INVESTIGATION OF THE NATURE OF THE DOMINANT RECOMBINATION CENTERS ON THE REAL SURFACE OF GERMANIUM *

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A method combining the large-signal sinusoidal field effect and the steady-state photoconductivity was developed for the investigation of the parameters of fast surface states and of surface recombination centers in a wide range of values of the surface potential. This method can be used to investigate the kinetics of changes in these parameters. An experimental investigation was made of the changes in the surface properties of germanium due to exposure to oxygen, ozone, water vapor, and several other liquids, as well as the changes due to heating in vacuum and in various gaseous media. This investigation was used as the basis of a model of surface recombination centers, which was in good agreement with all the results obtained by the present author and with the published data. This model was employed to develop a method for obtaining low and stable values of the surface recombination velocity on germanium.

Introduction

Surface recombination plays an important and sometimes decisive role in the operation of many semiconductor devices. If the geometrical dimensions of a device are less than the diffusion length of the excess carriers, every change in the surface recombination velocity will give rise to a change in the device characteristics and to instability. Investigations of surface recombination have become especially important in recent years in connection with the development of microelectronics. The effect of the surface on the characteristics of microminiature elements is much greater than the influence on conventional semiconductor devices. The stability of the characteristics is essential to the improvement of the reliability of the operation of microminiature elements which are used in exceedingly large numbers in complex electronic circuits.

Investigations of the nature of surface recombination centers should provide technologists and device designers with an opportunity to control the concentration of these centers and thus obtain stable and low values of the surface recombination velocity.

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Studies of the surface recombination processes are not only of practical importance. The surface is a very convenient medium for the investigation of the influence of various impurities and defects on the properties of semiconductors. Simple methods involving changes in the ambient atmosphere or the field effect can be used to alter the position of the surface Fermi level within a wide range of values. In the bulk of a semiconductor such changes in the Fermi level are impossible at a constant temperature and this makes it necessary to investigate batches of many samples.

Moreover, the concentration of recombination impurities such as copper, gold, iron, and nickel cannot be altered in the bulk of a semiconductor during measurements. This complicates studies of these recombination impurities to the extent that considerable progress has been made only in the study of the mechanism of recombination at radiation defects because such defects can be controlled during measurements.

The processes of adsorption and desorption allow us to investigate surface recombination at various impurities by removing some impurities and depositing others and thus investigating the effect of a wide range of different impurities on the same sample. A warning must be added that this ease of deposition of impurities on the surface requires a very careful control of the ambient medium and all stages of the surface treatment.

Investigations are complicated considerably by the presence of a "background" of recombination centers of unknown origin which are introduced during chemical treatments. Therefore, many investigators have prepared atomically clean surfaces and have investigated the influence of the adsorption of various impurities on the properties of such a surface. At first, the purpose of these investigations has been to model the real surface by starting from a clean surface. Investigations of the real surface have been regarded as studies of contaminated conditions. However, it is now clear that clean and real surfaces are independent objects and that investigations of real surfaces are of fundamental interest. On the other hand, although the real surface of a semiconductor carries a considerable concentration of recombination centers of unknown origin, the parameters of these centers are usually fully reproducible and independent of the etching method. This shows that there is nothing accidental in the appearance of these centers. The purpose of the investigation reported in the present paper was to determine the nature of these surface recombination centers.

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CHAPTER I

Electron Processes on the Surface of a Semiconductor

1. Surface States

The special role played by the surface of a semiconductor is due to the presence of surface states which are located in the forbidden band. The electrons in these states are localized