Additive-Free MXene Liquid Crystals for Highly Conductive Fibres

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Abstract
Liquid crystals (LCs) are thermodynamically stable mesophases that exhibit both liquid-like fluidity and crystal-like order. The development of LC phases in materials provides an opportunity to achieve highly ordered structural characteristics, which are highly desirable for fibre-based applications. For instance, LC dispersions of carbon nanotubes [1] and graphene oxide [2] could be spun into strong and conductive fibres for applications in flexible and wearable devices. Consequently, imparting LC behaviour to highly conductive and electrochemically active nanomaterials can provide a platform for the development of next-generation fibres through macroscopic assembly of highly ordered structures. Two-dimensional nanosheets of transition metal carbides and nitrides, known as MXene ($M_{n+1}X_n$ – M: transition metal, X: carbon and/or nitrogen, n: 1-4) [3], offer an outstanding electrical conductivity of up to ~15,000 S cm^{-1} (on a par with metals) [4] and a high specific capacitance of up to ~1,500 F cm^{-3} (>10 times higher than activated carbon used in commercial supercapacitors) [5]. MXene has been found suitable for a wide range of devices such as supercapacitors, batteries, sensors, antennas, electromagnetic interference shields, and neural interfaces. Here, by carefully tuning the aspect ratio of the MXene flakes and the concentration, additive-free Ti_3C_2 MXene dispersions are developed that exhibit nematic LC phases [6]. The presence of the nematic LC phase in MXene dispersions is confirmed by the emergence of birefringence observed under polarised optical microscopy. The LC MXene formulations are then spun into pure MXene fibres using a wet-spinning technique which involves extruding the aqueous LC MXene formulations into a coagulation bath. By carefully tuning the coagulation rate, Ti_3C_2 MXene fibres are developed with a high electrical conductivity of up to ~7,750 S cm^{-1}, which is two orders of magnitude higher than the electrical conductivity of the LC graphene oxide-assisted MXene composite fibres developed before [7]. Moreover, when used as supercapacitor electrodes, the pure Ti_3C_2 MXene fibres exhibit a remarkable volumetric capacitance of ~1,270 F cm^{-3} at the scan rate of 10 mV s^{-1}, comparable to the freestanding MXene film electrodes. This simple method is extended to other members of the MXene family such as Ti_2C and $Mo_2Ti_2C_3$. LC MXene fibres provide a novel platform to investigate MXene's potential applications as energy storage electrodes in functional fabrics and heating elements in thermal comfort fabrics since they offer excellent electrical and electrochemical properties, surpassing other nanomaterial-based fibres. With application as electrical conductors, Joule heaters, and electrodes for energy storage devices, MXene fibres have accelerated the development of textile-based electronics that could be worn like everyday clothes.

References

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