

BRITISH STANDARD CODE OF PRACTICE

CP 1016: Part 1: 1968

Confirmed August 1980

THE USE OF SEMICONDUCTOR DEVICES

Part 1. General considerations

**THE COUNCIL FOR CODES OF PRACTICE
BRITISH STANDARDS INSTITUTION**

UDC 621.382.2/.3

BRITISH STANDARD CODE OF PRACTICE

CP 1016 : Part 1 : 1968

THE USE OF SEMICONDUCTOR DEVICES

Part 1. General considerations

THE COUNCIL FOR CODES OF PRACTICE

BRITISH STANDARDS INSTITUTION

British Standards House, 2 Park Street, London, W.1

CP 1016 : Part 1 : 1968

THE USE OF SEMICONDUCTOR DEVICES

This Code of Practice has been prepared by a committee convened by the Codes of Practice Committee for Electrical Engineering. It has been approved by the Council for Codes of Practice and was published under the authority of the General Council on 14 November, 1968.

SBN: 580 00365 5

This Code makes reference to the following British Standards:

- BS 204. Glossary of terms used in telecommunication (including radio) and electronics.
- BS 441. Rosin-cored solder wire, 'activated' and 'non-activated' (non-corrosive).
- BS 3494. Recommendations on semiconductor devices. Part 1. Essential electrical and mechanical ratings and characteristics.
- BS 3771. Recommendations on semiconductor rectifier diodes (mono-crystalline).
- BS 3896. Recommendations on reverse blocking triode thyristors.
- BS 3934. Dimensions of semiconductor devices.
- CP 1006. General aspects of radio interference suppression.

The following BSI references relate to the work on this Code of Practice:

Committee reference ELCP/29
Draft for comment 67/10852

CODE DRAFTING COMMITTEE ELCP/29

DIODES, TRANSISTORS AND RELATED SEMICONDUCTOR
DEVICESMr. E. L. Jones—*Chairman**Nominated by:**British Electrical and Allied
Manufacturers' Association
Electronic Engineering Association
Electronic Valve and Semiconductor
Manufacturers' Association**Institution of Electrical Engineers**Institution of Electronic and Radio
Engineers**Ministry of Defence (Naval Department)**Post Office**Radio and Electronic Component
Manufacturers' Association**Scientific Instrument Manufacturers
Association**Society of British Aerospace Companies**Telecommunication Engineering and
Manufacturing Association**United Kingdom Atomic Energy Authority*

Dr. J. Shields }
Mr. J. M. Woodgate }
Mr. K. Sims
Mr. P. A. Fleming

The Chairman of the }
Electronics Division }
Mr. G. Hennessey

Mr. J. J. Limb
Mr. J. H. Combridge
*Mr. E. L. Jones

Mr. S. N. Pocock

Mr. H. K. Winwood
*Mr. E. L. Jones

Mr. S. L. Skinner

*Nominated by more than one organization.

CONTENTS

	Page
Foreword	6
SECTION 1. INTRODUCTION	
1.1 Scope	6
SECTION 2. CONSIDERATIONS APPLICABLE TO ALL SEMICONDUCTOR DEVICES	
2.1 General electrical considerations	6
2.1.1 Basic semiconductor properties	6
2.1.1.1 Types of semiconductor material	6
2.1.1.2 Modification of conductivity	7
2.1.1.3 Semiconductor junctions	8
2.1.1.4 Basic junction static characteristics	9
2.1.1.5 Junction capacitance	10
2.1.1.6 Charge storage	10
2.1.1.7 Junction breakdown	11
2.1.2 Published data	12
2.1.3 Electrical design	12
2.1.3.1 'Worst-case' design	14
2.1.3.2 'Worst-probable case' design	14
2.1.3.3 Variations of characteristics with temperature	15
2.1.3.4 Variations of characteristics with life	16
2.1.3.5 Observance of ratings: derating	16
2.1.3.6 Series and parallel operation	18
2.1.3.7 Matching	19
2.1.3.8 Interference and spurious signals	20
2.1.3.9 Effects of overdrive and underdrive	20
2.1.3.10 Conditions not envisaged by the device manufacturer	21
2.1.3.11 Design considerations with regard to the setting-up and adjustment of equipment	21
2.2 General mechanical considerations	22
2.2.1 Soldering and welding	22
2.2.2 Leads and seals	23
2.2.3 Mounting conditions	23

CONTENTS (*continued*)

2.2.4	Stud-mounted devices	23
2.2.5	Flat-base devices	24
2.2.6	Shrinkage of insulating material	24
2.2.7	Encapsulation of assemblies	24
2.3	General thermal considerations	25
2.3.1	Ambient ratings	25
2.3.2	Case ratings	25
2.3.3	Precautions in mounting devices on heat sinks	25
2.3.4	Special precautions for devices con- nected in parallel (or series)	26
2.3.5	Coolant failure	26
2.3.6	Thermal effects in encapsulated assemblies	26
2.4	General environmental and installation considerations	26
2.4.1	Effects of atmosphere	26
2.4.2	Effects of visible, ultra-violet and infra- red radiation	27
2.4.3	Effects of high-energy radiation	27
2.4.4	Effects of vibration and shock	27
2.4.5	Environmental derating	27
2.4.6	Storage and transport	28
2.5	Precautions during assembly of equipment	28
2.5.1	Leads	28
2.5.2	Cooling fins	28
2.5.3	Soldering	28
2.5.4	Cleaning	29
2.5.5	Surface damage	30
2.5.6	Magnetic fields	30
2.5.7	'Live' cases	30
2.6	Precautions during setting-up, adjustment, operation and maintenance of equipment	30
2.7	Precautions during testing of devices	31

This Code of Practice represents a standard of good practice and therefore takes the form of recommendations. Compliance with it does not confer immunity from relevant statutory and legal requirements.

BRITISH STANDARD CODE OF PRACTICE ON THE USE OF SEMICONDUCTOR DEVICES

Part 1. General considerations

FOREWORD

In this Part, only the general considerations applying to all semiconductor devices are dealt with, but in due course it is intended to publish additional parts each dealing with the particular considerations applying to specific groups of or types of semiconductor device.

SECTION 1. INTRODUCTION

1.1 SCOPE

This Code of Practice is intended to give guidance to all concerned with the design, construction, use or maintenance of equipment using diodes, transistors, semiconductor integrated circuits or other similar devices so that optimum performance and life may be secured. The approach adopted is primarily practical. The treatment is self-contained as far as is possible but some cross-references are given to sources of further information than is practicable to include in the Code.

SECTION 2. CONSIDERATIONS APPLICABLE TO ALL SEMI-CONDUCTOR DEVICES

2.1 GENERAL ELECTRICAL CONSIDERATIONS

Certain general electrical considerations are fundamental to the proper application of all semiconductor devices if satisfactory initial performance and satisfactory life are to be ensured. Their relative importance may vary widely from one case to another.

2.1.1 Basic semiconductor properties. The following brief outline of semiconductor properties is given as an aid to understanding the reasons for the various recommendations that follow, so that the recommendations may be applied intelligently rather than blindly.

2.1.1.1 Types of semiconductor material. In 'n-type' semiconductor material, conductivity is predominantly due to the movement of 'free' electrons which carry negative charges in the opposite direction to the conventional current. In 'p-type' semiconductor material, conductivity is predominantly due to the movement of 'holes' (places where an electron is missing from the crystal structure) which carry positive charges in the same direction as the conventional current. The 'motion' of a hole actually involves successive motions of structural electrons in the opposite direction, each such motion destroying the original hole and creating a new one, but for present purposes it is sufficient to regard any hole simply as a mobile positive charge.

In 'intrinsic' (pure) semiconductor material, conductivity is due to nearly equal contributions from (free) electrons and holes which are present in equal

numbers. The electrons contribute somewhat more than half the total conductivity because they are about twice as mobile as the holes.

For convenience of description, both free electrons and holes are referred to as 'carriers'. In n-type material the electrons are present in greater numbers and are therefore called 'majority' carriers, while any holes present are called 'minority' carriers. In p-type material, on the other hand, the more numerous holes are majority carriers and the electrons are minority carriers.

Ideally pure semiconductor material has only its intrinsic conductivity. The introduction of a very small proportion of 'impurity' atoms (normally too small a proportion to be detected spectroscopically) can make it either n-type or p-type, as required, increasing the conductivity by many orders of magnitude. Impurity atoms causing n-type conductivity are called 'donors' and those causing p-type conductivity are called 'acceptors'. Where impurities of both kinds are present, the conductivity-type of the material is controlled by the difference in their effective concentrations.

2.1.1.2 Modification of conductivity. The conductivity of any specimen of semiconductor material may be raised by increasing the number of carriers. The rise in conductivity is only temporary; when the cause of the increase ceases, the number of carriers present (and thus also the conductivity) decays towards its original equilibrium value in a manner characteristic of the particular specimen and conditions.

Means of increasing the number of carriers fall into two groups. The first group includes:

- (1) the effects of electromagnetic radiation (visible or invisible).
- (2) the effects of increased temperature.
- (3) the direct effects of high electric field strength (within a poorly conducting semiconductor).
- (4) the effects of collisions of existing carriers with the crystal structure when the carriers have attained enough energy from an accelerating electric field.
- (5) some other less commonly used effects.

In all these cases 'excess' carriers are generated in pairs, one hole for each electron, and the material as a whole remains substantially neutral electrically. (Except in the immediate vicinity of junctions or other boundaries, the net charge densities associated with normal semiconductor operating conditions are very small compared with the total charge densities of opposite signs present in the crystal structure.) The second group contains basically only one type of process: that of introducing carriers of a single type at a boundary of the semiconductor region in question—normally at its junction with a metallic contact or with another semiconductor region of opposite conductivity type. In this case substantial neutrality is maintained by a redistribution of the carriers of the opposite type already existing in the material, the necessary

charge being supplied eventually from some other point of connection to the region in question.

The conductivity of n-type or p-type semiconductor material may be locally decreased by the application of an electric field that drives the majority carriers (electrons for n-type, holes for p-type) out of the region near the surface or interface (junction) at which the field is applied. This forms a 'depletion layer' of material almost free from carriers; this layer has a high resistivity like that of intrinsic material. The space-charge associated with the field is provided by the fixed ionised impurity atoms, whose charges are normally neutralized by those of the carriers now expelled.

Inside the bulk of any given semiconductor material in equilibrium at any given temperature, the product of the free-electron density and the hole density is a constant. In n-type or p-type material the number of carriers of one kind greatly exceeds that of the other; the total net charge of the carriers is neutralized by the opposite total charge on the fixed ionised impurity atoms. When excess carriers are introduced, as described above, and the source of excess carriers is suddenly removed, the number of carriers present decays back to normal approximately exponentially as pairs of carriers of opposite sign mutually annihilate one another with release of energy (usually to the crystal lattice, though sometimes as radiation). The time-constant of the decay (usually referred to the minority or less-numerous carriers only) is called the 'life-time' of the carriers. The life-time is very sensitive to the presence of imperfections and impurities (deliberate or otherwise) in the crystal structure. Since there is very little electric field within the bulk of a semiconductor under normal operating conditions, the movement of the excess carriers during their life-time is predominately a random diffusion process. During their life-time, carriers may diffuse distances large compared with the essential dimension (thickness of the base-region) of a transistor; thus carriers injected at one (forward-biased, 'emitter') junction can increase the conductivity at a second (reverse-biased, 'collector') junction nearby. This is the basis of conventional transistor action.

2.1.1.3 Semiconductor junctions. An interface between n-type and p-type regions within a single crystal of semiconductor material is known as a 'junction'. (The proportion of deliberately introduced impurities is normally so small that it does not seriously disturb the regularity of the crystal structure, which is thus continuous across the junction.)

Junctions are usually formed by taking semiconductor material of one conductivity type and then introducing an appropriate impurity in sufficient amount to give the material the opposite conductivity type within a defined region. The impurity may be introduced in several ways, of which the commonest are 'alloying' and 'diffusion'. In alloying, the prepared crystal is locally melted in contact with the impurity and then allowed to recrystallize.

In diffusion, the prepared crystal is not melted, but the impurity is allowed to diffuse into it from the surface for a controlled time at a high temperature. Other methods are sometimes used.

While the fundamental electrical characteristics of all types of junction are similar, certain detailed properties depend on the method of manufacture. Among these are the variation of junction capacitance with voltage and the forward-conduction characteristic at very low and very high current densities.

Where a semiconductor device involves several junctions, they are sometimes made by different processes.

2.1.1.4 Basic junction static characteristics. A junction between n-type and p-type semiconductor material has an asymmetric voltage/current characteristic; for moderate voltage (V) and current (I) the relation is approximately

$$I \simeq A [\exp(BV) - 1]$$

the 'constants' A and B depending on temperature and also varying slightly with V . At moderate 'forward' currents

$$I \simeq A \exp (BV)$$

For most devices (but not all), $B \simeq 35$ to 40 at room temperature, so that the current increases by a factor of ten for a voltage rise of about 60 mV. For a given current, $dV/dT \simeq - (2 \text{ to } 2.5) \text{ mV/degC}$ in this region. At higher forward currents the effect of unavoidable series resistance modifies the characteristic; additionally, the value of that part of this resistance that lies in the bulk of the semiconductor tends to fall with increase of current ('conductivity modulation'), and this further modifies the observed characteristic. In the 'reverse' direction the current 'saturates' at a small fraction of a volt and remains substantially constant up to the voltage at which carrier multiplication mechanisms become significant—usually at least half the breakdown voltage of the junction. The saturation current is an approximately exponential function of temperature, usually doubling for a temperature rise of between 8 and 12 degC. At and below room temperature, and particularly with silicon devices where the junction saturation current is low, the behaviour is often complicated in practice by leakage currents, whose dependence on voltage and temperature may be different from that of the saturation current. These leakage currents are often associated with the surface of the device and may vary considerably.

Although the values of the constants in the above relations can be predicted the values deduced from simple theory are not always realised in practice because simple theory ignores many significant details, some of which are very dependent on device structure. The figures given represent good generalizations of current practical values but the device manufacturer's information should be used wherever possible in critical work.

The numerical values of the static characteristics of a junction depend