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100-Hz Laser Sharpens Detection of Short-Lived Molecular Dynamics

By Eric Kennehan

Nanosecond transient absorption spectroscopy (TAS) is a time-resolved pump-probe technique that reveals how molecules and materials behave in the first moments after they absorb light. Instead of producing a single static absorption spectrum, the method tracks how the spectrum evolves over time after a short excitation pulse from a laser.

The reason TAS is such an effective tool is that it allows researchers to measure dynamic behaviors that cannot be measured through steady state spectroscopy. A number of significant photophysical and photochemical processes such as triplet and charge-carrier dynamics, exciton migration, and metastable photochemical intermediates, occur in the nanosecond to millisecond time domain and often produce weak, transient absorption features that require sensitive time-resolved spectroscopy for detection.

By directly measuring these short-lived spectral changes, nanosecond TAS gives researchers insight into the relationship between molecular structure and functional performance in photovoltaic devices, photocatalytic systems, light harvesting assemblies, biological chromophores, conductive polymers, and new energy conversion materials.

Now advances in laser technology are rapidly redefining the operational limits of nanosecond TAS. In particular, the emergence of tunable, high repetition rate lasers that dramatically increase pulse delivery frequency while maintaining ultrafast temporal resolution.

Tunable lasers allow researchers to precisely adjust the excitation wavelength in the UV, visible, and near-infrared (NIR) portions of the spectrum. At high repetition rates, these systems increase the amount of data collected per unit time, which reduces the effect of random noise on the measured signals and improves detection of weak transient components. The result is a more complete study of the kinetics of the system and a better understanding of the dynamic processes that occur.



Fully integrated benchtop nanosecond transient absorption spectrometers are designed for advanced time-resolved spectroscopy applications. (Credit: Magnitude Instruments)

The Excitation Laser

In a basic TAS setup, a nanosecond or shorter pump pulse excites a portion of the sample from the ground state into an electronically excited state. A weaker probe beam then passes through the same region at a controlled delay. By comparing the probe transmission with and without excitation, the system produces a wavelength-resolved differential absorption signal.

The laser light source contributes significantly to the overall performance of the measurement system. Pulse duration defines the achievable temporal resolution. Pulse energy governs how effectively the pump pulse drives measurable population changes within the sample. Source stability is essential to maintain clean differential signals and prevent noise from obscuring subtle effects.

The laser's repetition rate is also an important factor in determining the ability of the transient absorption technique to produce high quality measurements. Although it affects both the amount of signal averaging that can be performed as well as the quality and

throughput, it is often overlooked when evaluating a system.

Until recently, however, most tunable lasers have been limited to an operating repetition rate of 10–20 Hz. Exceeding this threshold requires a new generation of diode-pumped solid-state (DPSS) lasers capable of operating at 100 Hz or higher.

Improving Signal-to-Noise Ratio to Improve Kinetic Clarity

One of the principal challenges in TAS is detecting weak signals that are frequently masked by electronic noise. Traditionally, improving the signal-to-noise ratio (SNR) in TAS measurements involves averaging the results of multiple experiments, where the SNR increases with the square root of the number of averaged data points. Averaging one hundred measurements only reduces the noise level tenfold, for instance.

However, when using lower repetition-rate lasers, this method is time-consuming and impractical when repeated measurements are required. Fluctuations in the

pump laser's shot-to-shot stability and drifts in the probe light source's intensity can also affect the SNR of TAS measurements during long data collection periods.

Additionally, SNR can still be poor even after prolonged scanning when using this approach, specifically when probing the vibrational dynamics of materials following photoexcitation. The signals generated from these dynamic processes are typically weak and therefore difficult to detect due to the presence of unwanted electrical noise; in fact, several hours of collected data may not be enough to adequately remove unwanted noise.

At higher repetition rates, more pump-probe pulses can be collected in less time with fewer variances in the entire system, thus improving the signal-to-noise ratio and enabling the use of lower pulse energies. Gentler excitation conditions reduce the risks of cumulative heating or photodamage and shorten the time required to obtain a full kinetic map.

However, the rate cannot be pushed too high, since samples must have time to relax or exchange between pulses. A 100 Hz excitation source strikes a desirable balance for many nanosecond-scale systems: fast enough to achieve efficient averaging, yet slow enough for most condensed-phase samples to fully recover between pulses.

To improve SNR, the company has prioritized the development and implementation of advanced noise suppression technologies (NSTs). NSTs enable the precise subtraction of electronic artifacts that traditionally obscure weak signals in TAS measurements. This advancement allows researchers to collect the entire time axis for TA measurements directly from the detector response with each laser shot, dramatically accelerating data collection times and enhancing accuracy.

By incorporating patented noise suppression technologies, we have achieved more than one hundredfold enhancement in the speed and sensitivity of transient absorption measurements on the nanosecond-millisecond timescale. Previously, the strategy to improve signal detection in TAS was to increase the pump fluence, thereby increasing the total number of excited states that could be probed. While this approach can improve signal visibility,



A new family of DPSS-based OPO lasers, the Opolucis C, can deliver a repetition rate of 100 Hz and peak OPO energy of up to 45 mJ per pulse. (Credit: OPOTEK)

it also may induce nonlinear interactions among excited states.

Such interactions occur when the high concentration of excited states begin interacting with one another, which can complicate and often obscure the interpretation of the results. Critically, elevated pump fluences can also hasten sample degradation, notably affecting sensitive biological specimens or materials prone to photodegradation.

Integrating Tunable Lasers

For most applications, a fixed wavelength Nd:YAG laser capable of generating excitation wavelengths of 1064, 532, 355, and 266 nm is included in nanosecond TAS systems. However, when a project requires wavelength flexibility, Magnitude Instruments, for example, integrates an OPO (optical parametric oscillators) or OPA (optical parametric amplifier) sourced from a qualified supplier.

The ability to vary the wavelength enables researchers to select and activate discrete electronic or vibrational transitions within their samples with a high degree of precision and control. This allows researchers to achieve more detailed and application-specific results from their experiments.

Higher repetition rates reduce background interference, resulting in cleaner signals and improved overall data quality. High repetition rates also enable detection of weaker signals while operating at lower laser fluences. This approach minimizes the risk of sample damage or degradation during measurement. At the same time, it reduces complications such as nonlinear effects, multi-exciton generation, excited-state annihilation, and thermal artifacts that

can develop on nanosecond to microsecond timescales.

Although several manufacturers offer 100 Hz OPO systems, each presented distinct advantages and trade-offs. Magnitude Instruments partnered on the project with OPOTEK and chose a new family of DPSS-based OPO lasers, the Opolucis C. It delivers a repetition rate of 100 Hz and peak OPO energy of up to 45 mJ per pulse.

Historically, the adoption of diode-pumped lasers was constrained by the high cost and limited supply of high-power diode assemblies. Producing these diodes required a specialized manufacturing process, and only a small group of global suppliers had the capability to deliver devices that met the performance demands of high-energy laser systems. Fortunately, recent improvements in diode fabrication and supply availability have made this approach commercially viable for use in OPO lasers.

The compact footprint of the Opolucis C was particularly compelling, as reducing overall system size remains a central design objective for Magnitude Instruments. Historically, transient absorption spectroscopy setups have posed considerable challenges for many laboratories due to the large, complex, and expensive nature of the equipment required to make TAS measurements.

As nanosecond transient absorption spectroscopy continues to gain traction in biotechnology and medical research, high-repetition-rate lasers are becoming less of a premium feature and more of a practical necessity. With high-repetition-rate lasers, data collection is much faster, enabling scientists

to sample and process more points in an order of magnitude less time.

By dramatically increasing the number of pulses per second, it is expected that scientists to collect and evaluate many more data points in about one order of magnitude less time than with low-repetition-rate lasers.

As laser platforms continue to evolve toward higher stability, greater tunability, and scalable repetition rates, their integration into TAS setups is expected to significantly enhance both performance and experimental versatility. This progression opens new possibilities for investigating nanosecond time scale phe-

nomena in increasingly complex systems.

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Shielding Ethernet Upgrades for Medical Manufacturing and Laboratory Automation

By Mencom Corp.

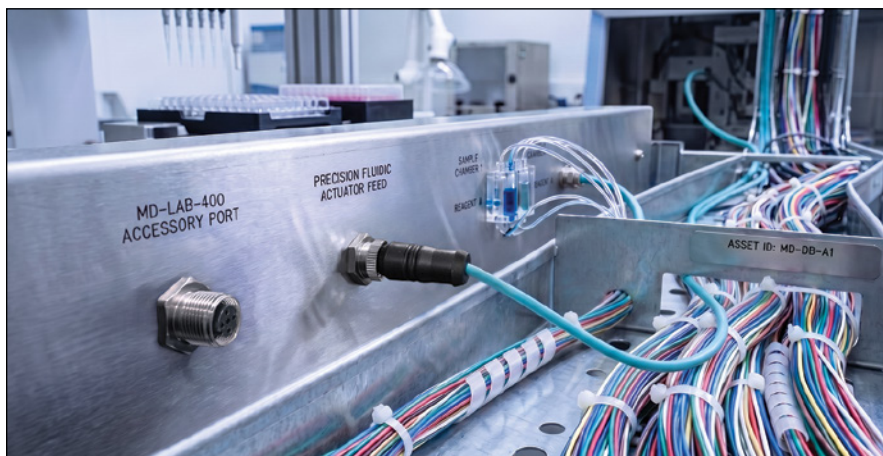
Medical device manufacturing and laboratory automation can present many of the same networking and electromagnetic interference (EMI) challenges found in other automated industrial environments. Production cells may use machine vision, motion control, robotics, and in-line inspection, while laboratory automation platforms exchange instrument, sample, and quality data.

When these environments are retrofitted, limited cable pathways may force new Ethernet lines to run near motor leads, switching power supplies, variable-frequency drives, relays, or other electrical noise sources. The resulting EMI can degrade signal integrity and contribute to intermittent communication faults or packet loss. In medical production and laboratory settings, those disruptions may delay an automated process, interrupt data transfer, or complicate troubleshooting.

EMC Is a System-Level Design Issue

EMI is unwanted electromagnetic energy that introduces noise or distortion into electrical or electronic systems. Electromagnetic susceptibility describes how readily a device or cable is affected by those disturbances. Together, emissions and immunity are addressed under electromagnetic compatibility (EMC): the ability of equipment to operate as intended without causing unacceptable interference to other equipment.

A connector or cable does not establish compliance for a finished medical device or system. However, cable routing, shield continuity, enclosure bonding, and connector termination can influence overall EMC performance and should be considered as part of the system design.



Medical device manufacturing and laboratory automation can present many of the same networking and electromagnetic interference challenges found in other automated industrial environments. (Credit: Mencom)

Use Rugged Ethernet Where the Environment Requires It

Shielded M12 D-coded Ethernet cordsets provide one option for connecting field equipment to switches, controllers, or gateways. Mencom's M12 Ethernet product line combines a keyed M12 field connection with Cat 5e industrial Ethernet cabling and, in selected configurations, an RJ45 termination for equipment located inside a protected enclosure.

These products may be evaluated for medical-device production equipment, laboratory automation, and related support systems when their published specifications align with the installation requirements. The M12 interface on the products described by Mencom is rated IP69, while the RJ45 interface is rated IP20 and is intended for use within an enclosure. Mencom offers PVC, PUR, and TPE cable-jacket options for different mechanical and environmental requirements.

Shielded variants are available with different shield-termination arrangements. The appropriate configuration should be selected as part of the equipment grounding and bonding plan.

Maintain Shield Continuity at the Enclosure

Where a cable shield must be bonded at a panel or enclosure wall, an EMI shielding cable gland can provide a mechanical and electrical connection between the cable shield and the enclosure. For example, Mencom's nickel-plated brass shielding glands are rated IP68 and are available with PG and metric threads.

For an existing medical manufacturing or laboratory-automation enclosure, those thread options may allow a gland to be matched to an available panel opening. The enclosure design, gland installation, and bonding method remain part of the overall EMC strategy.