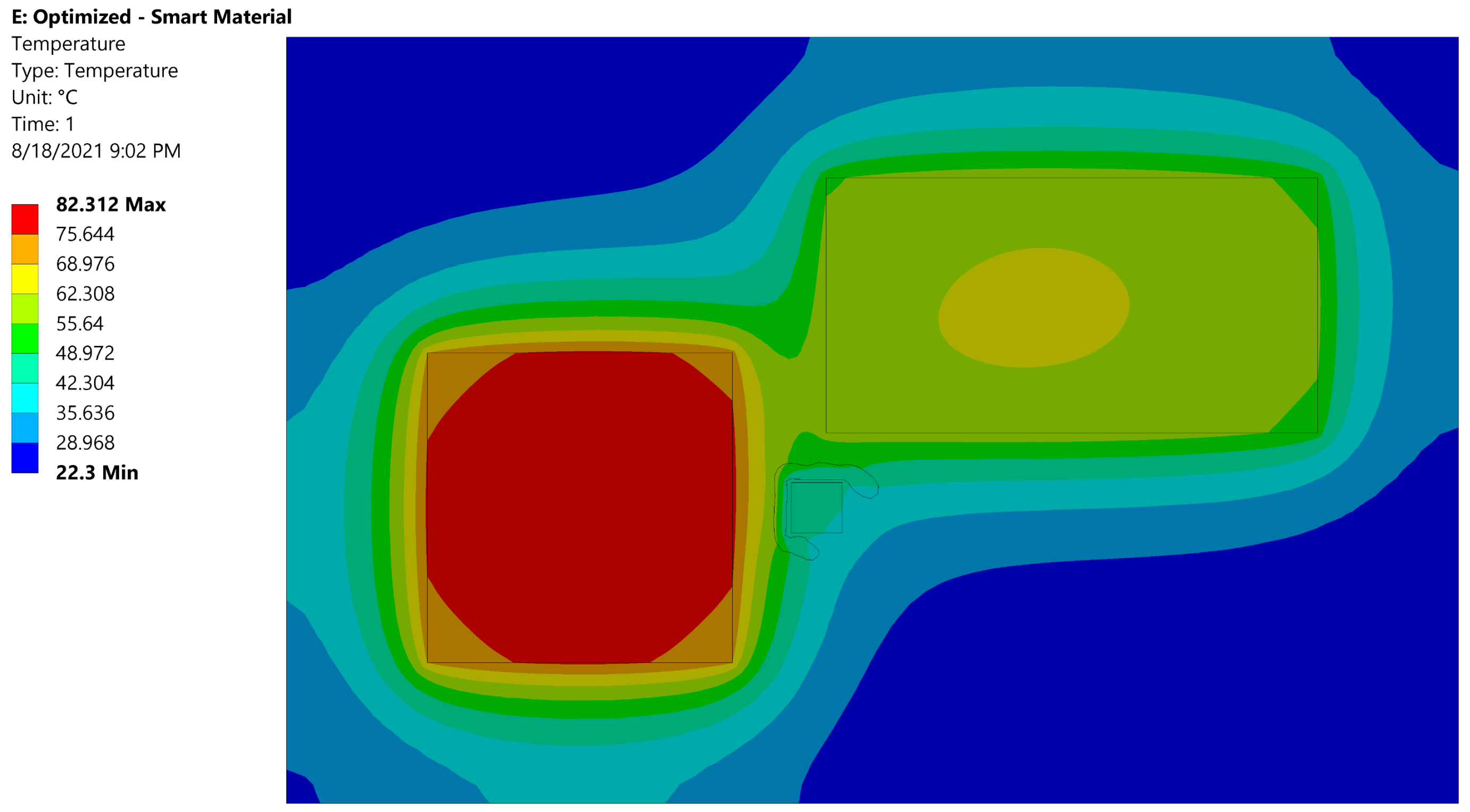

Figure 4: Temperature model of topology optimized PCB with material replaced.

Conclusion & Discussion

- ANSYS Workbench’s thermal topology optimization has several limitations:
  - Works with steady-state cases only
  - Requires a constant thermal conductivity
  - Can either have only temperature loads or only thermal loads (i.e., non-temperature loads)
  - Restricted to default objective function
  - Can only subtract existing material, unable to add new material
  - Only able to remove material, not capable of replacing material
- ANSYS Workbench can produce a solution for cases that abide by these restrictions and require a specified region to be maintained below a specific temperature.
- The specific maximum temperature should be conservative, as the specified region exceeds the maximum temperature when the material removed by the optimization process is replaced with material in the low thermal conductivity state.

References

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