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Theory of ion beam induced charge measurement in semiconductor devices based on the Gunn's theorem

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Abstract

Ion beam induced charge collection (IBIC) is a powerful experimental technique to characterise semiconductor materials and devices. It is based on the measurement of the charge induced in a given electrode by the motion of charge carriers generated by MeV ions.

The problem of IBIC pulse formation is usually solved by the Shockley–Ramo theorem in which charge carriers are moving in presence of an electric field and all the electrodes are maintained at constant potentials. This theoretical model was demonstrated according to basic electrostatic principles and was first applied to evaluate the induced currents in vacuum tubes and then in semiconductor devices even in presence of stationary space charge. However, the basic assumption underlying such theorems is the independence of the space charge distribution on the applied bias voltage. Such a hypothesis is clearly not valid in partially depleted semiconductor devices where the extension of the depletion region depends on the conditions of the boundary electrodes.

We present in this paper a new theoretical approach based on a general expression for electrostatic induction deduced by J.B. Gunn in 1964, which overcomes any limitation on space charge distribution. The resulting simple new formalism reduces to the Ramo–Shockley theorem as a special case. In order to clarify this theoretical approach, some simple IBIC experiments on semiconductor p–n and Schottky diodes are presented and discussed.

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1. Introduction

More than 60 years ago, Shockley [1] and Ramo [2] presented a method given "for computing the instantaneous current induced in neighbouring conductors by a given specified motion of electrons" [2] and applied it to study the induced current in high frequency vacuum tubes.

This theoretical approach, usually named as the "Shockley–Ramo theorem" (SRT) and subsequent extensions [3,4], is based on the reciprocity Green's theorem [5] which defines the mutual relation of potentials and charges in a multielectrode system.

The SRT has been widely applied not only to vacuum tubes but mainly in simulating semiconductor devices. It is the theoretical approach

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