We propose an efficient approach to improve few-cycle soliton compression with cascaded quadratic nonlinearities by using an engineered multi-section structure of the nonlinear crystal. By exploiting engineering of the cascaded quadratic nonlinearities, in each section soliton compression with a low effective order is realized, and high-quality few-cycle pulses with large compression factors are feasible. Each subsequent section is designed so that the compressed pulse exiting the previous section experiences an overall effective self-defocusing cubic nonlinearity corresponding to a modest soliton order, which is kept larger than unity to ensure further compression. This is done by increasing the cascaded quadratic nonlinearity in the new section with an engineered reduced residual phase mismatch. The low soliton orders in each section ensure excellent pulse quality and high efficiency. Numerical results show that compressed pulses with less than three-cycle duration can be achieved even when the compression factor is very large, and in contrast to standard soliton compression, these compressed pulses have minimal pedestal and high quality factor.
