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Design, optimization, fabrication and analysis of Cu microheater for loop-mediated isothermal amplification (LAMP) applications

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ABSTRACT

A paper presents the design, fabrication, and thermal evaluation of a printed circuit board (PCB) based copper (Cu) microheater that can be integrated with microfluidic chips to initiate the loop-mediated isothermal amplification (LAMP). A series of 3D finite element electro-thermal simulations were carried out to analyze the thermal uniformity and power consumption of the micro heater. The optimal design was fabricated using the etching technique and analyzed with a heat spreader to enhance thermal uniformity. The simulation results of the microheater reveal that the meander configuration outperforms other designs. In addition, the microheater with a heat spreader has a thermal difference of only < 5 ℃ when compared with ~10 ℃ in a microheater without a heat spreader. The developed microheater has a long shelf life and can be used to handle wet biological samples when encapsulated with polyethylene terephthalate (PET). The paper microfluidic chip on the glass substrate has a temperature difference of only 0.5 ℃. The low-cost microheater integrated microfluidic chips has the great potential to develop inexpensive home-based diagnostic kits and trigger the access of diagnostic kits in underdeveloped countries to reduce the spread of infection and initiate treatment plans.

1. Introduction

A microheater is a thin film with a thickness of ~100 nm to ~100 µm that utilizes the Joule heating, radiation, or ultrasound effect to generate heat up to 1900 ℃ with precise control. Multiple physics, including electrical, mechanical, and thermal, as well as material qualities and geometric designs, influence the temperature of the microheater [1]. Several microheaters are available for amplification, but they are either costlier for reuse or inexpensive for disposal. Some of the widely used microheater materials are Platinum (Pt), Gold (Au), Silver (Ag), Nickel (Ni), Tungsten (W), and Titanium (Ti). The use of expensive microheaters for low-temperature applications is unworthy, as low-cost microheaters can deliver adequate temperature. Hence, proper substrate and heating element material should be chosen. Sputtering or PVD manufacturing procedures are considered time-consuming for large-scale disposable applications and increase the overall workforce. Thus, the commercialized product will be expensive due to the high cost of materials and fabrication methodology.

For DNA amplification applications, maintaining constant temperature distribution is crucial [2]. Polymerase chain reaction (PCR)

Abbreviations: Au, Gold; Ag, Silver; ℃, Degree Celsius; Cr, Chromium; C_p, Thermal Conductivity; CU, Copper; DC, Direct Current; DNA, Deoxyribonucleic acid; *E*, Electric Field; FR-4 PCB, Flame Retardant Printed circuit board; $FeCl_3$,, Ferric Chloride; FEM, Finite Element Method; *J*, Current Density; IPA, Isopropyl Alcohol; *k*, Heat Capacity; Kg, Kilogram; LOC, Lab-on-Chip; LAMP, Loop-Mediated Isothermal Amplification; m^2·K, Metre-Kelvin; Ni, Nickel; PCR, Polymerase Chain Reaction; Pt, Platinum; POC, Point of Care; POCT, Point of Care Test; P, Power Consumption; PCB, Printed circuit board; PET, Polyethylene Terephthalate; PVD, Physical Vapour Deposition; Q, Electric Charge; R, Resistance; RT-LAMP, Reverse Transcription Loop-Mediated Isothermal Amplification; RNA, Ribo Nucleic Acid; SARS-CoV-2, Severe Acute Respiratory Syndrome Coronavirus 2; S/m, Siemens per Metre; ρ, Density; T, Temperature; Ti, Titanium; V, Volt; W, Tungsten; W, Watt.

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