Design and fabrication of a lab-on-a-chip system with integration of superparamagnetic nanoparticles for contactless heating applications

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Context

To weaken cancer cells while leaving surrounding tissue unharmed, the use of **heat generated by superparamagnetic (SPM) nanoparticles via magnetic hyperthermia therapy (MHT)**, which can be seen in Figure 1, is a useful technique. With this technique, heat is generated when **SPM nanoparticles** are brought **into an alternating magnetic field (AMF)**, where magnetic energy is converted into **thermal energy**.

A **lab-on-a-chip (LOC) system for contactless heating** applications would make it possible to do more **research on the effect of MHT** in the form of SPM nanoparticles exposed to an AMF **on temperature rise and**, at later stages, **on the weakening of tumors**.

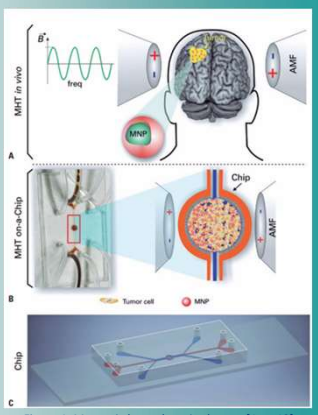


Figure 1: Magnetic hyperthermia therapy [1, p. 10]

Problem and objectives

There are already **LOC systems for heating** applications **on the market**, but these **focus mainly on heating via resistors and infrared (IR) radiation**, and pose problems as shown in Table 1.

Table 1: Problems resistance and IR radiation heating approach

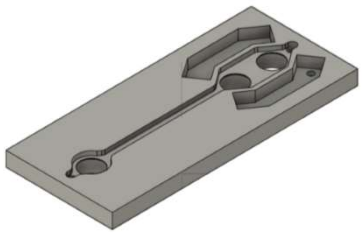
Problems resistance and IR radiation heating approach	
Heating approach	**Problems**
Resistor	Not contactless (hinders mobile health)
	No direct contact with medium to be heated
IR radiation	No direct contact with medium to be heated

An **LOC system heated by heat from MHT with SPM nanoparticles** is a **solution** to these problems.

Aim of this master's thesis:

- **design and fabrication** of an **LOC system** with a water-filled channel (see Figure 2);
- **at least a 5 K temperature gradient** over the water-filled channel **after a 5-minute heating period**.

Figure 2: Initial idea structure LOC system with more than one container



The **final version** of the **designed LOC system with more than one container** in Fusion 360 and that was fabricated with an SLA 3D printer can be observed in Figures 5 and 6.

Figure 5: Top view fabricated LOC system

Figure 6: Bottom view fabricated LOC system

The temperature measurements, which were performed by an IR thermal camera on the final version of the designed and fabricated LOC system **show that an average temperature gradient of 5.09 K**, which is equal to a temperature increment rate of 0.017 K/s, **could be achieved** over the water-filled channel **after a heating period of 5 minutes**. This temperature gradient was achieved over the water channel **because** the **temperature at the end of the channel increased** by **3.90 K** (see Figure 7), **and** because **a temperature gradient was already present due to** the **retained heat in the volume of ferrofluid** at the end of the channel.

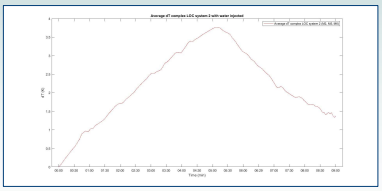


Figure 7: Average ΔT over 3 measurements on complex LOC system 2 with water injected (at end of channel)

Results and conclusion

Method

The **SLA 3D printing principle** and the **MHT heating method** to increase the temperature, which are used are shown in Figure 3 and 4.

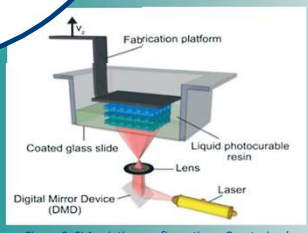


Figure 3: SLA printing configurations. Constrained surface approach. [2, p. 2002]

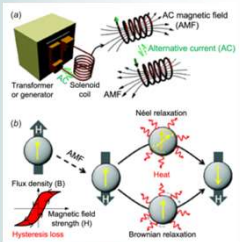


Figure 4: Setup of magnetic induction heating (a) and schematic illustration of the AMF for heating SPM nanoparticles (b) [3, p. 2]

Preliminary work

- filling and sealing of containers with SPM nanoparticles;
- designing, fabricating and characterizing of inductance coils;
- design and fabrication of LOC system with more than one container via SLA 3D printing.

Temperature measurements

- determining of best heating container and coil configuration;
- determining of temperature increase (and temperature gradient):
  - on commercially available LOC system with one container;
  - on LOC systems with more than one container.

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[1] J. B. Mamani et al., "Magnetic hyperthermia therapy in glioblastoma tumor on-a-Chip model," Einstein (Sao Paulo), vol. 18, p. eAO4954, 2020

[2] S. Waheed et al., "3D printed microfluidic devices: Enablers and barriers," Lab on a Chip, vol. 16, no. 11. Royal Society of Chemistry, pp. 1993–2013, 2016

[3] E. A. Kwizera, S. Stewart, M. M. Mahmud, and X. He, "Magnetic Nanoparticle-Mediated Heating for Biomedical Applications," J Heat Transfer, vol. 144, no. 3, Mar. 2022