Spatio-temporal light shaping for parallel nano-biophotonics

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Spatial and temporal light modulation may be visualized as forming light shapes by altering a property of light, e.g. its intensity. From this perspective, focusing light tightly and generating ultrashort light pulses are seen, respectively, as varying the width and the thickness of light. It is obvious that a 1 µm-wide focused light indeed describes the dimension of light and, though less obvious, a 10 femtosecond pulse describes a 3 µm-thick light chunk. In this picture, the "femtosecond-barrier" in ultrashort pulses and the "diffraction barrier" in focused light are mere consequences of geometry, where the wavelength of light sets a lower limit in how small we can shape light's thickness and width.

This light shaping process suggests a natural marriage of spatial and temporal shaping (i.e., spatio-temporal modulation). However, the spatial and temporal light sciences have traditionally followed separate tracks. Width-shaping, or spatial techniques, have mostly ignored light's thickness (using continuous-wave lasers), while thickness-shaping, or temporal techniques, typically ignored the beam width. This disconnected spatial and temporal track also shows in our own research where we developed Generalized Phase Contrast (GPC) [1] for diverse spatial light-shaping applications. We can dynamically shape light to interact with microscopic matter and we have contributed to the field of optical micromanipulation [2]. Beyond microscopy, we can apply non-contact forces onto biological cells and light-sculpted microtools [3] using our BioPhotonics Workstation which is now on its way to commercialization.

Why do we need spatiotemporal modulation? Ultrashort pulses can unravel details of ultrafast phenomena while tightly focused light can map out features with finer spatial details. However, the thin light sheets in ultrashort pulses and the narrow light shapes in focused light are simply examples of general arbitrary light shaping. For example, focusing ultrashort pulses creates narrow and thin light that achieves precision micromachining of inorganic materials such as glass and organic materials such as polymers or biological matter. Focusing ultrashort pulses compresses light and packs high energy densities that can excite multiphoton processes having much finer features. Shaping light to create an array of such high-energy chunks enables parallel processing for getting higher throughput. Another step is to vary light's pulsewidth (thickness) as it propagates to get maximum compression (and highest energy density) at a chosen target plane. This temporal focusing can selectively look at a defined cross-section within a sample with only minimal disturbance from other regions. It can also do plane-by-plane micromachining for faster laser processing compared to scanning a focused laser spot.

Our previous work on spatial light shaping, together with the interplay between spatial and temporal modulation, invariably provides a strong position to pursue application-oriented spatio-temporal approaches [4]. Combining our GPC technology with temporal focusing, we can precisely stimulate single neuronal processes, neurons or groups of neurons, despite the highly complex neuronal structures [5] (see Fig. 1). Our recent paper in Nature Methods, within the emerging field of *optogenetics*, opens the use of shaped light for electrode-free and contact-free switching of brain circuits, e.g. to probe underlying mechanisms in disorders like Alzheimers or Parkinsons.

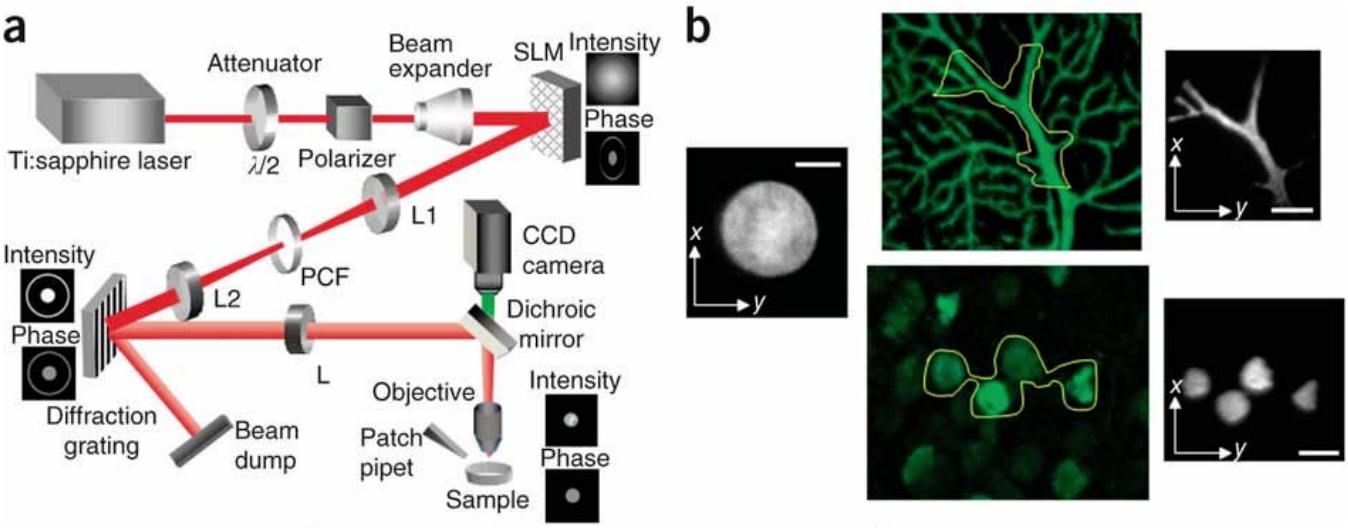

Fig. 1: Combining our GPC spatial modulation technology with temporal focusing for optogenetics: (a) Optical layout; (b) Complex neuronal structures and the spatio-temporally shaped light for switching (adapted from [5])

References

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