

On the prospect of bioelectronics and biosensors with the novel topological phases of matter

Abstract

Herein, the application capabilities of novel topological phases of matter in the field of bioelectronics and biosensors are assessed. Topological insulators could enable a novel generation of biosensors, exploiting the reduction of the low-frequency noise arising from the suppressed backscattering. Case-study examples of biosensors based on bismuth chalcogenides are discussed.

Keywords: topological insulators, biosensors, bioelectronics, low-frequency noise

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Opinion

Biosensors are devices of great importance for medical diagnostics, therapy monitoring, environmental science, biotechnology etc. The recent achievements in this fields are based on research on (i) materials and (ii) optimization of processes. By adopting standard solutions, further noteworthy advancement is unfeasible. Conversely, unexplored materials could provide interesting perspectives. The isolation of graphene in 2004 has paved the way for disruptive technologies based on two-dimensional materials.^{1,2} However, the absence of a band gap in graphene³ impedes the achievement of a good ON/OFF ratio in nanodevices.⁴ Following graphene, other two-dimensional van der Waals semiconductors, combining finite band gaps^{5,6} and flexibility^{7,8} are emerging in recent years as the most promising materials for nanoelectronics.^{4,9} Topological insulators (TIs) are a class of innovative materials, whose physical properties have enormous potential for technological applications.¹⁰

TIs represent unique phases of matter with semiconducting bulk and conducting edge or surface states, immune to small perturbations, such as backscattering due to disorder. This stems from their peculiar band structure, which provides topological protection. Moreover, electron spin and momentum in topologically protected states are locked, thus enabling (i) the control of electron flow and (ii) the reduction of low-frequency noise in TI-based electronic devices.¹¹ As a matter of fact, the suppression of the backscattering of spin-polarized charge carriers of surface states, with the subsequent suppression of the fluctuation of mobility of surface-state charge carriers, could reduce electronic noise, so as to lower the detection limits of sensors below those already reported.¹¹

Despite great interest from the scientific community, the huge potential of TIs for technological applications has been just started to be exploited.¹² Recent works report superb performance in TI-based nanodevices,¹³ also thanks to the progress in the control of single-crystal quality during the TI growth process. Among TIs, layered bismuth chalcogenides have attracted much attention since they can be easily grown by Bridgman-Stockbarger method and, moreover, since they show TI properties at room temperature.¹³

The discovery of the unique properties of TIs, such as fast electron transportation,¹⁴ high thermal conductivity,¹⁵ good biocompatibility,¹⁶

can give rise to a new generation of biosensors based on TIs. Glucose sensors based on Bi₂Se₃ have been developed by exploiting the high electrochemical catalytic activity of Bi₂Se₃ for the reduction of dissolved O₂.¹⁷ Likewise, prussian blue/Bi₂Se₃ hybrid films with immobilized glucose oxidase have been used to fabricate an amperometric glucose biosensor.¹⁸ The detection limit was estimated for 3.8 μM defined from a signal/noise of 3. The resulting biosensor was tested to detect the blood sugar in human serum samples.¹⁸

Recently, an effective colorimetric biosensor based on highly catalytic active Au nanoparticle-decorated Bi₂Se₃ has been fabricated.¹⁹ The low redox potential of Bi₂Se₃ and its TI properties enable providing and accumulating electrons at the surface. Such unique properties contribute to strong synergistic catalytic effects with gold nanoparticles. The outstanding catalytic activity of Au/Bi₂Se₃ nanosheets can be “switched off” upon treatment of antibody of cancer biomarker such as anticarcinoembryonic antibody (anti-CEA). Adding the corresponding antigen such as cancer biomarker carcinoembryonic antibody (CEA) can sequentially favour “switch on” the catalytic activity of Au/Bi₂Se₃. The system can be thus used as a colorimetric sensor for detection of a particular cancer biomarker with high sensitivity and selectivity for the cancer biomarker, even for a concentration as low as 160 pg/mL for CEA. The devised colorimetric sensor shows good generality for detecting different kinds of cancer biomarkers, such as α -fetoprotein (AFP) and prostate-specific antigen (PSA). Moreover, the devised biosensor is efficient for detection of CEA, thus providing an alternative technique in cancer diagnosis.

Conclusion

In conclusion, bioelectronics and biosensors based on TIs are just at their infancy, in spite of their high potential. However, the creation of new disruptive technologies based on TIs is conditional to reaching a variety of objectives and overcoming several challenges

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Conflict of interest

The author declares no conflict of interest.

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