Breaking the Energy Barrier in Two-Photon Polymerization Using Strain-Activated Photochemistry

Kacper Piskorz[1], Katarzyna Starzak[2], Malgorzata Noworyta[2], Konrad Cyprych[4], Krzysztof Bartkowski[3], Zahra Badri[3], Sukhvinder Dhiman[3], Cina Foroutan-Nejad[3], Jaroslaw Mysliwiec[4], Marcin Lindner[3], Joanna Ortyl[1,5,6]

[1]Cracow University of Technology, Faculty of Chemical Engineering and Technology, Warszawska 24, Cracow 31–155, Poland, kpiskorz.p3@wp.pl
[2]Cracow University of Technology, CUT Doctoral School, Faculty of Chemical Engineering and Technology, Warszawska 24, Cracow 31–155, Poland
[3]Institute of Organic Chemistry, Polish Academy of Sciences, Marcina Kasprzaka 44/52, 01-224 Warsaw, Poland
[4]Faculty of Chemistry Wroclaw University of Science and Technology Wybrzeże Wyspiańskiego 27, Wroclaw 50-370, Poland
[5]Photo HiTech Ltd., Bobrzynskiego 14, 30–348 Cracow, Poland
[6]Photo4Chem Ltd., Lea 114, 30-133 Cracow, Poland

Two-photon polymerization (2PP) has emerged as a powerful technique for high-resolution three-dimensional microfabrication; however, its broader application is often constrained by the requirement for high laser intensities and limited photochemical efficiency of conventional photoinitiators. In this work, we present a novel approach to 2PP based on strain-activated photo-dehalogenation, enabling efficient radical generation under significantly reduced energy input. The investigated system employs mechanically strained molecular precursors that undergo photoinduced bond cleavage upon single- and two-photon excitation, producing reactive species capable of initiating polymerization [1-3].

Our results demonstrate that the incorporation of strain-activated chromophores enhances the sensitivity of the photochemical process, allowing for low-threshold two-photon absorption and improved spatial control during fabrication. Comparative studies reveal that this mechanism not only lowers the required laser power but also expands the accessible processing window, facilitating finer feature definition and reducing photodamage. Furthermore, the dual capability of one- and two-photon activation provides additional flexibility in tuning fabrication conditions and material response.This strategy opens new avenues for the design of next-generation photoinitiating systems tailored for advanced 2PP applications, including micro-optics, biomedical scaffolds, and functional microdevices. By leveraging strain-induced reactivity, the proposed method contributes to overcoming key limitations in current photopolymerization technologies, paving the way toward more energy-efficient and versatile 3D microfabrication processes [2, 3].

This research was funded by the National Science Centre (NCN, Poland), OPUS, ("Emerging strategy approaches for the design and functionalization of carbon dots as multifunctional, dynamic, green systems photoinitiators and photocatalysts involved in photopolymerisation processes") Grant No. UMO-2021/41/B/ST5/04533 and by the Ignacy Łukasiewicz ORLEN Foundation under the "TURBOgrant" grant, project no. DKN/00057/2025

REFERENCES

[1] Sun H. B., Kawata S., (2004) "Two-Photon Photopolymerization and 3D Lithographic Microfabrication". Chemical Reviews, 104, 4891–4945. DOI: 10.1007/b94405
[2] Li L., Gong H., Zhang S., (2017) "Two-Photon Polymerization Initiators for Three-Dimensional Microfabrication". Journal of Materials Chemistry C, 5, 11487–11504. DOI: 10.1039/C7TC04274E
[3] Piskorz K., Starzak K., Noworyta M., Cyprych K., Bartkowski K., Badri Z., Dhiman S., Foroutan-Nejad C., Mysliwiec J., Lindner M., Ortyl J., (2025) "Strain-Activated Photo-Dehalogenation Unlocks Low-Energy One- and Two-Photon 3D Microfabrication". Advanced Functional Materials, 36, e16241. DOI: 10.1002/adfm.202516241