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Celebrating Holography after 60 years of successful application

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The invention of Holography by Dennis Gabor[1] goes back to the year 1948. Gabor could show that the complete original wavefront of the object both with its amplitude and phase can be reconstructed by adding a coherent background to a wave coming from an object while recording in a storage medium. However, because no adequate source of coherent light was available at this time, the small coherence length of the mercury lamp forced him to arrange everything along one axis. This setup, known as in-line holography, has the disadvantage that the desired reconstruction is in line with disturbing diffraction orders, and can be separated from these disturbances only by focusing. Gabor finally gave up his investigations and mentioned in 1955 to his collaborator Michael W. Haine, "*It was a very ill wind which I let out now almost eight years ago which blew nobody any good, least of all to myself*."

The holographic principle, on which Gabor had set his high hopes, especially with respect to the enhancement of the resolution of the electronic microscope, seemed to retain only the status of a scientific curiosity. But the breakthrough would be achieved a couple of years later. In the early 1960s, Emmett Leith and Juris Upatnieks, two physicists at the University of Michigan, implemented their off-axis scheme as a smart combination of Gabor's holographic principle with the carrier frequency technique known from side-looking radar. Their famous publication came out 61 years ago in 1961[2]. In this way the twin image problem could be effectively eliminated. However, it resulted in the requirement of increased temporal coherence which could be satisfied using a powerful coherent light source only. Such a source was soon available. In 1958, Charles Townes at the Columbia University, and a Russian research group led by Nicolay Basov and Aleksandr Prokhorov at the Lebedev Institute for Physics, Moscow, simultaneously and independently analyzed the possibilities of applying the principle of the Microwave Amplification by Stimulated Emission of Radiation (MASER) for the optical region of the electromagnetic spectrum.

The first operating optical MASER, now known as the laser, was constructed by Maiman and was demonstrated at the Hughes Research Laboratories in Malibu, California, in 1960[3]. The symbiosis of the holographic and laser principle opened the door for a large variety of new technologies and applications in optical imaging, information processing, and metrology. The 1960s were filled with a variety of successful practical applications and innovations such as display or volume holography[4], computer generated holography[5], holographic interferometry[6], holographic nondestructive testing, holographic pattern recognition, and holographic storage technology. Gabor took an active part in this development. 50 years ago, on the occasion of his Nobel lecture at the Imperial Colleges in 1971, he also tried to take a look into the future of holography[7]. Gabor mentioned "*However, there are important areas in which we can do much more, and where an improvement is badly needed. This is the area of microholograms for storing and for display. An even more ambitious scheme, probably even farther in the future, is three-dimensional cinematography, without viewing aids such as Polaroids*". The basics for

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such a technological leap like digital storage, reconstruction, and synthesis of holograms were already on the way[8,9] when Gabor made this prediction.

Holography also established the basis for new measurement technologies that play an important role in manufacturing. 1966 Karl A. Stetson and Robert L. Powell published their groundbreaking article "Holographic Interferometry" [6]. A.J. McGovern and J.C. Wyant proposed 1971 a new method for testing optical elements based on computer generated holograms[10]. Later Karl Stetson correctly mentioned "*The novelty of Holography is Speckle*". This astonishing effect because of the interaction of coherent light with scattering media was observed already many years ago. But to use Speckle as an outstanding tool for non-destructive testing goes back to the early 70th[11] and was also stimulated by holography. The application of video tubes instead of photo plates and electronic recording was a further major step in 1971 to make Speckle metrology called ESPI (Electronic Speckle Pattern Interferometry) to a mature technology[12].

In 2021, 60 years after the publication of the seminal article by Leith and Upatnieks, 55 years after the invention of Holographic Interferometry by Stetson and Powell, and 50 years after Gabor's remarkable Nobel lecture, the editors took the opportunity to celebrate these groundbreaking contributions to modern optics with a special edition of "*Light – Advanced Manufacturing*". Our call for papers found an impressive echo in the international community. We received 45 contributions from well-known experts in the field who reported about the history, state of the art and perspectives of holographic technologies. Finally, we could accept 39 papers and present this impressive collection in that special issue. Because these contributions address many different issues, we decided on a structure into 5 main topics:

- 6 papers[13–18] "Celebrating Holography and its Impact over 60 Years"
- 8 papers[19–26] dealing with the "Digital Transition of Holography"
- 8 papers[27–34] describing the Potential of Holography for the "Making of New Optical Components"
- 10 papers[35–44] addressing the "Wide Field of Applications" opened by holography
- 7 papers[45–51] discussing "Perspectives of Holographic Technologies".

Our thanks go to all authors who joined our journey through 60 years of a meanwhile traditional but even young discipline of modern optics. All these contributions express the conviction that this journey has just started and that we can still expect many remarkable innovations in the coming years. Further thanks go to all reviewers who helped us with their comments and proposals to keep the high quality of our LAM journal. We know about the large workload that we transfer to the colleagues with the request for careful assessment of all submissions. Finally, we thank all members of the editorial office of LAM who made it possible to publish that extensive collection of papers in a relatively short time after the acceptance of all submitted papers. Special thanks go to Shuai Ding and Siqiu Guo for their careful assistance and support.

The editors hope that this issue will find an interested audience and will be a welcome contribution to another successful 60 years of holography.

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Conflict of interest

The authors declare that they have no conflict of interest.

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References

1. Gabor, D. A new microscopic principle. *Nature* **161**, 777-778 (1948).
2. Leith, E. N. & Upatnieks, J. New techniques in wavefront reconstruction. *Journal of the Optical Society of America* **51**, 1469-1473 (1961).
3. Maiman, T. H. Stimulated optical radiation in ruby. *Nature* **187**, 493-494 (1960).
4. Denisyuk, Y. N. On the reflection of optical properties of an object in the wave field of light scattered by it. *Doklady Akademii Nauk SSSR* **144**, 1275-1278 (1962).
5. Brown, B. R. & Lohmann, A. W. Complex spatial filtering with binary masks. *Applied Optics* **5**, 967-969 (1966).
6. Stetson, K. A. & Powell, R. L. Hologram interferometry. *Journal of the Optical Society of America* **56**, 1161-1163 (1966).
7. Gabor, D. Physics 1971-1980. Nobel Lecture, Lundqvist, S. Ed. , World Scientific Publishing Co. , Singapore (1992) dedicated to the award of the Nobel Prize in 1971.
8. Goodman, J. W. & Lawrence, R. W. Digital image formation from electronically detected holograms. *Applied Physics Letters* **11**, 77-79 (1967).
9. Huang, T. S. Digital holography. *Proceedings of the IEEE* **59**, 1335-1346 (1971).
10. McGovern, A. J. & Wyant, J. C. Computer generated holograms for testing optical elements. *Applied Optics* **10**, 619-624 (1971).
11. Leendertz, J. A. Interferometric displacement measurement on scattering surfaces utilizing speckle effect. *Journal of Physics E:Scientific Instruments* **3**, 214-218 (1970).
12. Butters, J. N. & Leendertz, J. A. Holographic and Video techniques applied to engineering measurement. *Measurement and Control* **4**, 349-354 (1971).
13. Stetson, K. A. The discovery of holographic interferometry, its development and applications. *Light:Advanced Manufacturing* **3**, 2 (2022).
14. Trolinger, J. D. The language of holography. *Light:Advanced Manufacturing* **2**, 34 (2021).
15. de Groot, P. J. et al. Contributions of holography to the advancement

of interferometric measurements of surface topography. *Light:Advanced Manufacturing* **3**, 7 (2022).
16. Sirohi, R. Shearography and its applications–a chronological review. *Light:Advanced Manufacturing* **3**, 4 (2022).
17. Osten, W. & Pedrini, G. 55 Years of Holographic Non-Destructive Testing and Experimental Stress Analysis: Is there still Progress to be expected. *Light:Advanced Manufacturing* **3**, 8 (2022).
18. Häusler, G. & Willomitzer, F. Reflections about the holographic and non-holographic acquisition of surface topography: where are the limits. *Light:Advanced Manufacturing* **3**, 25 (2022).
19. Fratz, M. et al. Digital holography in production: an overview. *Light:Advanced Manufacturing* **2**, 15 (2021).
20. Claus, D. et al. Snap-shot topography measurement via dual-VCSEL and dual wavelength digital holographic interferometry. *Light:Advanced Manufacturing* **2**, 29 (2021).
21. Schnars, U. & Falldorf, C. Parallax limitations in digital holography: a phase space approach. *Light:Advanced Manufacturing* **3**, 28 (2022).
22. Gao, P. & Yuan, C. Resolution enhancement of digital holographic microscopy via synthetic aperture: a review. *Light:Advanced Manufacturing* **3**, 6 (2022).
23. Kim, M. K. Phase microscopy and surface profilometry by digital holography. *Light:Advanced Manufacturing* **3**, 19 (2022).
24. Utadiya, S. et al. Integrated self-referencing single shot digital holographic microscope and optical tweezer. *Light:Advanced Manufacturing* **3**, 37 (2022).
25. Schelkens, P. et al. Compression strategies for digital holograms in biomedical and multimedia applications. *Light:Advanced Manufacturing* **3**, 40 (2022).
26. Wang, Z. et al. Digital holography as metrology tool at micro-nanoscale for soft matter. *Light:Advanced Manufacturing* **3**, 10 (2022).
27. Kress, B. C. et al. Holographic optics in planar optical systems for next generation small form factor mixed reality headsets. *Light:Advanced Manufacturing* **3**, 42 (2022).
28. Du, Y. et al. Hybrid multimode – multicore fibre fordeep-tissue neurophotonics. *Light:Advanced Manufacturing* **3**, 29 (2022).
29. Abdurashitov, A. S. et al. Integrated binary hologram to monitor cargo release from a drug-eluting film. *Light:Advanced Manufacturing* **3**, 30 (2022).
30. Choporova, Y., Knyazev, B. & Pavelyev, V. Holography with high-power CW coherent terahertz source: optical components, imaging, and applications. *Light:Advanced Manufacturing* **3**, 31 (2022).
31. Stark, A. W. et al. Miniaturization of a coherent monocular structured illumination system for future combination with digital holography. *Light:Advanced Manufacturing* **3**, 34 (2022).
32. Petrov, N. V. et al. Design of broadband terahertz vector and vortex beams: I. Review of materials and components. *Light:Advanced Manufacturing* **3**, 43 (2022).
33. Petrov, N. V. et al. Design of broadband terahertz vector and vortex beams: II. Holographic assessment. *Light:Advanced Manufacturing* **3**, 44 (2022).
34. Zepp, A. et al. Simulation-based design optimization of the holographic wavefront sensor in closed-loop adaptive optics. *Light:Advanced Manufacturing* **3**, 27 (2022).
35. Zhou, H., Hussain, M. M. & Banerjee, P. P. A review of the dual-wavelength technique for phase imaging and 3D topography. *Light:Advanced Manufacturing* **3**, 17 (2022).
36. Hartlieb, S. et al. Multi-positional image-based vibration measurement by holographic image replication. *Light:Advanced Manufacturing* **2**, 32 (2021).
37. Piniard, M. et al. Melt pool monitoring in laser beam melting with two-wavelength holographic imaging. *Light:Advanced Manufacturing* **3**, 11 (2022).
38. Tornari, V. A symmetry concept and significance of fringe patterns as a direct diagnostic tool in artwork conservation. *Light:Advanced Manufacturing* **3**, 18 (2022).
39. Georges, M., Zhao, Y. & Vandenrijt, J. F. Holography in the invisible. From the thermal infrared to the terahertz waves: outstanding applications and fundamental limits. *Light:Advanced Manufacturing* **2**, 22 (2022).
40. Koukourakis, N. et al. Investigation of human organoid retina with digital holographic transmission matrix measurements. *Light:Advanced Manufacturing* **3**, 23 (2022).
41. Shanmugam, P. et al. Variable shearing holography with applications to phase imaging and metrology. *Light:Advanced Manufacturing* **3**, 16 (2022).
42. Tang, H. et al. Ultra-high speed holographic shape and displacement measurements in the hearing sciences. *Light:Advanced Manufacturing* **3**, 15 (2022).
43. Hall, M. L. et al. The application of digital holography for accurate three-dimensional localisation of mosquito-bednet interaction. *Light:Advanced Manufacturing* **3**, 20 (2022).
44. Hasegawa, S. et al. In-process monitoring in laser grooving with line-shaped femtosecond pulses using optical coherence tomography. *Light:Advanced Manufacturing* **3**, 33 (2022).
45. Blanche, P. A. Holography, and the future of 3D display. *Light:Advanced Manufacturing* **2**, 28 (2021).
46. Sando, Y. et al. Holographic augmented reality display with conical holographic optical element for wide viewing zone. *Light:Advanced Manufacturing* **3**, 12 (2022).
47. Blinder, D. et al. The state-of-the-art in computer generated holography for 3D display. *Light:Advanced Manufacturing* **3**, 35 (2022).
48. Park, J. H. & Lee, B. Holographic techniques for augmented reality and virtual reality near-eye displays. *Light:Advanced Manufacturing* **3**, 9 (2022).
49. Takeda, M., Osten, W. & Watanabe, E. Holographic 3D Imaging through Random Media: Methodologies and Challenges. *Light:Advanced Manufacturing* **3**, 14 (2022).
50. Anand, V., Rosen, J. & Juodkazis, S. Review of engineering techniques in chaotic coded aperture imagers. *Light:Advanced Manufacturing* **3**, 24 (2022).
51. Situ, G. Deep holography. *Light:Advanced Manufacturing* **3**, 13 (2022).