REMTES

TECHNOLOGY FOR REMOTE TEMPERATURE MEASUREMENTS IN MICROFLUIDIC DEVICES

PROGRAM-PRIZMA-2023-2026
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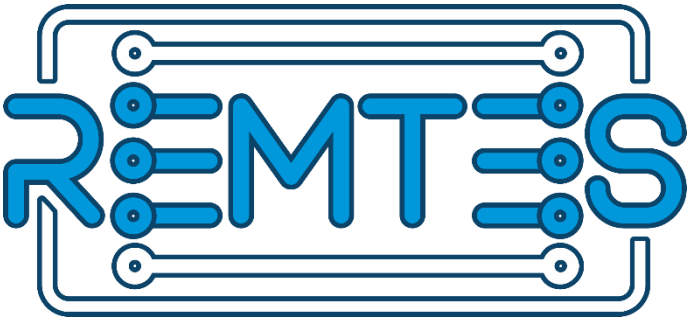

Deliverable 2.1

Report on the fabrication, optical, morphological, and thermal properties of the microfluidic chip

Version Final

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INTRODUCTION

REMTES – "Technology for remote temperature measurements in microfluidic devices" is a Science Fund of the Republic of Serbia funded project (Program PRIZMA, Grant Contract No. 7017) coordinated and completely executed by "Vinča" Institute of Nuclear Sciences – National Institute of the Republic of Serbia, University of Belgrade (VINS). The project will run from December 1st 2023 to November 30th 2026.

REMTES is a highly ambitious and innovative project aimed at developing a breakthrough system for measuring sample temperatures on the nanoliter scale. The project will develop an optical self-referencing thermometer for use in micro- and nanofluidics in the 0–100 °C temperature range by exploiting temperature-induced changes in the luminescence of materials and nanomaterials; that is, by advancing luminescence (nano-) thermometry in a targeted manner. The project aims to go beyond the state of the art and implement a radically new technology that merges the fields of luminescence thermometry, photothermal spectroscopy, and microfluidics to develop new-generation luminescent thermometry probes using cutting-edge luminescent, temperature-sensitive, and chemically stable inorganic materials in bulk and nanomaterial forms. The probes will be embedded in microfluidic chip channels to enable self-referenced remote temperature measurements, and the technology will be validated by a portable microfluidic luminescent thermometer, as well as in-situ temperature measurements of fluid flow in nanoliter volume samples. Multiple conceptual breakthroughs can be further envisaged from the proposed technology credibly spreading its impact to multiple technological areas.

The present document – **D2.1: Report on the fabrication, optical, morphological, and thermal properties of the microfluidic chip** is a deliverable of the W2 (joint effort with WP3) of the REMTES project. The report describes fabrication, optical, morphological, and thermal properties of a microfluidic chip, with up to four designs selected for further development.

D2.1: Report on the fabrication, optical, morphological, and thermal properties of the microfluidic chip

In this phase of the project, a range of microfluidic devices with varying microchannel geometries were designed and modeled using CAD software. The designs were subsequently fabricated via stereolithography (SLA) 3D printing on a Formlabs Form 3+ printer (Figure 1). The printer is purchased during the REMTES project and is composed of:

- **Resin Cartridge:** Contains the liquid resin that is dispensed into the resin tank.
- **Resin Tank:** Holds the liquid resin and includes a mixer to ensure consistent resin quality.
- **Build Platform:** The aluminum base where the printed parts are attached.
- **Cover:** A metal and orange-tinted cover that protects the printer and the resin from light and exposure to the lasers.
- **Light Processing Unit (LPU):** The enclosed optics engine that directs the lasers to cure the resin, ensuring consistent and accurate prints.
- **Touchscreen:** A 5.5" LCD touchscreen interface for controlling the printer, displaying print information, and error messages.
- **Status Light:** Indicators that pulse to indicate the printer's status, including active printing, completed prints, or errors.
- **Leveling Disc:** Used to adjust the printer's height using the leveling feet.
- **Leveling feet:** Adjustable feet to ensure the printer is stable and level.

Figure 1 Formlabs Form 3+ printer

To achieve the necessary optical transparency required for fluorescence imaging, Clear Resin V4 was used during the printing process. Initially, three designs were fabricated:

1. One channel with 1mm depth, straight design
2. One channel with 1mm depth, curved design
3. Three channels with 1mm depth, mixed straight and curved design.

The printed microfluidic devices (Figure 2) underwent a comprehensive two-step post-processing protocol to ensure optimal performance and structural integrity. In the first step, the devices were thoroughly washed in isopropanol to remove any uncured resin residues that may have remained on the surface or within the microchannels following the printing process. This washing step is critical for eliminating potential contaminants that could compromise device functionality or interfere with subsequent steps. Following the cleaning phase, the devices were subjected to a controlled UV curing process. This step was performed to finalize the polymerization of the resin, thereby enhancing the overall mechanical robustness of the devices. Additionally, UV curing significantly improved the optical clarity of the microchannels, which is essential for applications involving optical detection or imaging. After the post-processing was completed, each fabricated device underwent meticulous inspection under a high-magnification stereomicroscope. This inspection ensured that the printed microchannels were free of defects, properly formed, and within the specified dimensional tolerances.

Figure 2 Printed microfluidic devices

Subsequently, approximately 1 μL of a gadolinium orthovanadate ($GdVO_4$) colloidal solution doped with 50 mol% europium (Eu^{3+}) ions was carefully injected into selected microchannels of the fabricated microfluidic devices, each channel having a uniform depth of 1 mm. The selection of $GdVO_4$:Eu^{3+} as the luminescent material was driven by its well-documented and robust photoluminescent characteristics, including high quantum yield, chemical stability, and sharp emission lines, particularly in the red spectral region, which makes it highly suitable for fluorescence-based imaging applications. These properties render $GdVO_4$:Eu^{3+} an ideal candidate for investigating the optical performance of microfluidic channels through fluorescence microscopy.

Fluorescence imaging was conducted using a B-510LD4-SA LED fluorescence microscope, which was configured with a high numerical aperture (NA) 40× objective to ensure optimal spatial resolution and efficient light collection. For excitation, a 265 nm ultraviolet (UV) light source was employed, capable of effectively exciting the Eu^{3+} ions within the $GdVO_4$ host lattice. The emitted fluorescence signal, primarily in the visible red region, was captured using a 510LP long-pass emission filter, which blocks shorter wavelengths while transmitting the desired emission band, thus enhancing

image contrast. Images were recorded with an OPTIKA C–B CMOS camera, with acquisition parameters optimized for sensitivity and clarity. An exposure time of 100 ms was selected to achieve a high signal-to-noise ratio while minimizing potential photobleaching effects that could degrade the sample over time. The resulting fluorescence microscopy image of the selected microfluidic chip design, illustrating the distribution and intensity of the luminescent probe within the channels, is presented in Figure 3.

After conducting a comprehensive analysis of the various microchannel configurations, including assessments of dimensional accuracy, structural integrity, and compatibility with the intended experimental protocols, a single microchannel design was selected for further investigation. The chosen configuration featured a straight geometry with a uniform depth of 1 mm, offering the most favorable characteristics in terms of fabrication reproducibility, fluid flow predictability, and ease of optical access for downstream imaging applications. This selection was based on both qualitative observations under a stereomicroscope and quantitative measurements confirming that the printed features closely matched the design specifications. The adoption of this specific channel layout marked a key progression in the project, facilitating the transition from prototype evaluation to practical experimentation. As such, the successful identification and validation of the optimal microchannel design led to the **formal completion of Milestone 3.1: Microfluidic Chip Design Selected**, as outlined in the project plan.

This procedure established a robust and reproducible workflow encompassing the fabrication, post-processing, and optical characterization of custom-designed microfluidic devices tailored for advanced analytical applications. Each stage of the process—from the initial 3D printing and resin curing to the injection of photoluminescent probes and high-resolution fluorescence imaging—was carefully optimized to ensure high structural fidelity, functional integrity, and compatibility with downstream optical analysis techniques. The methodology demonstrated here can serve as a foundational protocol for future device iterations, enabling rapid prototyping and performance validation in a laboratory setting.

To support further use and replication of the design, the computational model developed for the selected microfluidic chip is provided as a separate downloadable file. This file includes the full geometry, layout parameters, and technical specifications used in the design process. It is available on the REMTES project webpage under the **Deliverables** section, offering researchers and collaborators access to a validated reference model that can be adapted or modified for related microfluidic studies.

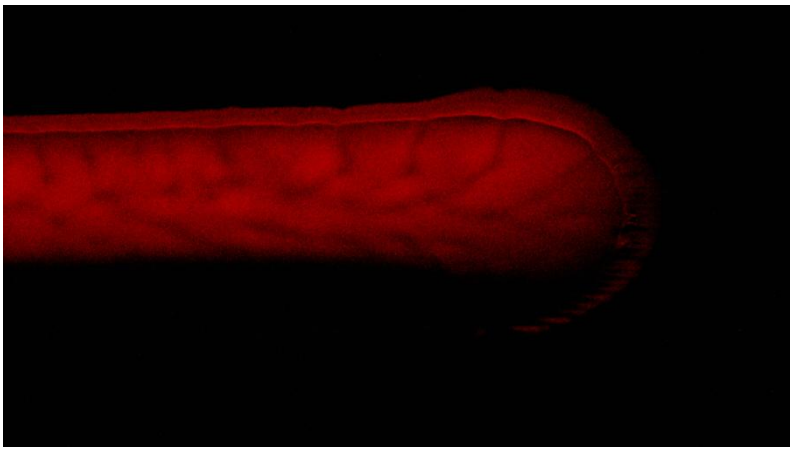

Figure 3. Fluorescence imaging of microchannel with $GdVO_4$:Eu^{3+} under excitation of 265 nm