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## Review

## Surface transfer doping of semiconductors

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## ABSTRACT

Surface transfer doping relies on charge separation at interfaces, and represents a valuable tool for the controlled and nondestructive doping of nanostructured materials or organic semiconductors at the nanometer-scale. It cannot be easily achieved by the conventional implantation process with energetic ions. Surface transfer doping can effectively dope semiconductors and nanostructures at relatively low cost, thereby facilitating the development of organic and nanoelectronics. The aim of this review is to highlight recent advances of surface transfer doping of semiconductors. Special focus is given to the effective doping of diamond, epitaxial graphene thermally grown on SiC, and organic semiconductors. The doping mechanism of various semiconductors and their possible applications in nanoelectronic devices will be discussed, including the interfacial charge transfer and the energy level alignment mechanisms.

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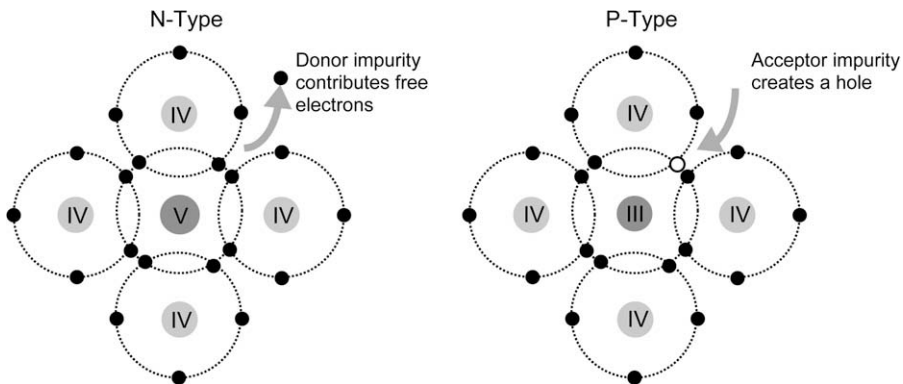
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## 1. Introduction to surface transfer doping

Doping of semiconductors is the process of locally manipulating their charge carrier density and conductivity, and it represents a key technology for semiconductor-based electronic devices [1]. Conventional doping is usually achieved via the bombardment of semiconductors with energetic ions (the dopants) followed by thermal annealing; this is referred to as ion implantation. This doping process has been very successful in silicon technology in the past a few decades. It allows external impurity atoms (dopants) with appropriate properties to be incorporated into the host lattice of the semiconductor. Depending on their number of valence electrons, the dopants (as donors) can either donate excess electrons as negative free charge carriers to the semiconductor conduction band at moderate temperature (*n*-type doping), or they (as acceptors) can accept additional electrons from surrounding atoms to complete the covalent chemical bonding, leaving positively charged holes as charge carriers in the semiconductor valence band (*p*-type doping). This phenomenon is shown schematically in Fig. 1.1 for a group-IV elemental semiconductor. With the realization of both *n* and *p* type doping of semiconductors, the most basic architecture in semiconductor devices, the *p*-*n* junction, could be built.

The increasingly stringent requirements of microelectronics device minimization down to the molecular regime require the fabrication of well-defined nanostructures with controllable and reproducible nano-scale doping. However, it is difficult to achieve a doping range and abruptness down to



**Fig. 1.1.** Schematic bond diagram for *n*-type doping of group-IV elemental semiconductor (Si, C, Ge, Sn) with group-V elements (N, P, As etc.) as dopants, and for *p*-type doping with group-III elements (B, Al, Ga etc.).

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