Time-Domain Waveform Characterization of a 100 GHz Ultrafast Photodetector Based on Asynchronous Electro-Optic Sampling

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Abstract

This paper reviews work carried out at Beijing Institute of Radio Metrology and Measurement (BIRMM) on an optoelectronic measurement of the impulse response of the ultrafast photodetector (PD) with a nominal bandwidth of 100GHz based on high-speed asynchronous electro-optic sampling (ASEOS).

1. Introduction

Photodetectors are important devices, which can transfer the optical signal to electrical signal. The bandwidth of PDs is more and more broad. The relative impulse response is faster, which is always characterized by Oscilloscopes or synchronous electro-optic sampling system. BIRMM has been constructing a new system based on ASEOS for the time domain waveform characterization of the ultrafast PDs over several years, resulting in improved capabilities for PDs and pulse generators. We report our progress towards characterizing the latest generation of commercial 100 GHz PD.

2. Experimental Setup

Our high speed implementation of ASEOS system shown in Figure 1 operates with two femtosecond fiber lasers at 1560 nm, which give <150 fs duration pulses at a repetition rate of 250 MHz. The repetition rate of the master laser is free running and the slave laser repetition rate is stabilized with an offset Δf, using a phase-locked loop. The repetition rates are stabilized with a constant offset frequency $\Delta f = 1\,\text{kHz}$. The frequency offset synchronization unit is locked to the reference atomic clock. The output signal of the ultrafast PD is transferred to a coplanar waveguide (CPW) using a standard microwave probe (MWP, MPI T110A-GSG-50) with a 1.0 mm coaxial connector. The CPW consists of a 30 µm broad signal stripe separated by 20 µm from two 500 µm broad ground stripes and has a length of 3 mm. The structure has been evaporated onto a 500 µm thick GaAs substrate. The characteristic impedance of the CPW is close to 50 Ω. The CPW is terminated by use of a second MWP (MPI T67A-GSG-50) with a 1.85 mm coaxial connector, which is connected to a 50 Ω load using a 1000 mm long coaxial cable. By this, reflections of the voltage pulse are minimized.

To probe the voltage pulses traveling on the CPW, the electro-optic effect of the GaAs substrate is employed. For this, a probe beam from the slave laser is focused through the backside of the structure on the center line of the CPW. The back reflection of the probe beam is phase-modulated due to the electrical pulses propagating on the CPW. This phase modulation is proportional to the electric field of the voltage pulses and measured using a balanced detection scheme consisting of a lambda-half plate, a lambda-quarter plate, a Wollaston prism and a balanced detector.

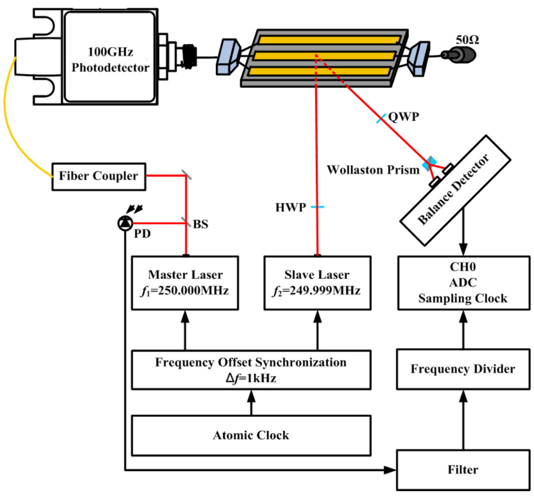

Figure 1. Schematic of the ASEOS system at BIRMM.

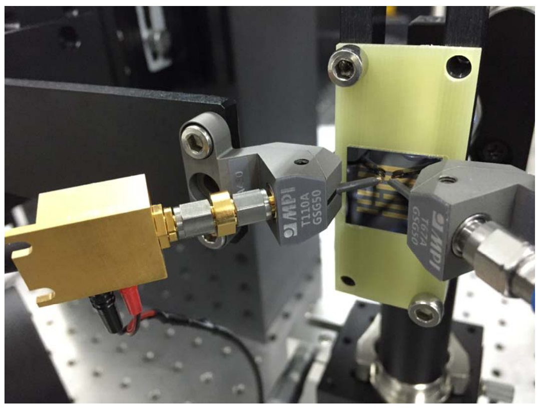

Figure 2. Photograph of the ASEOS system at BIRMM.

The signal from the balanced detector is digitally sampled by an analog-to-digital converter with 14 bit resolution. The ADC is fed with a 250 MHz clock signal, generated by the laser pulses and a photodiode. Dividing the clock signal by 5, a sample rate of f_{sr} = 50 MHz is achieved. With this sample rate, the computational hardware allows for a continuous stream of data points to a hard disk. The Photograph of the ASEOS system is shown in Figure 2.

3. Measurement of the Impulse Response of the Photodetector

The measurement values of time domain impulse response of the ultrafast PD are saved as a raw data file on a hard disk and the data processing algorithm is applied. The offset frequency of two lasers is 1 kHz, so the repetition frequency of the measured data is also 1 kHz according to the principle of ASEOS. The sample rate is 50 MHz, a continuous stream of 5×10^7 data points per second has been recorded. There are 5×10^4 data points in one period of the measured voltage pulse. We cannot obtain the resulting voltage pulse waveform just only using one period data points due to noise. We can obtain good signal to noise ratio (SNR) pulse waveform through data average per period. The data average time influences the SNR achievable with our experimental setup. This effect is demonstrated for the streamed data in Figure 3.

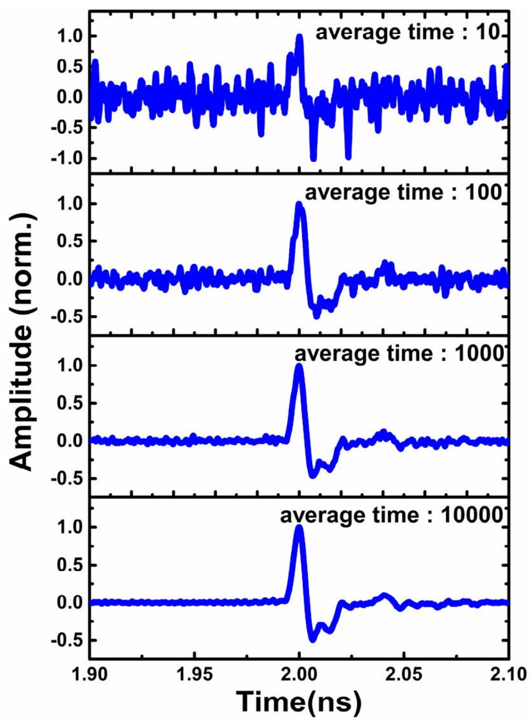

Figure 3. Influence of the raw data average time on the SNR of the measured voltage pulse.

According to our experiment results, we can obtain a good SNR pulse waveform when the average time is more than 1000 times.

In our experimental setup, the coaxial connector of the ultrafast PD is 1.0 mm, whose cut off frequency is 110 GHz. To study whether the frequency components above 110 GHz influence the impulse response waveform or not, we show the time domain impulse response waveform calculated from the spectrum whose frequency components above 110 GHz were cut off using a 10th-order Butterworth filter having a 3 dB bandwidth of 110 GHz and above 200 GHz were cut off using a 10th-order Butterworth filter having a 3 dB bandwidth of 200 GHz. Clearly the altered spectrum leads to a broader pulse waveform. And the measured impulse response without spectrum filter has some oscillations at the bottom of the waveform because of mismatch.

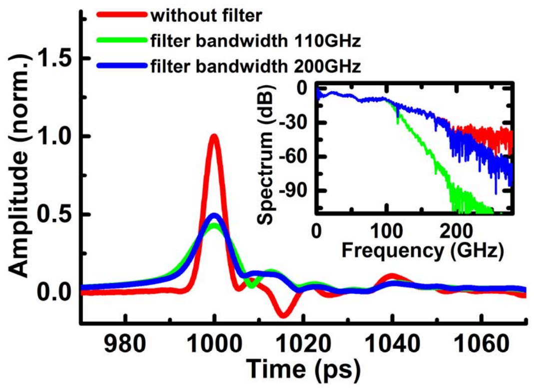

Figure 4. Impulse response of the ultrafast PD without filter and with different filter bandwidth.

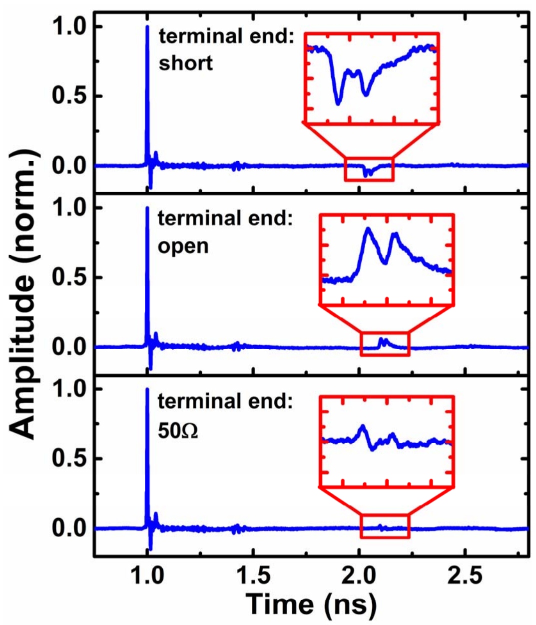

Figure 5. Impulse response of the ultrafast PD with different terminal end.

To investigate the mismatch, we change the terminal end. When the terminal end is short, a new more mismatch appears in the voltage pulse waveform shown in Figure 5. If changing the short terminal end to open terminal end, the reflection due to mismatch is reversed. The time interval between the main peak and the reflection of short or open terminal end is just equal to the double physical length from the probe beam point to the coaxial terminal end. The reflection due to terminal end is far away from the main pulse, whose influence is negligible.

To study the influence of the mismatch close to the main pulse, we corrected the measured impulse response waveform with a Gaussian fit in Figure 6. The bottom oscillations of the measured impulse response waveform are corrected and meantime the shape of the main pulse cannot be changed. The spectrum of the corrected pulse waveform is more flat than the original spectrum, but the obtained frequency components up to 200 GHz are nearly the same. So the reflection close to the main pulse may also be negligible if it is relatively small.

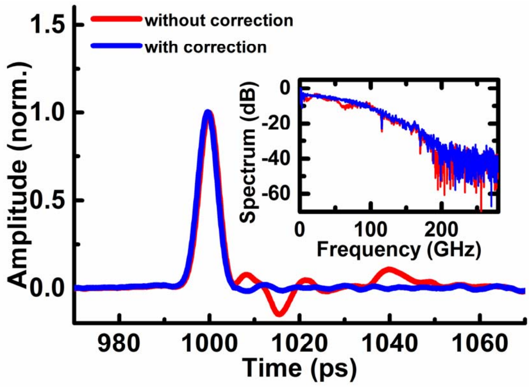

Figure 6. Impulse response of the ultrafast PD without correction and with Gaussian fit correction.

4. Comparison to Sampling Oscilloscope

We have also performed the impulse response measurements using an Agilent 86100C (86116C module) digital sampling oscilloscope (DSO) with a nominal bandwidth of 80 GHz. The normalized time domain impulse response waveform and spectrum is shown in Figure 7.

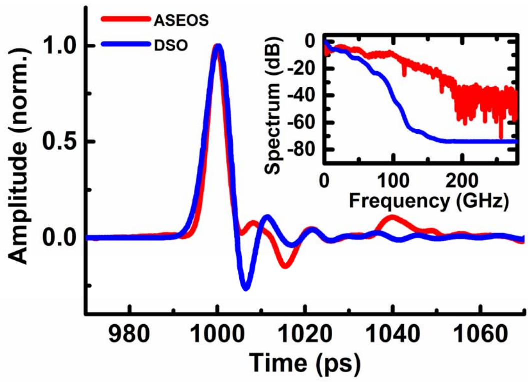

Figure 7. Comparison of the impulse response waveform of the ultrafast PD using ASEOS and DSO.

The FWHM of the impulse response is 5.0 ps and 5.9 ps respectively using ASEOS and DSO. The insufficient bandwidth of the DSO leads to the broader pulse duration and the obtained frequency components are only up to 100 GHz, which is higher than the nominal bandwidth of the DSO.

Note that measurement uncertainties have not yet been evaluated, these measurement results are preliminary.

5. Discussion and Conclusions

Several initial measurements on the impulse response of the ultrafast PD with a nominal bandwidth of 100 GHz have been reported. The electrical pulses as short as 5ps have been recorded and frequency components measured up to 200 GHz. Our work is ongoing in several further areas, including uncertainty analysis, improving electrical pulse waveform measurement ability and comparing to the synchronous electro-optic sampling (SEOS).

6. References

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