NO. 40

Picosecond Laser Burst Machining of Silicon to Enhance Material Removal Rate and Quality

Machining of silicon is important in various industries such as integrated circuit (IC) back-end processing, microelectronics packaging and photovoltaics manufacturing. As wafer thicknesses have decreased over the years, mechanical processing has increasingly given way to laser technology due to the challenges of processing thin brittle materials with mechanical tools. Various nanosecond pulsed laser technologies have been used, including excimer, diode-pumped solid state (DPSS), and fiber. Increasingly, however, the use of ultrashort pulse laser technology is being considered to further improve quality and speed of machining.

To this end, picosecond laser technology is being adopted for machining with both good quality and higher throughput.

Spectra-Physics' IceFyre® picosecond laser delivers >200 µJ pulse energy and >50 W average power at a wavelength of 1064 nm. IceFyre's TimeShift™ ps technology offers versatile burst mode operation with variable separation time between the pulses within a burst. A unique property of TimeShift ps is that the temporal spacing and number of pulses within the burst envelope can be widely varied while maintaining the maximum output power of ~50 W.

Spectra Physics application engineers conducted a series of experiments using the IceFyre 1064-50 to characterize the effect of burst machining on various materials, including crystalline silicon. Volume ablation rates were characterized for variable number of pulses within the burst as well for different separation times between the pulses within the burst. The experiment consisted of pocket milling volumetric regions in 0.8 mm thick polished silicon wafers using various experimental conditions, measuring the depth of the milled pockets, and determining volume ablation rates and efficiencies. In addition, quality assessment of the milled surfaces was performed using an optical microscope.

In Figure 1, ablation rates are plotted for both single pulse output and for bursts of up to 10 pulses ("N" indicates number of pulses in a burst). For pulse bursts, the pulse repetition frequency (PRF) was fixed at 400 kHz while the temporal spacing between the pulses within the bursts was varied from 10 to 50 ns. For single pulse output, ablation rate was characterized at both 400 kHz and 1.6 MHz PRF.

The data in Figure 1 demonstrates a clear advantage for using burst mode output for volume ablation of silicon. With a 10 pulse burst, the ablation rate is more than 5 times higher compared to single pulse output. It is also clear from the data that having shorter pulse separation times within the burst is advantageous.

Optical microscope inspection of the features provides information on the effect of burst machining on quality. In Figure 2, the left and center images show the machined surfaces for single pulse output at 400 kHz and 1.6 MHz PRF, respectively, and the right image shows the surface machined with a 10 pulse burst at 400 kHz PRF.

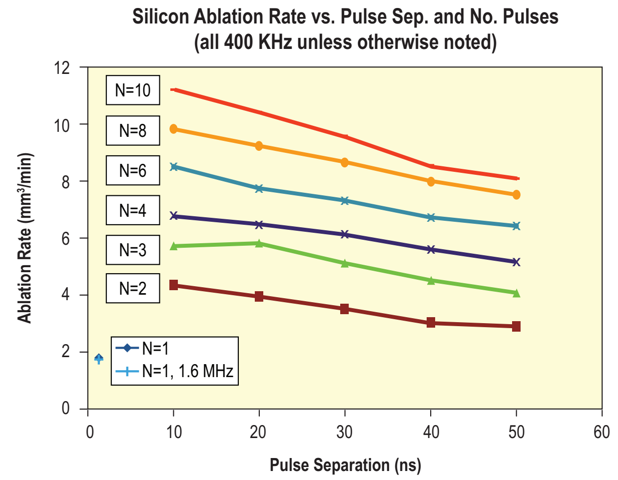

Figure 1: Ablation rate data indicating more pulses in a burst and shorter burst pulse separation times increases material removal rates.

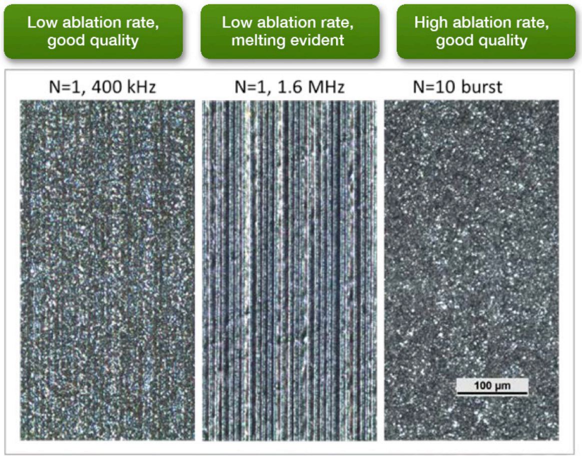

Figure 2: Optical microscope images show surface quality of ablated features.

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The images in Figure 2 show that the appearance of single pulse ablated surfaces at 400 kHz and 1.6 MHz is markedly different while the data from Figure 1 shows ablation rates to be nearly identical. At the lower PRF, the fine granular appearance indicates material was removed with little heat generation due to the short picosecond pulse duration. At 1.6 MHz, however, the ablated surface show clear signs of melting, most likely due to the pulse-to-pulse heat accumulation known to occur at high PRFs. The data shows that using the 10-pulse burst mode output of the laser not only enhances the material removal rate by more than a factor of 5, it also provides a clean, melt-free surface.

An additional experiment was performed to characterize the ablation rates when using more than 10 sub-pulses within the burst and with the pulse separation time fixed at the shortest possible value of 10 ns. The data from this test is plotted in Figure 3.

The data plot in Figure 3 shows that even more significant gains in material removal rates are achieved as the number of burst pulses is increased from 10 to 50. With 50 pulses in the burst, the ablation removal rate of >27 mm^3/min is an enhancement of more than 13x over the single pulse removal rate of 1.7 mm^3/min. With the highly flexible pulse tailoring capability found in IceFyre's TimeShift ps technology, the ability to greatly enhance volume material ablation rates and quality in Silicon machining is clearly demonstrated.

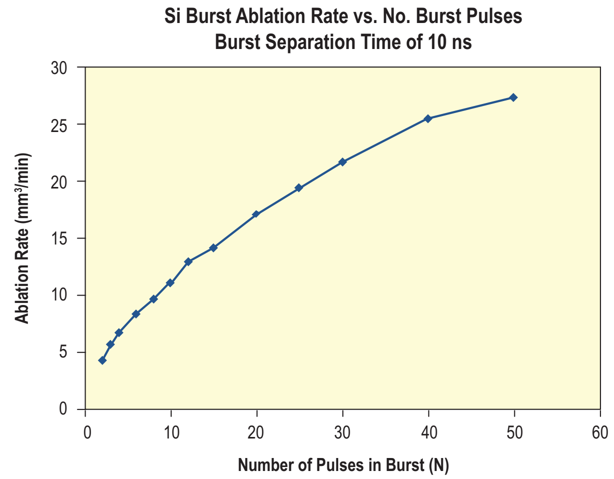

Figure 3: Further increase in material removal rate is seen as the number of pulses within the burst is increased from 10 to 50.

PRODUCT: *ICEFYRE 1064-50*

IceFyre redefines picosecond micromachining lasers with a patent-pending design to achieve exceptional performance and unprecedented versatility at industry leading cost-performance. Based on Spectra-Physics' It's in the Box™ design, IceFyre integrates laser and controller into the industry's smallest package. IceFyre's unique design exploits fiber laser flexibility and Spectra-Physics' exclusive power amplifier capability to enable TimeShift ps programmable burst-mode technology and wide adjustability of repetition rates. A standard set of waveforms is provided with each laser; an optional TimeShift ps GUI is available for creating custom waveforms. The laser provides pulse-on-demand triggering with the lowest jitter in its class for high quality processing at high scan speeds, e.g. when using a polygon scanner.

	IceFyre 1064-50
Wavelength	1064 nm
Power	>50 W
Maximum Pulse Energy, typical	>200 µJ single pulse at 200 kHz
Repetition Rate Range	Single Shot to 10 MHz
Pulse Width, FWHM	<20 ps
Pulse-to-Pulse Energy Stability	<1.5% rms
Power Stability (after warm-up)	<1%, 1 σ over 8 hours
Spatial Mode (TEM_{00})	<1.3
Beam Asymmetry	1.0 ±10%
Beam Pointing Stability	< ±25 µrad/°C

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