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Photonics goes synergy FREE

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After a number of groundbreaking discoveries in photonics during the past 10 years, the field has begun to combine ideas emerging from seemingly unconnected phenomena. In the next decade, photonics will break new frontiers by exploring the synergy of the field and develop innovative concepts and applications based on multiple research directions. As a multidisciplinary photonics journal, *APL Photonics* is the perfect platform for publishing these novel developments.

In the last decade, photonic sciences were boosted beyond anyone's expectations due to a plethora of groundbreaking ideas and discoveries. Never before was photonics itself playing such an important role in fundamental science rather than being "only" an enabling technology for other research fields. This can be nicely illustrated by a few examples. The first is the concept of "accelerating beams," which allows the bending of light rays around opaque obstacles, in contrast to common intuition. Being a wave phenomenon, the idea of "wave acceleration" is of importance to many fields, not just to plasmas and electron beams. The "transverse localization of light" paved the way for studying the impact of disorder—in particular, Anderson localization—in any wave-physical system. With its origin in photonics, disorder-induced localization is now a well-explored phenomenon in many different systems, ranging from acoustics to cold atoms. Moreover, the realization of "two-dimensional lattice solitons," where nonlinearity and lattice geometry are crucially interacting, opened a new field, which is now being explored well beyond photonics. The concept of "PT-symmetry" that employs refractive index landscapes with gain and loss changed our perspective of quantum mechanics and the (non-)necessity of Hermitian Hamiltonians as a requirement for real eigenvalue spectra. The breakthrough idea of "linear photonic quantum computation" using quantum coherence of indistinguishable photons opened new directions for the development of quantum algorithms and eventually the realization of all-optical quantum computers. This field evolved as a serious competitor to cold atoms, trapped ions, and superconductors and is now acknowledged as a potential platform for future quantum computation schemes. The idea of implementing "synthetic dimensions" was born in photonics, as a promising way to break the experimental limitations of the four-dimensional limit in which we live. And last, but not least, the invention of "topological photonics" was and is breaking new grounds, enabling novel and innovative waveguiding schemes for routing and switching light along arbitrary trajectories without any backscattering due to topological protection.

Most of these recent inventions were inspired by analogies from other fields, such as quantum mechanics, solid state physics, etc. But now, photonic sciences discovered something new: synergy. There is a clear trend observable during the last two years to seek for synergetic connections between all those fields. Whereas in the last decade, the above mentioned and also other research directions were essentially on their own; now, scientists try diligently to connect them.

A good example is quantum optics with indistinguishable photons, which focuses normally on the implementation of quantum algorithms with a particular emphasis on quantum gates. Today, scientists work to combine quantum optics with other topics from fundamental science. This year, two papers were published about the evolution of single-photon light in a topological structure,[1,2] where the ideas of topological photonics in first quantization were successfully transferred to second quantization, where nonlocality and nonrealism dominate light evolution. Topology in photonics was originally introduced as a mere classical wave phenomenon; these works lifted this field to new heights by entering a new realm of physics—using a photonic platform. This leap, based on synergy of two seemingly distinct fields in photonics, carries a lot of potential, not only for fundamental science, but also for innovative applications, where the quantum features of light might be topologically protected, in addition to the classical topological protection against scattering. In another recent work,[3] the realization of single photon evolution in a PT-symmetric structure was reported. Although the experiment was performed using a single photon, that is, still first quantization was used, the direction is clear: PT-symmetry will very soon be demonstrated in second quantization, that is, with two or more indistinguishable photons. This will be nothing less than a breakthrough, opening the gate to a new era of quantum optics. Beyond the constraints of Hermiticity, there are numerous new effects and phenomena based on PT-symmetric quantum optics waiting to be explored.

In a further interesting and recently published manuscript, topological photonics was combined with PT-symmetric.[4] Before this work, it was speculated that topological edge states cannot exist in PT-symmetric structures, as their very existence breaks this global symmetry. This lively discussion was brought to a definite end, as the existence of such states was demonstrated theoretically and experimentally. However, the results presented in Ref. 4 raised further interesting questions, in particular, about the character of topological invariants in non-Hermitian systems and how they can be defined at all. It is clear that topology in non-Hermitian systems bears many interesting concepts, which are impossible in Hermitian settings.

There are more examples like the ones discussed above; however, they all follow the same approach and, hence, carry the same scientific message. The combination of two interesting fields in photonics can result in a hybrid field that has the potential to be even *more* interesting than the individual components. The synergy arising from the interplay of two seemingly distinct research fields carries great potential for new research directions and applications as well, as it may unravel novel concepts that were considered impossible before.

However, there are conceptual challenges that must be overcome. The most important is to be able to combine two fields in a consistent manner. It may often be the case that concepts are based on particular conditions, which are in turn broken when changing the underlying setting. A good example is PT-symmetric quantum optics, as gain (required for PT-symmetry) and photon indistinguishability (required for quantum optics) do not go well together. This conceptual mismatch has to be overcome in an innovative manner, in order to benefit from both fields. However, as history has shown, there is no doubt that the scientific community will be able to successfully tackle this problem.

There are exciting times in front of us, where synergy in photonics will results in new ideas, concepts, and processes that carry much potential for successful participation the international competition for new technologies, products, and markets. *APL Photonics*, as an interdisciplinary photonics journal, is the perfect distributor for these new developments, and the editorial team is excited about receiving your contributions that use the synergy in photonics.

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