Free-space photonic circuits for spatially structured light

F Cardano[1]

[1] *Università degli Studi di Napoli Federico II, Via Cintia, Napoli, Italy. Contact Phone: +081676113*
Contact Email: filippo.cardano2@unina.it

Free-space photonic circuits are emerging as a promising platform for the processing of structured light in both classical and quantum regimes. More generally, photonic circuits are designed to implement prescribed couplings among optical modes, and therefore act as processors for optical information encoded in multiple degrees of freedom. To date, the most developed implementations have relied on integrated photonics, typically based on meshes of beam splitters and phase shifters. However, free-space approaches offer an attractive complementary route, with direct access to large families of co-propagating spatial and polarization modes, broad optical bandwidth, and the possibility of low-loss high-dimensional transformations [1].

In this talk, I will present our recent advances in the development of a free-space photonic circuit technology based on patterned liquid crystal elements. These devices implement spatially varying polarization transformations and, through them, controlled coupling between polarization and transverse spatial modes of light. This provides a powerful and flexible framework for the manipulation of structured light and for the realization of high-dimensional optical transformations in compact free-space architectures. Our recent work demonstrates scalable mode processing in both one-dimensional and two-dimensional configurations, including schemes that redistribute a single optical input across large sets of output modes and more general programmable manipulations of structured light [2,3].

Beyond their classical functionality, these free-space circuits are naturally suited to quantum optical applications [4]. They offer new opportunities for manipulating multi-photon states, controlling high-dimensional interference, and implementing photonic protocols that benefit from large mode spaces. I will finally discuss ongoing efforts toward more general and ultimately universal free-space photonic circuits, based on the combined use of near-field and far-field transformations.

These results highlight the potential of liquid crystal based free-space photonics as a versatile platform for optical information processing with structured light.

References

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