OPEN ACCESS

Special Issue

Journal of Medical Materials and Technologies

Proceedings of 4th Euro BioMAT

4th Euro

BioMAT 2017

European Symposium and Exhibition on Biomaterials and Related Areas

09. - 10. May 2017
Weimar, Germany

Editors
Klaus D. Jandt
Thomas F. Keller

ISSN 2366-9136

OPEN ACCESS
Journal of Medical Materials and Technologies
Vol 1, No 2, Special Issue Proceedings of 4th Euro BioMAT, Page No. 5-7 (2017)
http://journal.medmat.online

ISSN: 2366-9136

Function and structure – Combined optical functionality and specific bio-interaction for multifunctional biomedical materials

Tina Sabel, Marga C. Lensen

Technical University of Berlin, Dept. of Chemistry, Nanostructured Biomaterials, Berlin, Germany
*Tina@physik.tu-berlin.de

Abstract – Novel multifunctional biomedical materials are discussed, capable for the integration of optical functionality and exploiting the correlation of structure and function. Therefore, volume holographic structuring can be applied for the integration of three-dimensional optical structures with specific functionality in terms of diffractive properties. The strategy to combine optical structuring of the volume and specific modification of the surface is particularly discussed for the design of advanced intra-ocular lens implants. Based on a multifunctional biomedical material with integrated optical functionality and operating by the principle 'function by structure', such a new type of intraocular lens is expected to attain enhanced functionality.

Keywords – multifunctional biomedical biomaterials, photosensitive polymer, surface patterning, volume holographic structuring

1. INTRODUCTION

The spectrum of applications for biomaterials is expanding with new or enhanced features such as integrated optical functionality. The correlation between function and structure opens-up new possibilities for the development of novel materials and methods for advanced applications [1].

In tissue engineering and medical science, many applications become accessible through explicit control over molecular structure and mechanical properties, such as elasticity, cross-linking degree or surface morphology [2]. In many cases, a given structure is linked to a certain functionality. Similarly, optical structures with diffractive properties are linked with specific functionalities, such as to concentrate light into a focus.

Volume holographic techniques provide the opportunity to attach 3D optical structures with variable functionalities to a photosensitive material. In this sense, the integration of optical functionality into biomaterials appears desirable in line with the idea of a correlation between structure and function.

Three-dimensional optical structures with specific functionality in terms of diffractive properties can be found in volume holograms [3]. Among existing techniques for three-dimensional optical structuring, such as direct laser-writing or self-assembly, volume holography provides the unique possibility to create optical structures through the entire volume beyond a point-by-point, line-by-line or plane-by-plane fabrication, with high resolution and accuracy in a single step.

Diffractive structures can fulfill classical optical functions, with an extremely flat shape and low weight. This results in a great potential to substitute classical refractive optical systems as well as adding new specific functionalities. Therefore, suitable photopatternable materials are required, that can operate by the principle 'function by structure'. An example of a diffractive structure with classical optical functionality are holographic lenses.

The strategy to combine optical structuring of the volume and specific modification of the surface has the potential to result in the design of advanced biomedical implants. In particular, intra-ocular lenses (IOLs), implanted in place of the natural eye lens in ophthalmic surgery (see figure 1), open up the prospect of substantial improvement to enhance the approximation to the original function of the natural eye lens.

Cataract, the irreversible turbidity of the crystalline eye lens, is one of the most frequent causes for global blindness and can only be treated by replacement of the cloudy lens (see figure 1) with an artificial IOL implant [4].

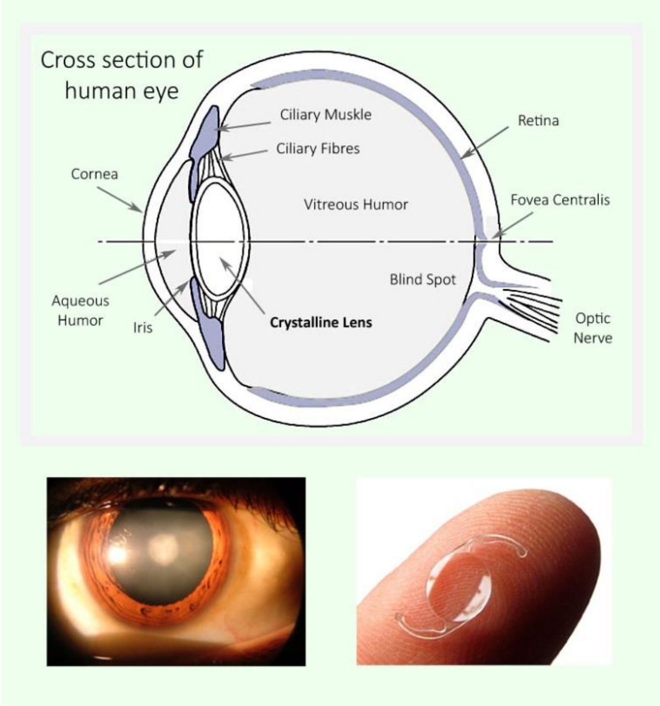

FIGURE 1
SCHEMATIC CROSS SECTION OF THE HUMAN EYE (TOP) AND EXEMPLARY IMAGES OF EYE WITH CATARACT, I.E. PATHOLOGICAL TURBIDITY OF THE LENS (BOTTOM LEFT) AND INTRAOCULAR LENS IMPLANT (BOTTOM RIGHT); PHOTOS VIA WIKIMEDIA COMMONS.

Persistent problems with IOLs include post-operative calcification [5] and secondary cataract [6]. The processes underlying such post-operative clouding, emerging in vivo from interaction with the biological environment, are still not well understood.

Prospective IOLs, based on multifunctional biomedical material with integrated optical functionality, could fulfill their function - i.e. to focus the light onto the retina - with an optically structured volume. As a result, the shape and surface of the IOL remain free and available for other purposes. Thus, subsequent surface modifications remain optional to achieve specific interaction with the biological environment.

Particularly interesting candidates for such multifunctional biomedical materials are hydrogels e.g. based on Poly(ethylene glycol) (PEG). They are highly interesting as scaffolds for tissue engineering applications, being biocompatible, intrinsic resistant against protein- and cell adhesion and they can be controlled and functionalized [7]. Hydrogels can also be structured photolithographically, taking advantage of diffusion processes [8].

2. MATERIAL AND METHODS

Investigations on volume phase gratings are based on free-surface, ultraviolet curable epoxy-based samples, prepared by micro resist technology GmbH [9].

Samples are spin coated on glass substrates with rotation speed of 800 min^{-1} resulting in layer thickness of approximately 200 µm. Subsequent pre-exposure bake is carried out on a hotplate (80 °C) for 30 minutes, driving out remaining solvent in order to receive a tack-free film.

Holographic exposure is performed by two freely propagating, s-polarized recording beams with 405 nm wavelength and 1 mm beam diameter. One-dimensional, plane-wave, transmission type volume holographic gratings are created with symmetric recording geometry, resulting in unslanted gratings with periodicity of $\Lambda \approx 2$ µm (500 lines per mm).

After completion of holographic grating formation, samples are fixed by UV flood cure with a dose of 350 mJ/cm^2. Remaining photoinitiator is used up during this curing step, resulting in a sample which is no longer light-sensitive. No postbake, hardbake or any additional developing was applied.

3. RESULTS

The hologram formation mechanism in photopolymers is based on an interplay of polymerization and diffusion, induced by the spatially modulated (interference) exposure [10]. A (generally 3D) light pattern is projected into the photosensitive medium, inducing local polymerization, proportional to the light intensity. Thereupon, a chemical gradient is induced, resulting in monomer diffusion and subsequent polymerization.

As a consequence, the hologram is formed as a periodic modulation of optical properties, according to the recording light pattern. A special characteristic of volume gratings is that their optical functionality can be attributed to very small modulations of optical properties inside the holographic material. In case of phase gratings with a layer thickness of 200 µm, a refractive index contrast in the order of only 10^{-3} already results in diffraction efficiency close to 100% [9].

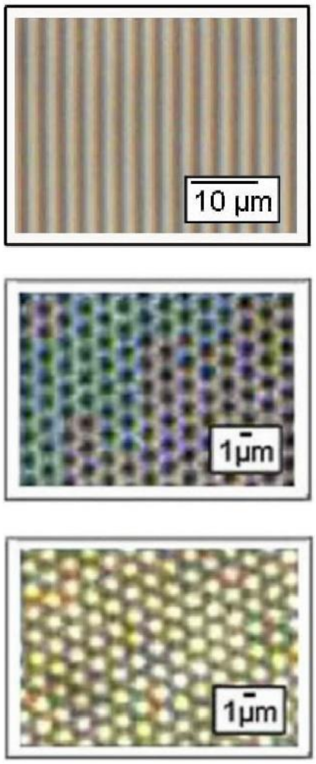

FIGURE 2
OPTICAL MICROSCOPIC IMAGING OF 1D (TOP) AND 3D (MIDDLE AND BOTTOM) VOLUME PHASE GRATINGS IN PHOTOSENSITIVE POLYMER [1].

Figure 2 shows holographically recorded volume phase gratings in photosensitive polymer [1,11].

The relationship of structure and function for a volume holographic grating is illustrated in figure 3. The grating is determined by its thickness d, grating constant Λ and refractive index contrast Δn (left hand side of figure 3). Those parameters determine the diffractive properties, exemplarily displayed as angular-resolved transmission (right hand side of figure 3, see Ref. [9]).

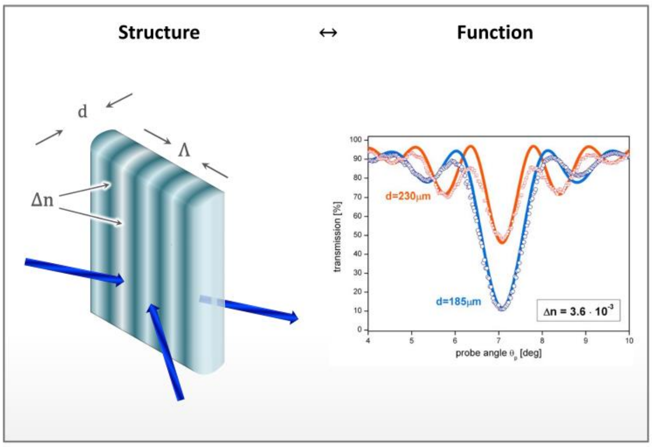

FIGURE 3
RELATIONSHIP OF STRUCTURE AND FUNCTION FOR A VOLUME HOLOGRAPHIC GRATING [1].

4. CONCLUSIONS

Volume holographic techniques can be applied to create 3D optical structures with variable optical functionalities into a photosensitive material. Thereby, the optical functionality in terms of 3D Bragg selectivity can be tuned by different parameters, such as recording geometry, exposure duration, recording intensity and the materials viscosity [12].

Taking advantage of diffusion processes in photosensitive polymers, hydrogels are particularly interesting candidates for novel biomedical materials with multifunctionality, based on the correlation of structure and function.

Thus, the transfer of the optical functionality from the surface into the volume of the IOL implant would result in enhanced functionality and multiple advantages such as the free surface for specific interaction with the biological environment.

Acknowledgment

The authors gratefully acknowledge support by the German Research Foundation (DFG), grant number SA 2990/1-1.

5. REFERENCES

[1] Sabel, T., Lensen, M.C., “Volume Holography: Novel Materials, Methods and Applications”, In *Holographic Materials and Optical Systems*; Naydenova, I.; Babeva, T.; Nazarova, D., Eds.; InTech: Rijeka, Croatia, 2017, 3-25.

[2] Lensen, M.C., Schulte, V.A., Salber, J. Diez, M. Menges, F. Müller, M., “Cellular responses to novel, micropatterned biomaterials”, *Pure and Applied Chemistry*, Vol. 80, No. 11, 2008, 2479-2487.

[3] Solymar, L. Cooke, D.J., “Volume Holography and Volume Gratings”, London: Academic Press; 1981.

[4] Artal, P., "Optics of the eye and its impact in vision: a tutorial", *Advances in Optics and Photonics*, Volume 6, 2014, 340-367.

[5] Izak, A.M., Werner, L., Pandey, S.K., Apple, D.J., "Calcification of modern foldable hydrogel intraocular lens designs", *Eye*, Vol. 17, 2003, 393-406.

[6] Trivedi, R.H., Werner, L., Apple, D.J., Pandey, S.K., Izak, A.M., "Post cataract-intraocular lens (IOL) surgery opacification", *Eye*, Vol. 16, 2002, 217-241.

[7] Nguyen, K.T., West, J.L., "Photopolymerizable hydrogels for tissue engineering applications", *Biomaterials*, Vol. 23, 2002, 4307-4314.

[8] Hahn, M.S., Miller, J.S., West, J.L., "Three-Dimensional Biochemical and Biomechanical Patterning of Hydrogels for Guiding Cell Behavior", *Advanced Materials*, Vol. 18, 2006, 2679-2684.

[9] Sabel, T., Orlic, S., Pfeiffer, K., Ostrzinski, O., Grützner, G., “Free-surface photopolymerizable recording material for volume holography”, *Optical Materials Express*, Vol. 3, No.3, 2012, 329-338.

[10] Zhao, G., Mouroulis, P., "Diffusion model of hologram formation in dry photopolymer materials", *Journal of Modern Optics*, Vol. 41, No. 10, 1994, 1929-1939.

[11] Sabel, T., Zschocher, M., “Imaging of Volume Phase Gratings in a Photosensitive Polymer, Recorded in Transmission and Reflection Geometry”, *Applied Science*, Vol. 4, 2014, 19-27.

[12] Sabel, T., “Spatially Resolved Analysis of Bragg Selectivity”, *Applied Science*, Vol. 5, 2015, 1064-1075.