principle realization of a GIP. Other prospective materials such as crystalline quartz, CaF_2 and glasses with low absorption (Suprasil 3002) can be used to avoid thermal lensing and nonlinear phase distortions.

The theoretically designed AR coating has a residual reflection of around 40% for p-polarized DF light and has no reflection for the s-polarized light, thus making GIP a polarizer. Polarization sensitivity is a necessary condition for the Hänsch-Couillaud method of locking an enhancement cavity to the seeding oscillator [25]. The XUV radiation generated is polarized parallel to the linearly polarized DF, in our case s-polarized. Delivering the out-coupled XUV beam to the experiment involves further XUV optics, which in general have better reflectivity for s-polarization. In order to realize an enhancement factor around 10^3, the residual GIP losses for DF have to be of the order of 0.05%. Numerical calculations show that this value is attainable and an advanced GIP can be manufactured with modern coating technologies.

As mentioned above, the reflection spectrum of GIP can cover VUV, UV and other spectrum ranges. The reflection of these spectral components should be considered not only from the upper AR layer of GIP as was considered for XUV, but from the whole AR multilayer structure. In our specific case, the upper layer of fused silica starts to become transparent at around 150 nm. Above this wavelength interference between reflections from different alternating layers cannot be neglected. Unfortunately, in our specific case there is a lack of knowledge about the optical constants of Nb_2O_5 below 400 nm. It is worth noting here that by exchanging the alternating material Nb_2O_5 with Ta_2O_5 (the optical constants of this material are known in the spectral range from 150 nm to 8000 nm) the design shown in Fig. 4, has >50% reflectivity in the ranges 135-140, 142-152, 155-175, 185-215, 240-290, 300-315, 380-480, 500-600, 1200-1700 and 2000-3300 nm, and smooth reflectivity >30% in the whole range 3500-8000 nm. By varying designs and materials one can expect other broadband smooth ranges of high reflectivity. New UV-VIS-MIR components can be generated inside the enhancement cavities by using nonlinear crystals instead of a gas medium.

6. Conclusion

We have described an extension of the Brewster plate previously used as an XUV output coupler inside enhancement femtosecond cavities where high harmonics of the fundamental radiation are generated. The proposed GIP, or grazing-incidence coated plate, has low losses for the fundamental light circulating inside the cavity and serves as a highly efficient, extremely broadband output coupler for XUV. Potentially, the short-wavelength reflectivity of GIP can reach the keV range. Due to several advantages the GIP concept allows further power/energy scaling inside the enhancement cavity. Further steps feasible with this concept can cover the VUV-UV spectral ranges and far beyond. GIP can be designed for either s- or p-polarization. Owing to its polarization properties, GIP can be used not only as a dichroic beam splitter but also as a beam combiner or a filter.

Acknowledgments

This work was supported by the Munich Centre for Advanced Photonics (MAP), Photonic Nanomaterials (PhoNa) and KORONA cooperations. The authors would like to thank Ioachim Pupeza for helpful discussions. We also acknowledge the help with the XUV measurements from Christian Laubis and Christian Buchholz from PTB Bessy, Sergiy Yulin and Norbert Kaiser from the Fraunhofer Institute for Applied Optics and Precision Engineering.