Preface

One form of avalanche breakdown has been known to mankind from ancient times: lightning, the terrifying gas discharge, the fear of which is inscribed in the tales and myths of all primitive tribes.

The first known practical application of the avalanche breakdown principle goes back to the first century of our era. There is a fish in the Mediterranean, the electric ray, or skate, which was called "*narcae*" by the ancient Greeks, a word which means "paralyzing". It is known nowadays that the voltage generated by this fish can reach 200 Volts. The Roman physician Scribonius, in his famous writing "De Compositiones Medicamentorum", published in AD 40, described the using of this *narcae* for the treatment of headaches, gout and some other diseases. The treatment was rather painful. This may be the reason why the term "breakdown" is associated very often with such unpleasant concepts as "failure" and "destruction".

Electrical breakdown itself is not connected with any form of destruction, however. One widely used microwave device, the IMPATT diode, for example, has a characteristic operation frequency of about 100 GHz (10^{11} Hz), which means that it goes into a mature avalanche breakdown regime 10^{11} times a second. Since the guaranteed lifetime of a commercial IMPATT diode is at least 5000 hours, each diode will go into this regime safely no less than $\sim 3 \times 10^{18}$ times. Moreover, impact ionization, avalanche and breakdown phenomena form the basis of many very interesting and very important semiconductor devices, such as avalanche photodiodes, avalanche transistors, suppressors, sharpening diodes (diodes with delayed breakdown), and IMPATT and TRAPATT diodes.

We should note at the same time that avalanche phenomena are always associated with high electric fields F, and that the optimal regimes of many devices can be realised only at high current densities j. Thus the power density $P_0 = j \times F$ can be extremely large. The value of the characteristic breakdown field F_i for a silicon IMPATT diode with an operation frequency of about 100 GHz, for example, is about 5×10^5 V/cm, its characteristic current density j is approximately 10^5 A/cm^2, and P_0 is about 5×10^{10} W/cm^3. As a result, the breakdown phenomena are often accompanied by a high temperature. It is probable, of course, that if the temperature is too high, the device may be destroyed due to melting or decomposition of the material of which it is constructed. This is *not an electric breakdown as such, but only "overheating", ("heat breakdown") causes the device destruction.*

It worth noting that operation in high electric fields is the backbone of modern semiconductor electronics. Indeed, the mainstream of the modern electronics lies in increasing the operation frequency and velocity of semiconductor device "switching". Both the operation frequency and the velocity of switching are inversely proportional to the length of the "active region" of the device, L. For the most important devices used in semiconductor electronics, Field Effect Transistors (FETs) and Bipolar Transistors (BJTs), the characteristic length of the active region (gate or base) is about 0.1 μm. With a standard operation bias V_0 of about 1 V, the average value of the electric field F_0 across the active region of the device is approximately 10^5 V/cm, which means that the maximal value of the electric field in the active region can be as large as (2-3)$\times 10^5$ V/cm, i.e. practically equal to the characteristic breakdown field F_i. Generally speaking, in order to provide maximal speed and maximal power, many semiconductor devices must operate either under breakdown conditions or very close to these. Consequently, an acquaintance with breakdown phenomena is very important and useful for any scientist or engineer dealing with semiconductor devices.

Many books contain chapters or sections devoted to the principal features of the avalanche and breakdown phenomena, and there are many good books and outstanding reviews concerning certain special aspects of these phenomena. The aim of this book is to summarize the main experimental results on avalanche and breakdown phenomena in semiconductors and semiconductor devices and to analyse them from a unified point of view. This book has been written by experimentalists for experimentalists. We will scarcely deal at all with fundamental theoretical aspects such as the distribution function of hot electrons, nuances of the band structure at high energy, etc., but instead we will focus our attention on the phenomenology of avalanche multiplication and the various kinds of breakdown phenomena and their qualitative analysis.

The book is organised as follows. In the introductory chapter (Chapter 1) we will briefly discuss the main definitions and establish the main approaches to describing breakdown phenomena.

Chapter 2 will be devoted to avalanche multiplication phenomena, and the main parameters of avalanche photodiodes will be discussed and analysed on this basis.

In Chapter 3 we will consider the reverse current-voltage characteristic of semiconductor diodes over an extremely wide range of current densities, including prebreakdown leakage current, microplasma breakdown, mature (homogeneous) breakdown, the part of the current-voltage characteristic with negative differential resistance at very high current densities, and the second part with positive differential resistance. The operation regimes and main characteristics of two important devices: suppressor diodes and IMPATT diodes, will be also observed in this chapter.

The phenomenon of avalanche injection will be discussed in Chapter 4 for samples of the $n^+ - n - n^+$ and $p^+ - p - p^+$ types and for bipolar transistors. The operation of Si avalanche transistors will be analysed for both a conventional regime and a very effective, fast operation regime realised at extremely high current densities (Section 4.4). In Section 4.5 we will discuss the recently discovered effect of extremely fast switching of GaAs avalanche transistors at high current densities.

The phenomena of so called "dynamic breakdown" will be analysed in Chapter 5. This regime is realized under conditions in which the avalanche ionization front moves along the samples with a velocity which is higher than the saturated velocity of free carriers (the TRAPATT zone or streamer). The operation regimes of Silicon Avalanche Sharpers (SAS) and Diodes with Delayed Breakdown (DDB) will be considered in this chapter.

The main ideas of the book will be summarised in the Conclusion.

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We will greatly appreciate any comments and suggestions which can be e-mailed to

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