Momentum alignment of photoexcited carriers in low-dimensional Dirac materials

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Devices made from conventional semiconducting materials manipulate electron flow based on their charge or spin (spintronics), the later offers the promise to revolutionize the way we do computing. In graphene and graphene-like materials, there is an alternative electron property which can be harnessed for device applications: the so-called valley degree of freedom, which could be utilized in an analogous manner to spin in spintronics and has been suggested as a basis for carrying information in graphene-based devices. The ability to control the valley degree of freedom practically is still an outstanding problem. We have proposed a new method of control, using linearly polarized light, to open the door to optovalleytronics.

One of graphene's most widely known optical properties is its universal absorption, defined through the fine-structure constant, which holds true across a broad range of frequencies from the sub-infrared into the visible. A lesser-known feature is that linearly polarized light creates a strongly anisotropic distribution of photoexcited carriers with their momenta predominantly aligned normally to the polarization plane [1]. We show how this momentum alignment effect together with graphene's spectrum anisotropy (trigonal warping) at high energies can be utilized for the spatial separation of carriers belonging to different valleys in graphene and gapped graphene-like materials. The optical control of valley polarization in gapped 2D Dirac materials such as phosphorene and single-layer transition metal dichalcogenides can also be achieved via a well-known effect of using circularly polarized light. In gapped materials, the optical selection rules associated with linearly polarized light of near-band-gap energies are valley-independent, in stark contrast to the valley-dependent optical selection rules associated with circularly polarized light. This valley dependence of the circularly-polarized transitions can be utilized to measure the degree of valley polarization induced by linearly polarized light of high (well above the band gap) energies, by analyzing the degree of circularly polarization of the band-edge luminescence at different sides of the light spot.

The celebrated Rashba effect, caused by substrate-induced system asymmetry, leads to a strong anisotropy in the low-energy part of the spectrum (near the Dirac cone apex in graphene). This results in optical valley separation by a linearly-polarized excitation at much lower frequencies compared to the high-energy trigonal warping regime discussed above. Accounting for the Rashba term shows that it is possible to control valley and spin spatial distributions using linearly-polarized photoexcitation of both low and high frequencies.

The momentum alignment phenomenon also explains the effect of the giant enhancement of the band gap edge interband optical transition rate in narrow-gap carbon nanotubes and graphene nanoribbons which occurs in the terahertz frequency range [2], thus opening a route for creating novel terahertz radiation emitters.

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References

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