n **-TYPE AND** ***p*** **-TYPE MATERIALS**

A semiconductor material that has been subjected to the doping process is called an extrinsic material.

There are two extrinsic materials of immeasureable importance to semiconductor device fabrication: n -type and p -type materials.

n **-Type Material**

Both *n* -type and *p* -type materials are formed by adding a predetermined number of impurity atoms to a silicon base. An *n* -type material is created by introducing impurity elements that have *five* valence electrons (*pentavalent*), such as *antimony* , *arsenic* , and *phosphorus.* Each is a member of a subset group of elements in the Periodic Table of Elements referred to as Group V because each has five valence electrons. The effect of such impurity elements is indicated in Fig. 1.7 (using antimony as the impurity in a silicon base).

Diffused impurities with five valence electrons are called donor atoms.

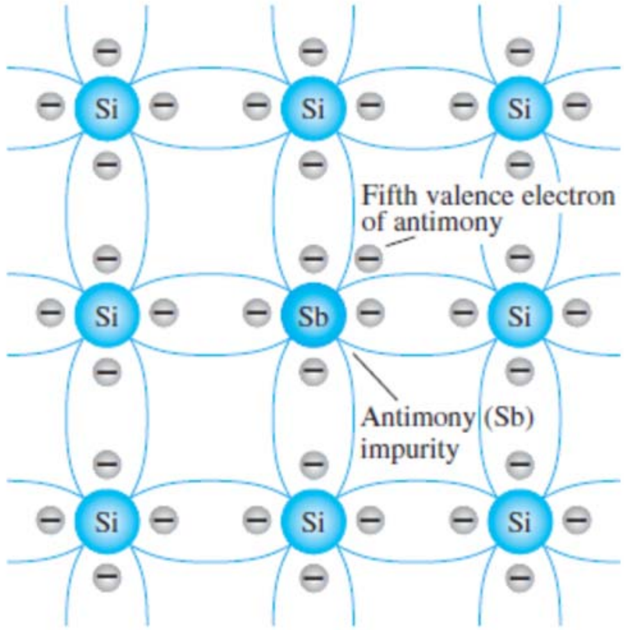

FIG. 1.7
Antimony impurity in n-type material.

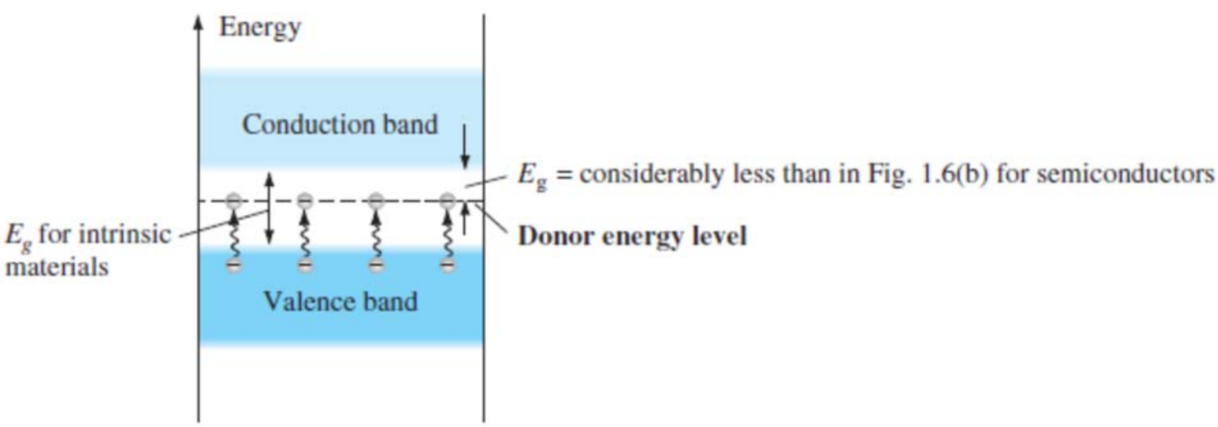

FIG. 1.8
Effect of donor impurities on the energy band structure.

p -Type Material

The p -type material is formed by doping a pure germanium or silicon crystal with impurity atoms having three valence electrons. The elements most frequently used for this purpose are boron , g allium , and indium . Each is a member of a subset group of elements in the PeriodicTable of Elements referred to as Group III because each has three valence electrons.The effect of one of these elements, boron, on a base of silicon is indicated in Fig. 1.9 .

Note that there is now an insufficient number of electrons to complete the covalent bonds of the newly formed lattice. The resulting vacancy is called a hole and is represented by a small circle or a plus sign, indicating the absence of a negative charge. Since the resulting vacancy will readily accept a free electron:

The diffused impurities with three valence electrons are called acceptor atoms.

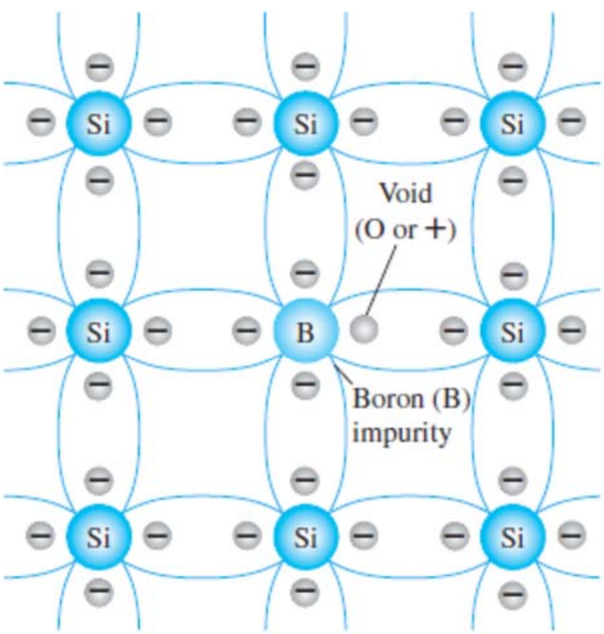

FIG. 1.9
Boron impurity in p-type material.

Majority and Minority Carriers

In the intrinsic state, the number of free electrons in Ge or Si is due only to those few electrons in the valence band that have acquired sufficient energy from thermal or light sources to break the covalent bond or to the few impurities that could not be removed. The vacancies left behind in the covalent bonding structure represent our very limited supply of holes. In an *n* -type material, the number of holes has not changed significantly from this intrinsic level. The net result, therefore, is that the number of electrons far outweighs the number of holes. For this reason:

In an n-type material (Fig. 1.11a) the electron is called the majority carrier and the hole the minority carrier.

For the *p* -type material the number of holes far outweighs the number of electrons, as shown in Fig. 1.11b . Therefore:

In a p-type material the hole is the majority carrier and the electron is the minority carrier.

When the fifth electron of a donor atom leaves the parent atom, the atom remaining acquires a net positive charge: hence the plus sign in the donor-ion representation. For similar reasons, the minus sign appears in the acceptor ion.

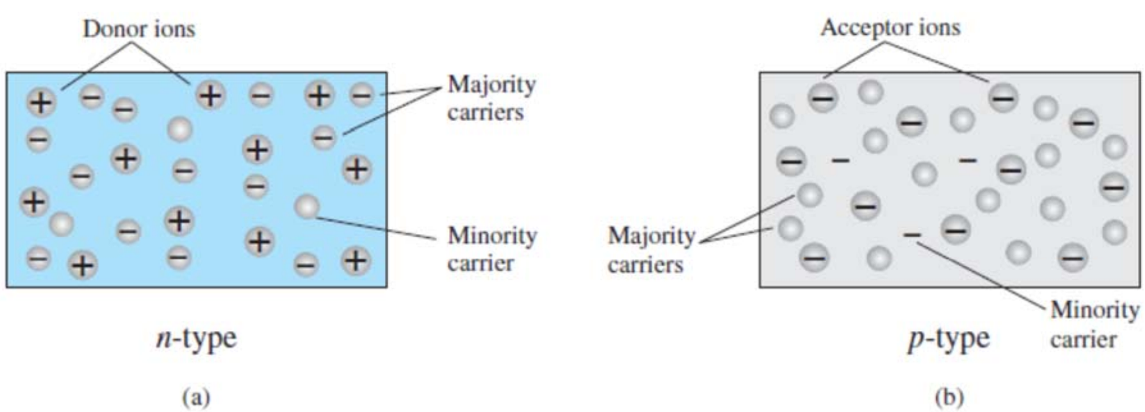

FIG. 1.11
(a) n-type material; (b) p-type material.