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APPLICATION NOTE 60

LITHIUM-ION BATTERY FOIL CUTTING WITH PICOSECOND IR LASERS AND BURST MODE

Lithium-ion batteries are the energy storage medium of choice for myriad applications, from mobile devices like cell phones and smart watches to the power packs in electric vehicles and home energy storage systems. Due to the growth in these and other markets, the demand for lithium-ion batteries also continues to grow, motivating the development of lower cost, faster production methods.

Lithium-ion batteries have a layered structure, comprised of several elements: a cathode battery foil, an anode battery foil, a separator material, and an electrolyte. The battery foils consist of a metal substrate – typically copper for the anode and aluminum for the cathode – and an active material applied as a coating to that substrate. For the anode the active material is very often graphite, however for the cathode several different active material chemistries are employed, such as NMC ($LiNiMnCoO_2$), LFP ($LiFePO_4$), or LNMO ($LiNi_{0.5}Mn_{1.5}O_4$).

Battery foils are processed reel to reel, usually requiring that they be cut using a single pass as rapidly as possible. Cut quality is also of particular importance however, as flaws in the cut edge have the potential to lead to shorting between foils and subsequent thermal runaway leading to catastrophic failure. Due to this demand for speed and quality, ultrashort pulse lasers are a natural fit, given their ability to process a wide variety of materials with minimal heating or melting.

Here we show processing results using the IceFyre® IR50 picosecond laser on battery foil materials. Of particular significance we show the speed and quality advantage of cutting using TimeShift™ burst mode, as compared to conventional single pulse processing.

Here we look at the single pass net cutting speed – given as the maximum speed at which the material is through-cut (though some negligible amount of bridging across the kerf is permitted) – and the coating pull-back, or the distance the coating has receded from the cut edge of the metal foil (due to its lower ablation threshold compared to the foil substrate).

For our tests we used a cathode material consisting of a ~16 µm thick aluminum foil coated on both sides with NMC for a total thickness of ~100 µm. The anode material we used consisted of an ~11 µm thick copper foil coated on both sides with graphite for a total thickness of ~98 µm.

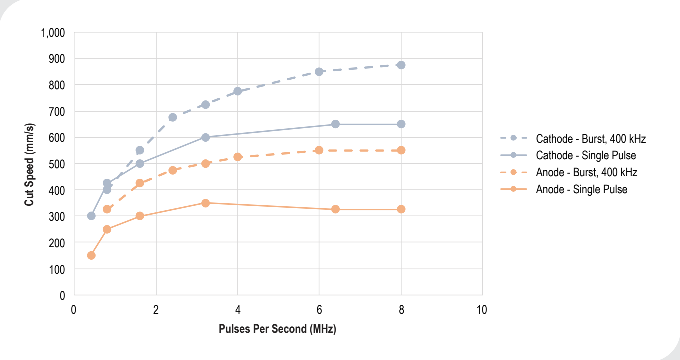

Figure 1. Net cut speed versus pulses per second for cut results comparing burst versus single pulse for both anode and cathode foils

Battery foil samples were processed using a single pass, and data was collected for both single-pulse processing, with a range of repetition rates from 400 kHz to 8 MHz, and burst-mode processing for a range of burst numbers (2 to 20 burst sub-pulses), all at 400 kHz. To compare the results, the burst-mode data is assigned an equivalent repetition rate that is computed by multiplying burst sub-pulse numbers by the set repetition rate of 400 kHz. For example, a burst with 10 sub-pulses operating at 400 kHz has 10×400,000 = 4,000,000 pulses per second and the corresponding data point is therefore plotted at the 4 MHz point along the horizontal ("X") axis. By the same token, a burst data point at the 8 MHz location indicates that the actual laser output (at 400 kHz) was 8,000 kHz/400 kHz = 20 burst pulses. This data representation allows both data sets to be plotted versus repetition rate on the same graph.

Net cut speed is plotted versus pulses per second for both the cathode and anode materials (Figure 1). For both materials, the plot shows a clear speed benefit to higher burst sub-pulse counts that quickly surpasses the single pulse cutting speeds. Burst mode shows an increase in net cutting speed over single pulse of ~35% and ~57% for the cathode and anode materials, respectively.

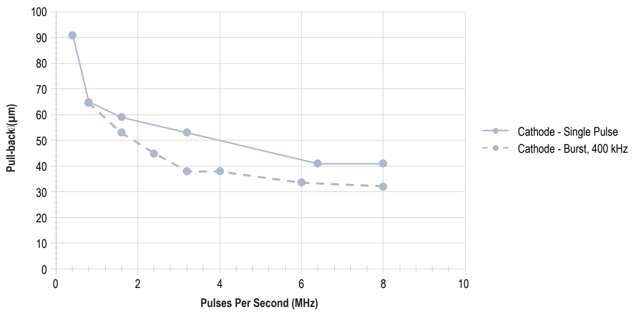

Figure 2. Pull-back versus pulses per second for cut results comparing burst versus single pulse for cathode foils

A similar plot was produced for the coating pull-back, showing pull-back versus pulses per second for the cathode material (Figure 2). This plot shows that for both single pulse and burst mode the pull-back is reduced for increased pulses per second, and that burst mode shows a ~22% decrease in pull-back versus single pulse when compared at their lowest values.

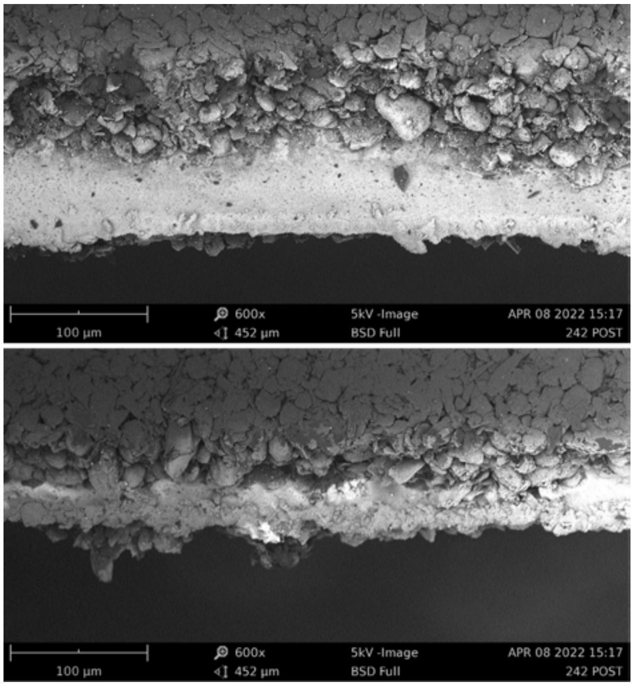

Figure 3. SEM images of anode foil cut edge. (Top) Sample was processed at 400 kHz using single pulse mode. (Bottom) Sample was processed at 400 kHz using a burst of 20 pulses. Images show some protrusion of the metal foil as expected due to the coating pull-back. The foil is confined to its layer, showing minimal burr or smearing.

Images were taken for visual inspection, providing a qualitative look at edge quality. Figure 3 shows two SEM (scanning electron microscope) images taken of the cut edges of the anode foil. In this case both were processed at 400 kHz with the upper and lower images showing cuts produced using single-pulse and 20-pulse burst processing, respectively. Both images show the pull-back of the coating from the metal foil cut edge; however the pull-back is much greater for the unoptimized single-pulse process. It is also noteworthy that in both cases — burst and single-pulse — the quality is very good, with little evidence of melting, burr formation, etc., that could otherwise negatively impact long-term reliability of high-performing battery cells.

In addition to looking at the coated battery foils, the net cutting speed was investigated for bare copper and aluminum foils. Burst performance was compared with single-pulse performance (Figure 4), and as with the coated foils, burst performance was significantly better, showing a ~71% increase in net cutting speed for aluminum and a ~165% increase for copper.

Based on these results, it is clear that burst processing has distinct advantages over single-pulse processing, leading to higher throughput with improved overall quality. Using the IceFyre IR50 picosecond laser with TimeShift technology enables flexible tailoring of burst parameters for superior optimization of various cutting processes required in lithium-ion battery manufacturing.

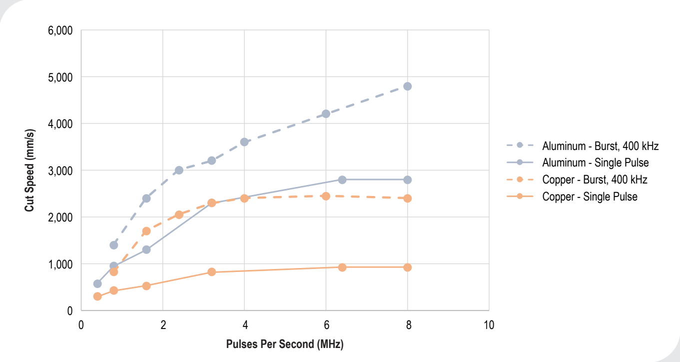

Figure 4. Cut speed versus pulses per second for bare aluminum and bare copper, showing both burst and single-pulse processing

PRODUCT

IceFyre® Industrial Picosecond Lasers

The IceFyre UV50 is the highest performing UV ps laser on the market, providing >50 W of UV output power at 1.25 MHz (>40 µJ) with 100's µJ pulse energies in burst mode, and pulsewidths of 10 ps. The IceFyre UV50 sets new standards in power and repetition rates from single shot to 10 MHz. The IceFyre UV30 offers >30 W of typical UV output power with pulse energy >60 µJ (greater pulse energies in burst mode) and delivers exceptional performance from single shot to 3 MHz. The IceFyre IR50 provides >50 W of IR output power at 400 kHz single pulse and delivers exceptional performance from single shot to 10 MHz.

IceFyre laser's unique design exploits fiber laser flexibility and Spectra-Physics' exclusive power amplifier capability to enable TimeShift™ ps programmable burst-mode technology for the highest versatility in the industry. A standard set of waveforms is provided with each laser; an optional TimeShift ps GUI is available for creating custom waveforms. The laser design enables true pulse-on-demand (POD) and position synchronized output (PSO) triggering with the lowest timing jitter in its class for high quality processing at high scan speeds, e.g. when using a polygon scanner.

	IceFyre IR50
Wavelength	1064 nm
Power	>50 W @ 400 kHZ
Maximum Pulse Energy, typical (greater pulse energy per burst possible with TimeShift ps)	>200 µJ @ 200 kHz
Repetition Rate Range	Single shot to 10 MHz
Pulse Width, FWHM	<15 ps (13 typical)
TimeShift ps	Yes
Pulse-to-Pulse Energy Stability	<1.5%, 1 σ
Power Stability (after warm-up)	<1%, 1 σ, over 8 hours
Spatial Mode	TEM_{00} (M^2 <1.3)
Beam Diameter (D4σ)	3.0 mm ±0.3 mm
Beam Divergence, full angle	<0.75 mrad
Polarization	>100:1, vertical

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