CHAPTER 8

Conclusion

In this thesis, some aspects of the interaction of intense laser pulses with transparent materials were addressed. Although there remains a number of open questions, the experimental analysis of irradiated transparent dielectrics like BK7 and a-SiO_2 provided relevant information in the perspective of better understanding the mechanisms taking place during laser-dielectrics interaction.

Phase contrast microscopy and optical transmission microscopy were employed to characterize the material after the laser action. As a main result, the role of nonlinear propagation was emphasized. We notably observed the independence of the damage threshold with respect to the chirp direction, suggesting that propagation drastically influences the spatial frequency distribution. Moreover, based on solutions provided by solving the nonlinear Schrödinger equation, a correspondence between microcavity formation and high energy exposure was established.

By modifying our phase contrast microscopy apparatus, we could follow the dynamics of the complex refractive index modification shortly after excitation, with a subpicosecond temporal resolution. The influence of the free carriers on the transient refractive index, the influence of self-focusing and heat transfer to the bulk material were visualized under high laser pulse energy irradiation conditions. When laser pulses energy close to the permanent damage threshold are used, we established, as a main result, that relaxation processes take place on nanosecond to microsecond timescales. This is the temporal signature of thermal mechanisms of relaxation. After laser energy deposition in the free carrier population by inverse bremsstrahlung, we could observe heat transfer to the bulk. Time-resolved experiments show that expansion commences immediately after energy transfer to the bulk, but continues after several nanoseconds. In fused silica, the formation of a microcavity corresponds to a region of maximal thermal expansion. This indicates that thermomechanical phenomena play a substantial role in material modification.

Consequently, the temperature map imprinted in the bulk immediately after excitation plays a key role in the subsequent material flow upon thermal expansion. Therefore, an adaptive closed loop setup was developed in order to demonstrate some control over the energy deposition and material relaxation, in the perspective of generating optical structures with arbitrary refractive index profiles on axis. The results show that by determining an adequate excitation sequence, a considerable flexibility could be obtained. Noticeably, the morphology of the laser induced structures could be controlled even in presence of strong spherical aberrations. When working at high repetition rate in BK7, the material is still in movement due to thermal expansion when irradiated with the next laser pulse. This provides additional flexibility and opens the possibility to influence the thermomechanical effects and trigger material inelastic flow resulting in a high density phase upon cooling. As an proof of principle, the standard response of BK7 upon ultrashort irradiation was flipped. Unfortunately, because of the complexity of the nonlinear propagation phenomena involved, it is difficult to give an accurate interpretation for the optimal temporal excitation sequences provided by the algorithm to obtain some insights into the mechanisms of laser induced material modification. Nevertheless, the hydrodynamics of the hot soften material may be identified as responsible for material compaction and index modification, and a technological potential exists.

In order to demonstrate the interest of temporal pulse shaping for fabrication techniques, we applied the results of the adaptive procedures to waveguide writting in BK7. We performed, for the first time to our knowledge, laser writing of embedded waveguiding structures at optical frequencies in BK7.

In a general way, this thesis aims at promoting ultrafast laser as flexible structuring tools, well adapted to genuine 3-dimensional micromachining of transparent materials. In this work, we attempted to synchronize the excitation sequence with the material response. Future research could investigate the possibilities offered by advanced material design. We emphasized the importance of the material intrinsic properties. Therefore, the chemical composition of the target is of crucial importance, and controlling the thermal properties of the target via its chemical composition, for instance, would be of considerable interest to explore the flexibility offered by ultrafast lasers in the perspective of designing 3 dimensional, embedded optical functions and components.