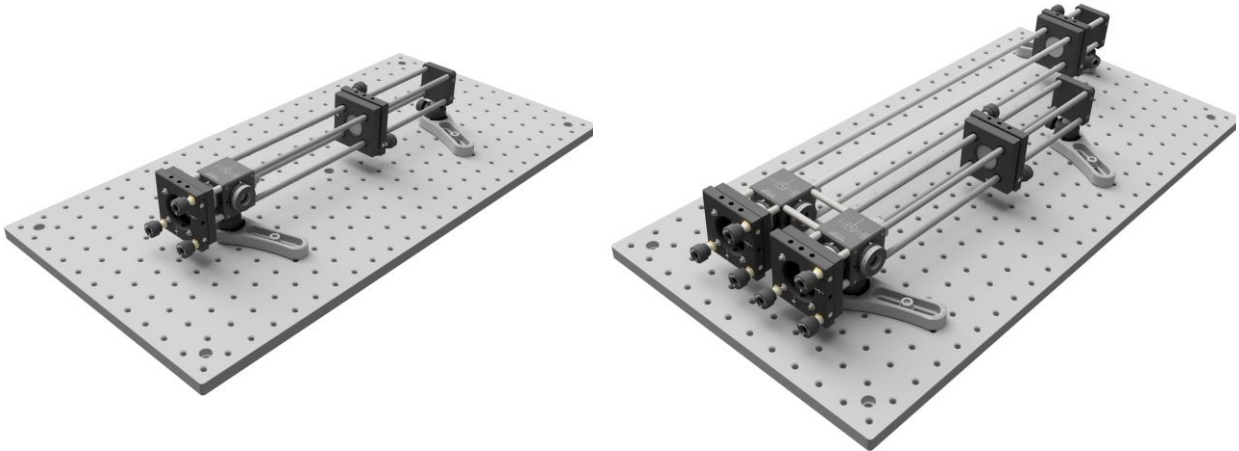


Burst Conversion Modules

An external module for conversion of ultrashort laser pulses to bursts



BCM1

BCM2

FUNCTIONS

Transformation of conventional laser pulsed radiation into burst mode

The controlled temporal distance between sub-pulses in burst

Controlled sub-pulse energy in a burst

Compatible with most ultrashort pulse lasers

APPLICATIONS

Ablation cooling effect and efficient material removal, with minimal thermal effect

High-throughput laser ablation

Laser processing of metals, semiconductors, and dielectrics

Internal modifications of transparent materials

TECHNICAL SPECIFICATIONS

Burst conversion module	BCM1	BCM2
Number of modules	1	2
Controlled time delay between sub-pulses ¹	0.5 ns - 2 ns, step 33 ps	
Controlled sub-pulse repetition rate ²	0.5 GHz - 2 GHz	
Controlled number of sub-pulses in the burst ³	2	4
Controlled delay line length ⁴	30 cm, gradation 1 mm	
Temporal delay between pulses ⁵	± 3.3 ps	
Orientation control of the half-wave phase plates ⁶	0° - 45°, step 2°	
Operating ambient temperature	15°C to 30°C	
Dimensions (xyz)	30 × 60 × 10 cm ³	

¹ The main and most prominent application of laser burst mode irradiation up to date is the ablation-cooling effect, which has attracted the attention of the scientific and technological communities due to high material removal efficiencies and minimal thermal effects on the processed material compared to standard pulse laser ablation, which was published by one international group of scientists in the high impact factor peer-reviewed journal *Nature* www.nature.com/articles/nature18619. To achieve this effect, the time interval between sub-pulses is shorter than the thermal relaxation time of the material, so that the heat from the first sub-pulse does not diffuse deep into the material before the second sub-pulse hits and all energy from the first and second sub-pulses is utilized together. For highly thermally conductive materials such as Si, Cu, Au, or various ceramics, the thermal relaxation times are estimated to be $\tau_0 \approx 1$ ns. Therefore, the Burst conversion module can control temporary delays between sub-pulses from 0.5 ns to 2 ns, step 33 ps.

² One basic condition required to achieve the cooling ablation effect is related to the repetition rate of the sub-pulses in the bursts, which must be close or greater than $f = 1/\tau_0 = 1$ GHz. This frequency is exactly what is used as the average value between sub-pulses in bursts. Also, there is the possibility to achieve the ablation cooling effect for less heat-conductive materials also for materials with higher conductivity. Therefore, the repetition rate of sub-pulse bursts can be controlled from 0.5 GHz to 2 GHz.

³ It has already been observed in the scientific literature that three sub-pulses give optimal results in the efficiency of laser ablation www.nature.com/articles/s41598-019-48779-w, and to further increase the number of sub-pulses does not make sense, therefore, the device is limited to a two number of modules that will generate a maximum of four sub-pulses. However, it will always remain possible to connect the third and fourth modules at the special request of the customer, if more sub-pulses in the burst are required for specific applications.

⁴ To achieve the time delay between sub-pulses (from 0.5 ns to 2 ns) and to create the first delay stage, a delay line with a controlled $L_1 = (c \cdot \tau_0)/2 = 15$ cm physical length is required, where $c = 3 \times 10^8$ m/s is the speed of light in vacuum. Correspondingly, a delay line with twice the longitudinal distances is required for the second node stage than in the first $L_2 = 2 \cdot L_1 = 30$ cm. The mechanical rails for optomechanical translation of mirrors with engraved 1 mm markings along the length, which ensures a delay line with a step of 33 ps when controlling every 5 mm distance.

⁵ Controlled 1 mm length scale accuracy of delay lines ensures ± 3.3 ps time delay accuracy between sub-pulses in the burst.

⁶ The energy characteristics of sub-pulse in bursts are controlled by changing the orientations of the half-wavelength physical plate before the polarizing beam splitter cube, from 0° to 90°, step 1°.

REQUIREMENTS FOR AN EXTERNAL LASER SOURCE

Burst conversion module	BCM1, BCM2
Wavelength of irradiation	1064 nm
Incoming beam radius at level $1/e^2$ ⁷	2 mm - 4 mm
Pulse repetition rate	0 Hz to 100 MHz
Gaussian beam quality	$M^2 < 1.3$
The damage threshold of optics ⁸	10 J/cm ² at 1064 nm, 10 ns, 20 Hz

⁷ The incoming laser beam must be collimated with a radius of at least 2 mm, for such a laser beam with a fundamental wavelength $\lambda = 1064$ nm the Rayleigh length of the beam is $z_R = 11.8$ m, the optical path across the node delay lines would be significantly smaller than that of Rayleigh length and would allow the combination of laser beams propagated by different optical paths. The upper limit incoming laser beam must be collimated with a radius of 4 mm is due to the aperture limitation.

⁸ The optical breakdown threshold was taken from the supplier of the optical components and measured at a fundamental wavelength of 1064 nm, pulse durations of 10 ns, pulse repetition frequency of 20 Hz.

CONTROLS

Manual control of the time delay between sub-pulses

The time delay between pulses is controlled manually by mechanically changing the lengths of the delay lines. The delay lines are constructed using manually operated mechanical rails for optomechanical translation. The rails with an optomechanical bracket with built-in mirrors in the delay line and have a screw for a position lock for precise setting and locking of the required delay between sub-pulses.

Manual control of energy ratio between sub-pulses

The energy characteristics of the sub-bulses in the burst are controlled by manually adjusting the orientations of the half-wave phase plates. The precision optomechanical components are selected for the finest tuning of energetical characteristics of sub-pulses in the burst.

DRAWINGS

