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Experimental investigation on the thermal length expansion of direct laser writing material

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The interest in micro applications increases in recent years due to new methods of fabrication. One fabrication process is direct laser writing, which can fabricate high-precision structures in the micrometer range. The material properties of the micro structures are related to the writing parameters, such as laser power, scan speed, distance between written lines and writing direction. This work presents investigations of the thermal length expansion coefficients of a laser-written polymer in regard to laser power. To this end cantilever structures are fabricated. The small cantilevers are heated and their length expansions observed using a microscope. Images of the cantilevers at different temperatures are taken and by image post processing, the change in length and their coefficients of thermal expansion is determined.

1 Introduction

Three-dimensional laser writing of micro structures is of great importance for optical, photonic, microelectromechanical, microfluidic and biomedical systems [1]. In cooperation with Prof. von Freymann's group of Optical Technologies and Photonics, Technische Universität Kaiserslautern, we use a three-dimensional direct laser writing system (Photonics Professional GT, Nanoscribe GmbH, Germany) to fabricate micro structures. It works like a 3D printer, but prints on a much smaller scale. The working principle of direct laser writing is called two-photon polymerization. This process uses a chemical reaction triggered by a laser. After laser irradiation, the liquid photoresist are polymerized and change its state from liquid to solid. After all desired positions of liquid are irradiated, the non-irradiated part of the photoresists are dissolved in developing baths. For direct laser writing, various writable materials with different properties are available. At present we use the standard photoresist (IP-S from Nanoscribe GmbH). As far as we know, the thermal length expansion is directly related to laser power of the direct laser writing process [2]. Because in the future we want to actuate the written micro structures by temperature, we consequently need to adjust the thermal length expansion within the structures. Hence, in this work, its relation to laser power during direct laser writing is presented.

2 Experimental setup and results

To measure the thermal length expansion of micro structures from IP-S photoresist, cantilevers are produced and tested. Fig. 1a) and 1b) show a CAD-model and an image of the small cantilevers under the microscope. The cantilevers are written on a BK7 glass substrate. The used power scaling factor of the laser varies from 50% to 100% with full power of 34 mW on the entrance pupil of the objective (25x, NA=0.8). The cantilevers can freely expand and have a length L_0 of about 890 µm at room temperature. We also design an experimental setup shown in Fig. 1c), on which we can heat up, observe and measure the cantilevers under a microscope. The setup consists of a microscope, a heating element with an integrated thermocouple and a controller. The glass substrate with the written cantilevers is fixed on the heating element using heat-resistant tape. After being heated and the set temperature is preserved, the expansion is measured. To easily determine the expansion of the cantilevers, reference lines as a scale are additionally written on the glass substrate, as shown in Fig. 1d). The thermal length expansion coefficient of BK7 glass is $\alpha_{glass} = 7.1 \times 10^{-6} K^{-1}$ [3]. Since the cantilevers and the reference lines are not at the same level and can not be focused simultaneously, at each temperature two pictures are captured, one focusing on the cantilever and one focusing on the reference line. With the image post processing software ImageJ, the two pictures are overlaid and the relative expansion of the cantilever ΔL is measured, as Fig. 1d) shows. However, we find that some cantilevers shrink when heated from room temperature. So when calculating the coefficient of thermal expansion, we only consider the expansion phases. Therefore, the initial length of the cantilevers is measured at different starting temperatures. After that, the coefficients of thermal expansion are determined by $\alpha = \Delta L/(L_0 \cdot \Delta T) + \alpha_{glass} \cdot (L_0 - d)/L_0$, where d is the displacement from the reference line to the end of the cantilever at different starting temperatures.

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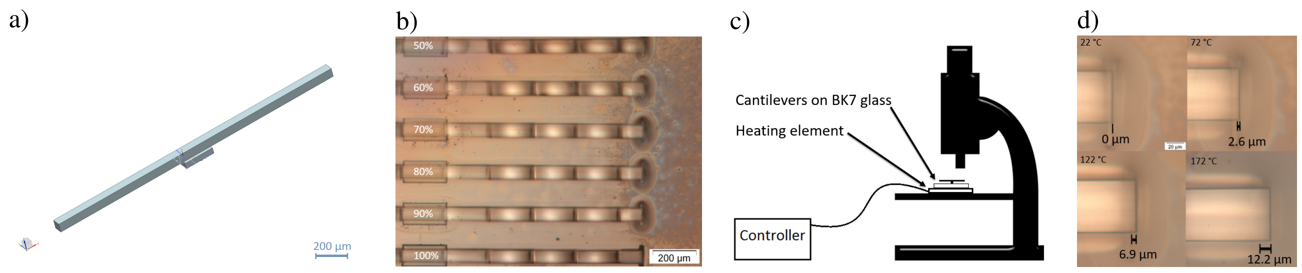

Fig. 1: a) CAD-model of the cantilever, b) written cantilevers under the microscope, c) experimental setup, and d) thermal length expansion of a cantilever at different temperatures.

Six cantilevers written by different laser power, which is represented by the power scaling factor (50% to 100%), are heated three times from 22 °C (room temperature) till 172 °C with a constant temperature step of $\Delta T = 25$ °C. Fig. 1d) illustrates the change of the cantilevers only during the expansion phases. If we subtract the initial length of each cantilever at the starting temperature, and fit a linear polynomial curve into all measurements in the expansion phases, we gain Fig. 2a). The cantilevers written with lower laser power (smaller power scaling factor) is expected to have a higher thermal length expansion. If we calculate the coefficients of thermal expansion of all three experiments, the result can be seen in Fig. 2b): the higher the power scaling factor, the smaller are their coefficients of thermal expansion. The explanation why cantilever written with power scaling factor of 70% has always smaller thermal expansions could lie in its fabrication and/or slight moving of the reference line.

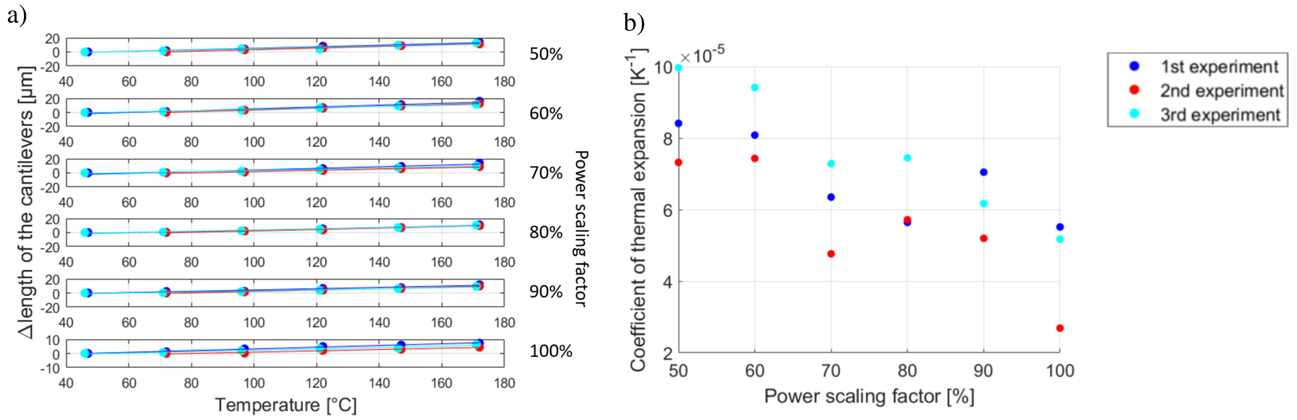

Fig. 2: a) Gradients of thermal length expansion of the cantilevers written with different power scaling factors, and b) coefficients of thermal expansion in relation with the power scaling factors.

3 Conclusion

In this work, several microscopic cantilevers out of IP-S photoresist are fabricated with different laser powers by using direct laser writing. With our experimental setup we are able to observe and measure the thermal length expansions of each cantilevers under the microscope. With the help of image post processing, the dependencies between the laser power and the thermal length expansion is determined. In summary, with increasing laser power during fabrication, the thermal length expansion of the direct laser writing material decreases. The determined coefficients of thermal length expansion also lie in the same order of magnitude as literature results of similar materials [2]. An interval of $2.7 \times 10^{-5} K^{-1}$ and $10.0 \times 10^{-5} K^{-1}$ is derived for the coefficients of thermal length expansion of the direct laser writing material.

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References

[1] M. G. Guney, G. K. Fedder, Estimation of line dimensions in 3d direct laser writing lithography, Journal of Micromechanics and Microengineering 26 (10) (2016) 105011. doi:10.1088/0960-1317/26/10/105011.

[2] J. Qu, M. Kadic, A. Naber, M. Wegener, Micro-structured two-component 3d metamaterials with negative thermal-expansion coefficient from positive constituents, Scientific Reports 7 (1) (jan 2017). doi:10.1038/srep40643.

[3] S. Shao, J. Shao, H. He, Z. Fan, Stress analysis of ZrO_2/SiO_2 multilayers deposited on different substrates with different thickness periods, Optics Letters 30 (16) (2005) 2119. doi:10.1364/ol.30.002119.

