Active matter: the beginning of a rich history, a promising future

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Active matter is a rather recent field of research at the interface between physics, chemistry, life science and engineering. It deals with a class of non-equilibrium many-body systems whose elementary units convert a local energy source into work, for example in the form of directed motion. Living matter is active in essence, whether it's a large group of animals, a colony of bacteria or a tissue of cells. But active matter also includes artificial systems, whether in the form of chemically propelled colloidal suspensions, swimming droplets, vibrated grains, or assemblies of robots. Active matter is the seat of rich collective phenomena, which on large scale translate into new forms of dynamical phase transitions.

The last 30 years have seen an influx of experimental observations and theoretical advances in the description of such phenomena in active liquids. The emergence of collective motion in large groups of animals - flights of starlings, shoals of fish - is the most spectacular manifestation of this and launched the field in the mid 1990s. The paper by Alexandre Solon, presented here, gives a nice overview of the fantastic progress that has been made in the understanding of such collective motions. It also illustrates how these systems challenge our intuition and provide us with unexpected surprises…

Such unexpected behaviors also hold in the simplest form of active matter, that is made of purely repulsive active particles subjected to thermal noise. For instance, pressure is generically not a state variable, and instead depends on the potential defining the wall on which it is exerted. Also, a liquid gas separation takes place, the so-called Motility Induced Phase separation, although the interactions are purely repulsive. In his paper, Heiko Rieger demonstrates how a fluid of such active particles confined in a container exhibit out of equilibrium steady currents, responsible for the fluid climbing along the wall of the container, as in the presence of capillary forces.

More recently, a growing interest in the dense phases of active matter has raised the question of the behavior of active solids. As described in the paper by Olivier Dauchot, several original phenomena such as flowing crystals and synchronous oscillations have been observed, but their full understanding remains to be developed. Active solids will certainly play a central role in the development of metamaterials whose active elementary cell will allow local and autonomous actuation. Obvious applications concern robotics and, more generally, the design of functional materials, but also our tissue mechanics and bioengineering.

It has also recently been realized that an important consequence of activity is the possibility of non-reciprocal interactions, *i.e.*, how a given active entity feels about another active entity is not necessarily the same as how the latter feels about the former. As discussed in Ramin Golestanian's paper, colloidal particles and enzymes exhibit such non-reciprocal interactions when they are catalytically active, leading to a wealth of self-assembly scenarios and new exotic phases of active matter.

Fundamentally, active matter is the place where symmetries and conservation laws, such as time-reversal invariance, Galilean invariance, conservation of momentum, action-reaction principle, that characterize conventional physics, are easily broken or violated. An important next step is to formulate a model-independent statistical physics of such systems. As discussed in the paper by Etienne Fodor, the development of general thermodynamics, *i.e.* the elaboration of the relations between information, work and heat in active systems, is definitely necessary to control active systems, to formulate design rules for active machines, or to develop a predictive theory for biological organizations and functions.

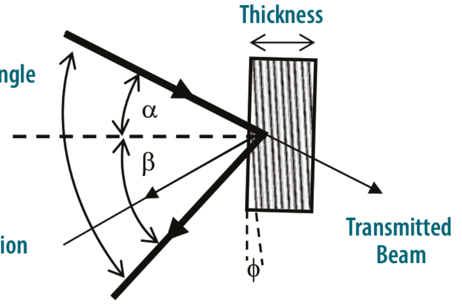
In addition to these important theoretical developments, there are also promising experimental avenues. The increasing mastery of the elementary components of living matter, from DNA, enzymes and proteins to cells, together with the mechanical miniaturization, lead us to anticipate a hybridization between artificial active matter and living active matter, towards a bionic, active and programmable matter with unprecedented possibilities.

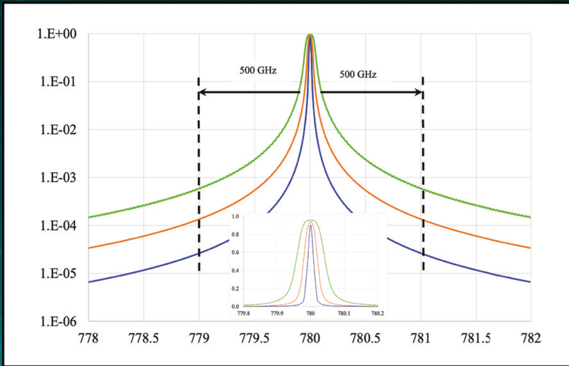
More generally, the study of active matter has shed new, transdisciplinary light on all fields where the question of collective dynamics, unconstrained by the laws of thermodynamic equilibrium, arises. This is, of course, the case in animal dynamics, but also in population dynamics, swarm robotics, cognitive and social dynamics, *etc.* The implications for these disciplines are certainly numerous but difficult to predict. ■

Volume Bragg Gratings (VBGs) for
Quantum Optics

Available wavelength range: 600-2500 nm
Standard Wavelengths: 780; 795; 852; 894 nm
Standard Bandwidths: 10; 25; 50 GHz
Diffraction Efficiency: > 95%
Unmatched side-lobes suppression: > 50 dB

Parameters of 25-GHz Filter:
Spectral Bandwidth: <25 GHz;
Efficiency: >92%;
Attenuation: > 30 dB at >150 GHz shift



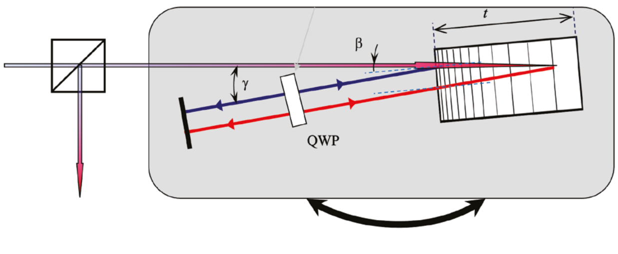


Spectral Shape of Reflecting VBG Filters with Bandwidth:
10 GHz; 25 GHz and 50 GHz

Chirped Bragg Gratings (CBGs) for
Qubit Control

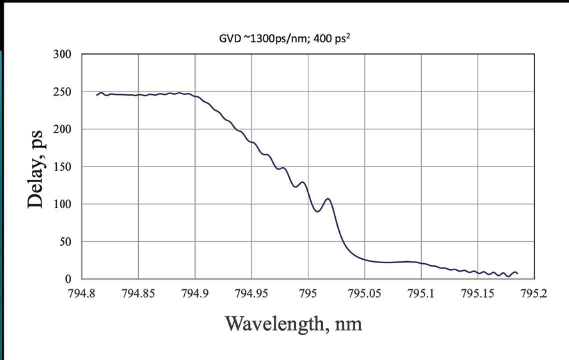
Extremely Large Dispersion 800 ps^2 enables effective and fast amplitude modulation

Spectral Range: 530-2500 nm; High Efficiency> 95%; Wavelength Tunable



Schematic Diagram of CBG deployment for Qubit Filtering and Control

Group delay dispersion of Chirped Bragg grating (CBG)



PTR glass based highly dispersive CBGs enabled passively stable, efficient, method of fast amplitude modulation compatible for high power laser sources. *[H. Levine at al. "Dispersive optical systems for scalable Raman driving of hyperfine Qubits," Phys. Rev. A 105, 032618 (2022)]*

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