AccuTrig™

Increasing throughput, accuracy, and stability of ultrashort-pulse micromachining lasers

The new AccuTrig feature from Lumentum allows external triggering of ultrashort-pulse micromaching lasers to increase throughput, accuracy, and stability

For most laser micromachining applications, the optical beam has to be moved across the workpiece, either by moving the beam or the workpiece itself. To maximize throughput, this movement should be as fast as possible. However, the required beam positioning accuracy can limit speed. When micromachining straight lines, scanning speed can be up to 10 m/s or faster. However, small and complex features constrain acceleration, limiting the maximum scanning speed to 0.3 m/s or even slower. As a result, scanning speed can vary widely during a processing job.

Micromachining with ultrafast lasers applies a large number of optical pulses to the workpiece. Ideally,

1) Each pulse has the same energy. This maximizes material removal (i.e., ablation efficiency) throughout the process*

2) Each pulse is evenly spaced on the workpiece. This minimizes heat affected zones (HAZ).

Because scanning speed varies, spatial pulse spacing can only be held constant if the pulse repetition frequency (PRF) of the laser follows the scanning speed..

From an application point of view, the ideal ultrashort laser would take a black-box approach. This means the laser would accept the arbitrarily-timed electrical-trigger pulses provided by, for example, the scanner card. The laser would then emit constant energy optical pulses with minimum timing jitter to minimize spatial jitter on the workpiece.

Unfortunately, such ideal ultrashort lasers do not yet exist and most applications hold the PRF constant.To maximize process quality, however, the laser still needs to maintain even pulse spacing, at least approximately. Scanning velocity can be kept constant throughout the job by operating at the slowest speed required, as determined by the most complex features. This approach is often inefficient and may even make a process uneconomical. Alternatively, the job can be run using variable speed. In this case, pulses will be more densely spaced at slower speeds. However, this often leads to unwanted thermal effects and lower process quality.

In effect, the lack of an ideal ultrashort laser results in a compromise of throughput, quality, or both. For many of today’s ultrafast laser applications and market, this is a significant limitation.

* LaserFocusWorld, Ultrafast Lasers: Picosecond lasers: Achieving maximum processing speed, Hubert Ammann and Andreas Oehler, 01/16/2014

Shortcomings of Pseudo-triggering
Pseudo-triggering is widely used to introduce a measure of flexibility with respect to the timing of the optical pulses when using ultrafast lasers. Pseudo-triggering typically takes one of two approaches, each with their own limitations.

(1) Pulse-on-demand (PoD): With PoD, a pulse-picker is located just before the laser's beam exit. The pulse-picker's basic function is to transmit or block any amplified pulses that enter the PoD. This is often called a "trigger function" since it can be configured to transmit one optical pulse upon receiving one external trigger pulse. However, PoD cannot provide true trigger functionality. This is because PoD is just a pulse gating mechanism and so cannot alter the pulse timing. In other words, it does not trigger the generation of optical pulses; rather, it can only select pulses from a rather slow pulse train at its input. If the PoD receives a trigger at an arbitrary time, there is usually no amplified pulse available, so there is nothing to transmit and the PoD has to wait for the next regular pulse to arrive. The end result is that the timing of optical pulses with respect to the trigger is fairly random. This inhibits accurate positioning of pulses on the workpiece.

(2) Trigger/SYNC: Some ultrafast lasers locate the pulse picker after the seed laser; i.e., before the amplifiers. The advantage with this positioning is that pulses from the seed laser have a very high repetition rate. This gives the pulse picker more pulses to choose from, in principle making more accurate pulse timing possible. However, arbitrary triggering before the amplifiers can result in considerable pulse energy fluctuations and potentially damage the laser. For this reason, access to this pulse picker is usually restricted to a few special cases, such as for occasional timing jumps (useful for polygon scanners) and repetitive external triggering within a predefined and rather limited PRF range.

The primary difference between these two methods is a trade off between stability and jitter. PoD provides optical pulses with excellent energy stability but large timing jitter. Trigger/SYNC, in contrast, provides optical pulses with reasonable timing jitter but poor energy stability. The two methods can be combined to create a compromise that may be acceptable in some specific cases. Unfortunately, combining the two methods typically achieves pulse energy variations around 10-20% with timing jitter on the order of a microsecond. This is far from what today's applications need.

AccuTrig – The ideal trigger
To overcome the stability and quality limitations of pseudo-triggers, Lumentum offers the AccuTrig feature for its PicoBlade® 2 micromaching lasers and future ultrashort laser models. The feature is easy to use and provides excellent performance. The laser controller accepts external trigger pulses and the laser generates one optical pulse per trigger pulse. These external trigger pulses will typically be provided by the user's scanner card or the controller of a motorized stage. When the laser system receives an external trigger pulse, AccuTrig responds by emitting one optical pulse (or pulse burst).

The performance of any laser trigger function is characterized by its pulse energy fluctuations and the timing jitter (electrical to optical) under irregular or arbitrary triggering conditions. Arbitrary refers to those times when the PRF may not be well-defined. Even under such challenging conditions, AccuTrig achieves energy fluctuations on the order of 1-2% root mean square (RMS) with a timing uncertainty of less than ±25 ns. This level of stability and accuracy means that, even at fast scanning speeds of 20 m/s, pulse positioning uncertainty on the workpiece is no more than ±0.5 µm. Such uncertainly is negligible for almost all practical micromaching applications.

Figure 1 shows the optical pulses of the PicoBlade 2 laser with AccuTrig under arbitrary triggering conditions. In this example, the laser is operating in burst mode, based on unique FlexBurst™ technology from Lumentum. The laser could also be operated in single pulse mode without affecting trigger performance.

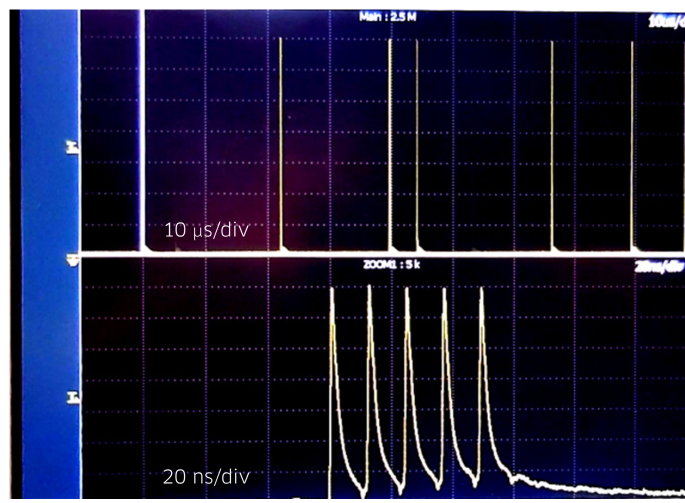

Figure 1: The optical output of the PicoBlade 2 under arbitrary triggering conditions and measured using a fast photodiode.

The upper oscilloscope trace displays an arbitrary sequence of picosecond pulse bursts. Note that individual pulses within the bursts are not resolved and show up as single vertical lines. Each burst is triggered by a user trigger pulse (not shown). As can be seen, the burst energies are stable despite irregular timing/triggering.

The lower trace is the same photodiode signal magnified by 500X. It reveals the bursted sub-structure of each line in the upper trace. Each of the five pulses within the burst represents a 10 ps optical pulse. Note the absence of energy fluctuations that would normally result from irregular triggering of ultrafast micromaching lasers.

External trigger requirements
To configure the external trigger requirements for accurate triggering, first determine the pulse energy required by the application. Remember, pulse energy is ideally held constant during a processing job. Next, compute the upper PRF limit that

the laser can support with its given power output. For example, a 40 W laser can support an energy of 100 μJ, enabling a maximum PRF of 400 kHz (100 μJ x 400 kHz = 40 W). This maximum PRF defines the minimum time between any two consecutive trigger pulses, in this case 1/400 kHz = 2.5 μs. Note that this is an intrinsic limitation based on the laser's output power. Finally, select the pulse format (i.e. single pulse, or pulse burst with a desired energy distribution) based on the maximum allowable PRF. The user can now freely trigger the laser provided that the spacing between any two trigger pulses is at least 1/PRF(max).

More efficient micromachining strategies

AccuTrig allows a pulsed laser to be triggered, thus improving quality and throughput for many different applications. One of the primary benefits AccuTrig offers is that the PRF can be dynamically adjusted so that it tracks with variable scanning speed. This removes any limitations to select a single, slow speed to accommodate the finest machining features. It also eliminates undesirable heat effects when the scanner slows down to maintain positioning accuracy; the user can simply slow down the laser pulses too. The end result is users no longer have to choose between higher throughput or higher quality. With AccuTrig, you get both at the same time.

The added stability and quality enabled by AccuTrig technology also enables new and more efficient machining strategies. For example, a common strategy for micromachining a large matrix of dimples is to complete each dimple before moving on to the next one. This increases machining time since the scanner has to frequently change its speed. In addition, applying the full laser power to one specific dimple results in a beam that is almost stationary, usually resulting in significant HAZs.

With active triggering through AccuTrig, it is possible to accurately trigger and position each optical pulse. Thus, the laser can apply one pulse to a dimple at a time while scanning over the matrix of dimples. Because each dimple gets only one pulse per scan, this dramatically reduces HAZ issues. At the same time, throughput is significantly increased since the scanner can move at its highest velocity.

Integration and compatibility with other laser features

Active triggering is the most natural way of using a pulsed laser. In fact, today's beam steering equipment, including most Galvano scanner cards, already output trigger pulses that Q-switched and other pulsed lasers rely on.

AccuTrig can be used with different wavelengths like 532 nm or 355 nm, Lumentum proprietary FlexBurst capabilities, MegaBurst™ technology that enables the highest burst energies on the industrial laser market, and real-time power modulation capabilities.

For more information on how Lumentum PicoBlade 2 micromachining lasers with AccuTrig can accelerate throughput, increase quality, and improve your bottom line, contact us.

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