In the PhD thesis "Harmonic Frequency Generation and Nonlinear Compression of Ultrashort Pulses" Martin Duda analyzes second harmonic generation (SHG) of short pulses in numerous configurations with the motivation of generating shortened harmonic pulses with an increase in peak power over the fundamental pulse. The key idea of this method is to use type II phase matching for the SHG, split the fundamental pulse into ordinary and extraordinary polarizations, and tune the relative delay of the pulses at the nonlinear second harmonic crystal. Because the two fundamental components travel at different speeds through the crystal, the harmonic generation is dependent on this initial relative delay and, for a range of delays, a second harmonic pulse with a shorter duration than the initial fundamental pulse can be generated.

Overview of Work Presented

The author presents the general theoretical framework for second order nonlinear effects, pulse front manipulation, and various diagnostic methods and standards. The analysis of the pulse shaping/shortening process includes numerical simulations (using the SNLO software package) for BiBO, BBO, and LBO crystals with and without group velocity tuning via pulse front tilt. These simulations were benchmarked against previously published work on this topic and also used to design the experimental demonstration. The effects of pulse shortening in the tilted and non-tilted configurations were experimentally demonstrated as well. In addition to the work on pulse shortening/shaping, conventional type I SHG was simulated and experimentally demonstrated with an emphasis on the optimum choice of crystal and intensity on the nonlinear crystal.

Novelty

Second harmonic of picosecond pulses in thin BBO and LBO crystals is well understood and is routinely implemented in laser systems. Given the modest conditions of the SHG described in chapter 2 relative to the current state-of-the-art and the level of understanding the community has for this process, I do not think that this contributes significantly to the novelty of the work; that said, I am glad that this was included in the thesis for multiple reasons. The chapter gives a good experimental control with which to benchmark the numerical code which is used throughout the thesis, introduces the reader to the impacts of effects such as back conversion on pulse stability, and shows the tradeoff between beam quality and SHG efficiency in concrete numbers. Certain relationships, such as M^2 and fundamental intensity, while certainly commonly observed, are seldom presented as systematically as here, which is nice to see as well.

As is pointed out in the thesis, the idea of pulse compression via type II phase matching with pre-delayed pulses was proposed and demonstrated previously in the 90's both in the pulse front tilted and non-tilted configurations. This topic has increased relevance with the progress in high average power, high energy ps pulses from Yb:YAG-based amplifiers. While these effects have been simulated and demonstrated previously, I am not aware of previous work that covers as wide a parameter space in measurement or simulation or approaches the effect from the point of view of understanding the behavior of the pulses for varying initial conditions.

Methodology

The author overall demonstrates a solid experimental methodology throughout the thesis. The experimental setups are well described and the results are presented clearly. Definitions are also

carefully specified throughout the thesis, which is particularly important here as differences in definitions such as full-width at half-maximum and D4σ have a large qualitative impact on what is being described. The author provides motivation for experimental steps and his measurements are convincing and fit with his experimental goals.

One aspect which was not clear to me was how much time was available for the author to use the pump laser and how much ability he had to tune or optimize it. In several cases I think the thesis could have been improved by repeating a measurement or investigating something further and I don't know why this wasn't possible. For example on page 67 the author points out how a 9 ns post pulse in the laser with 1/3 of the laser pulse energy was discovered which "devalued" his results and caused him to "abandon" the experiment which had just been working on. On page 59 there was unexplained behavior of very low SHG efficiency which unexpectedly decreased with increasing fundamental intensity without signs of back conversion. Identifying the problems with the pump laser and correcting them would be the next logical step in correcting these issues; but possibly the author was not able or authorized to investigate this. It also seemed that time was in short supply as an M^2 measurement of the pulse front tilt-generated SHG beam, which would have been quite relevant because of the potential for residual angular dispersion, was not performed because it was "...too time consuming." The walk-off pre-compensation for the pulse front tilt method was also not performed as the author would have liked because of a lack of time. I think that some more time with the laser to complete these measurements and some improvement of the driving laser could have strengthened the thesis significantly.

Conclusions

It seems clear to me from the thesis that the author has a very solid understanding of the physical processes at play in this work and a good approach to attacking the problem numerically and experimentally. His approach to investigating the behavior of the process and developing a good qualitative understanding to go with the results of his simulations and measurements goes beyond the analysis that I have seen previously and gives this work novelty. I have the impression that the thesis would have been strengthened by more investigation into the impact of the pump laser on some results or additional/repeated measurements, but it seems that much of these circumstances are outside of the author's control. I recommend this thesis for presentation and defense.