ASOPS Engine

Next generation time-domain spectroscopy system

Laser QUANTUM
A Novanta Company

- ASOPS technology with highest time resolution* on the market
- Enables two-colour pump-probe experiments
- Available at repetition rates of 84 MHz and 1 GHz
- Enables high-speed data acquisition up to 20 kHz
- Turn-key locking electronics
- Offset frequencies between 4 μHz and 20 kHz

Overview

As the leading supplier for ASynchronous OPtical Sampling (ASOPS) technology for almost 15 years, Laser Quantum's third generation ASOPS technique allows for the most precise and fastest time-domain spectroscopy available on the market today. The **ASOPS Engine** includes all components necessary for high-speed ASOPS time-domain spectroscopy: two femtosecond lasers, master and slave, in addition to the **TL-1000 ASOPS** electronic unit for stabilising the repetition rate of the slave laser with an offset to its master laser. Laser Quantum offers a choice of either 1 GHz or 84 MHz femtosecond laser options. Key features of the **ASOPS Engine** include extremely fast acquisition speed of up to 20 kHz, an unprecedented time-resolution of significantly below 60 fs* for 1 GHz lasers and below 100 fs for 84 MHz lasers respectively. This unique combination of high scan rates, long measurement windows and excellent time resolution is impossible with conventional time-domain spectrometers.

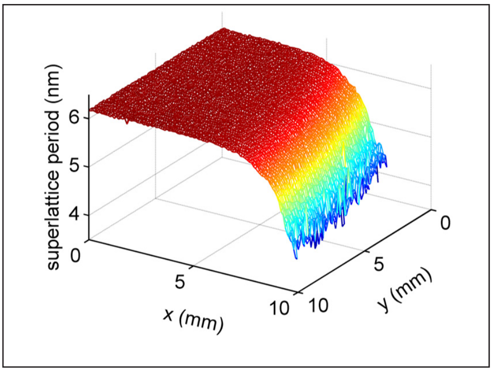
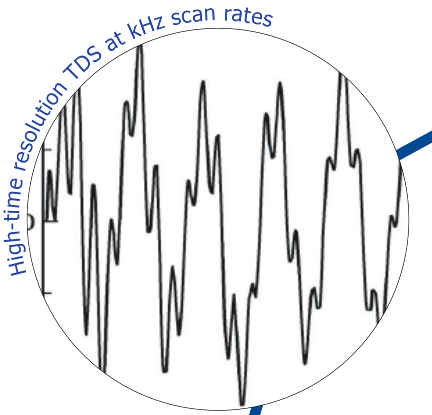


Fig. 1. Two-dimensional thickness measurement of a Si/Mo superlattice structure using ASOPS. At each pixel the time-resolved reflectivity change is measured and the superlattice period can be directly extracted from photoinduced ultrasonics with sub-nm resolution. The fast acquisition time allows quick measurement of a two dimensional 100x100 pixel scan with two adjacent pixels separated by 100 μm.



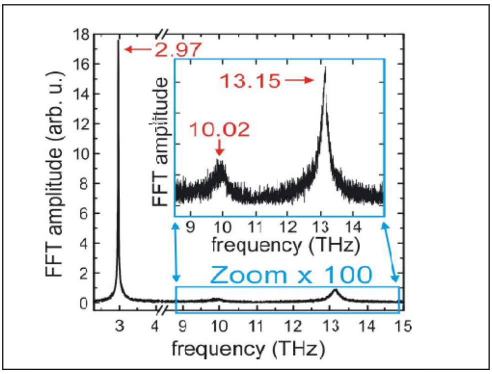
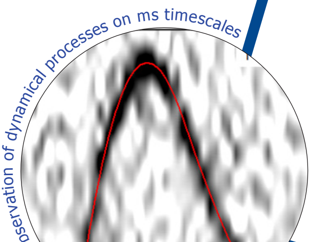
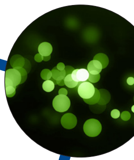


Fig. 2. Fourier transform of reflectivity measurements taken on ZnO samples with an ASOPS system. The excellent time stability provided by the **TL-1000 ASOPS** control unit allows it to measure even high phonon frequencies such as the observed 13.15 THz phonon mode in ZnO.





* typical values for the time resolution are <45 fs @ 1 GHz and < 100 fs at 84 MHz.

ASOPS Technology

The key feature of the ASOPS technology is the use of two femtosecond lasers with repetition rates f_R locked together in a master-slave configuration with a slight offset Δf_R. This offset, typically between 10 Hz and 10 kHz, causes the delay among pairs of pulses from the lasers to incrementally increase by $\Delta\tau = \Delta f_R/f_R^2$ with each shot, for example, a 10 fs increase at Δf_R = 10 kHz. If the lasers are then used as pump and probe lasers time-delay happens automatically, and the delay τ between pump and probe pulse pairs undergoes a linear ramp $\tau = t \times \Delta f_R/f_R$ as function of real time t, replicating itself at a rate given by Δf_R. Figure 3 illustrates the principle for an optical pump-probe time domain spectrometer (TDS) setup. The lasers are then used as they would be in a classical setup except that no translation stage is required. Timing precision is now determined by the ability to measure and stabilise the repetition rate offset. Uncertainties at the level of a few parts in 10^5 are reached — typically more than an order of magnitude better than mechanical delay generators.

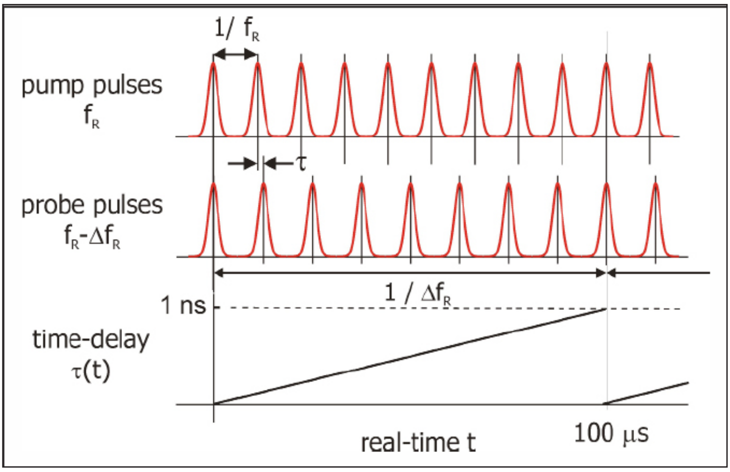


Fig. 3. Realisation of the time delay increment of an ASOPS system. The pulse to pulse separation for pump and probe pulse trains differs by the time increment τ which increases linearly over time as seen in the above graph. Very short scan times of the order 100 µs can be realised with a measurement window of 1 ns using the ASOPS technique based on our 1 GHz **taccor** laser range. If 84 MHz lasers are employed, much longer scan delays of up to 12 ns can be realised.

Excellent time-resolution

Excellent time-resolution of significantly below 60 fs for 1 GHz lasers and significantly below 100 fs for 84 MHz lasers is ensured by stabilising master and slave laser using the third generation **TL-1000 ASOPS** unit based on the patented DDS technology. The **ASOPS Engine** is available with the range of 1 GHz **taccor** lasers as well as the 84 MHz lasers from our **venteon** and **gecco** series. Typical time resolution values for both MHz and GHz **ASOPS Engine** systems can be seen in Figure 4 and 5 respectively.

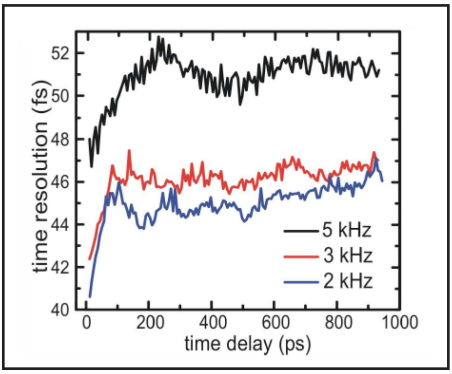


Fig. 4. Measured timing jitter for a 1 GHz based ASOPS system for offset frequencies between 2 and 5 kHz showing 60 fs or better. At larger offset frequencies the time resolution increases due to the limited bandwidth of the data acquisition card.

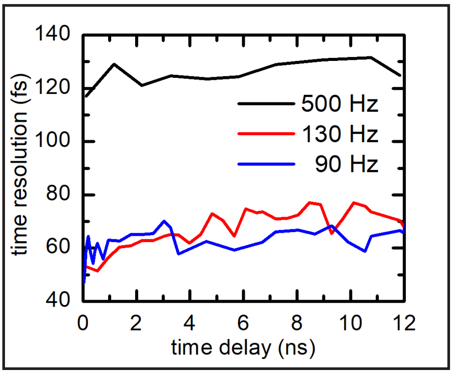


Fig. 5. Measured timing jitter for a 84 MHz based ASOPS system and offset frequencies between 90 Hz and 500 Hz. Note that at larger offset frequencies the time resolution is worse as the required real time bandwidth becomes comparable to the repetition rate.

Applications

High-resolution terahertz spectroscopy

Spectroscopy in the 0.1-10 THz range of the electromagnetic spectrum is an important application that relies on ultrafast optical TDS, where precision and speed are key factors in many applications. Terahertz spectroscopy has great potential for use in gas spectroscopy and sensing, explosives and drug detection and monitoring, in-line paper or foil thickness measurements, solar-cell inspection and many more. Employing the ASOPS technology can be used to perform measurements with high frequency precision at a resolution of 1 GHz. An absorption spectrum of water vapour in the THz frequency range is shown in Figure 6.

Ultrafast THz-spectroscopy in transient multitesla magnetic fields

The rapid data acquisition capability (up to 10,000 single-scan traces per second at 1 GHz resolution) permits the investigation of dynamic processes and studies under rapidly varying environmental conditions. An experiment was performed using the **ASOPS Engine** for THz spectroscopy where 100 THz traces were recorded while a magnetic field pulse of several tesla was applied to the sample. In this experiment the cyclotron resonance of a 2D electron gas in millisecond GaAs/AlGaAs heterostructure could be recorded as the magnetic field evolved on the ms timescale.

Figure 7 shows the evolution of the sample transmission and the measured magnetic field as function of time with a clear signature of the cyclotron resonance and correlation with the magnetic field. Electron mobility and effective values can directly be calculated from this measurement.

Spatially resolved wafer mapping via picosecond ultrasound

A common method for wafer metrology or monitoring the growth of multilayer nanostructures is the use of laser-induced picosecond ultrasound, where a strong laser pulse launches a heat wave (very high-frequency ultrasound) into a sample, often via a metallic transducer, and the echoes returning from buried interfaces are detected via reflectivity changes at the sample surface. We have used this technology to map an X-ray Bragg mirror consisting of 60 silicon/molybdenum (Si/Mo) layers sputtered onto a monocrystalline Si wafer to investigate post-manufacturing growth homogeneity. The nominal layer period is 6.8 nm and the total stack thickness is 408 nm. The result of a 100x100 pixel scan can be seen in Figure 1.

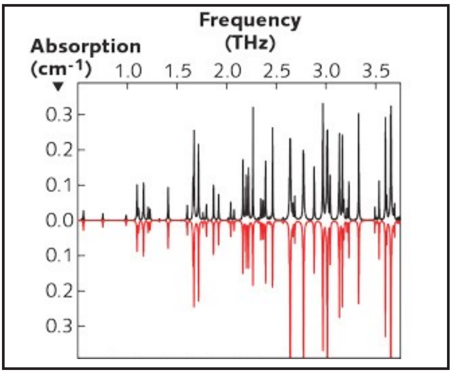


Fig. 6. Absorption spectrum of atmospheric air (black lines) compared to data compiled from HITRAN database (red lines) for 60 s acquisition time.

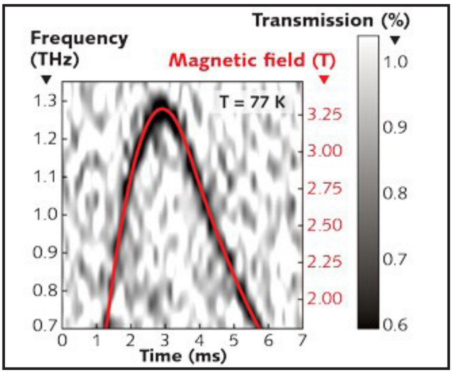
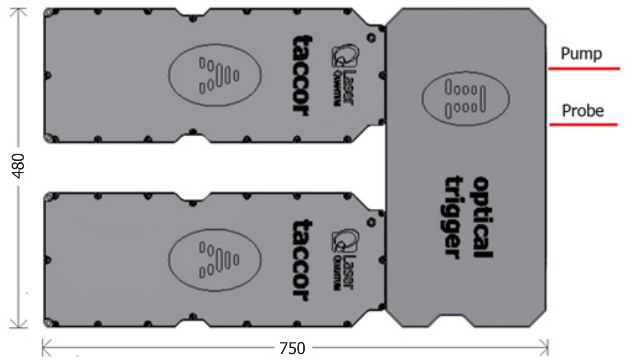
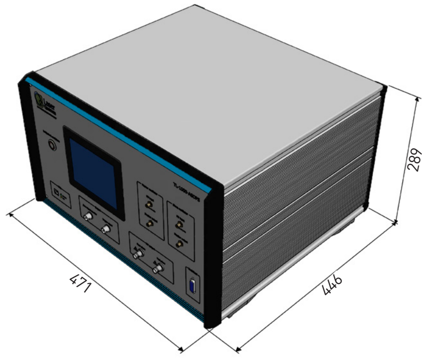


Fig. 7. Spectral THz transmission through a 2D electron gas sample in a transient multitesla magnetic field.

ASOPS Engine

Dimensions (mm)





Drawings are for illustrative purposes only. Please contact Laser Quantum for complete engineer's drawings.

System Configuration

The **ASOPS Engine** consists of two femtosecond lasers, a **TL-1000 ASOPS** for offset frequency stabilisation, an optical trigger unit, a high-speed balanced optical photoreceiver, a personal computer housing the data acquisition card and the HASSP-Scope software for measurement and analysis of time-domain data. The femtosecond lasers used can be chosen from either the 1 GHz or the 84 MHz range of lasers.

Specifications

	ASOPS Engine GHz	**ASOPS Engine** MHz
Repetition rate range	1 GHz	84 MHz**
Typical repetition rate offset	2 kHz to 20 kHz	10 Hz to 1 kHz
Time resolution	< 60 fs* over full 1 ns window	< 100 fs* over 5 ns window
Time delay window	1 ns	11.9 ns

* time resolution inherently increases at larger offset frequencies.
** the standard repetition rate is chosen to be 84 MHz. Customer specific repetition rates between 80 MHz and 90 MHz are available upon request.

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