THE MODIFIED KAW'S MODEL
BASED ON RECTANGULAR VOLTAGE PULSES
FOR THE CALCULATION
OF THE CHARGE PUMPING CURRENT IN MIS TRANSISTORS

M. ORGOŇ, J. BREZA, B. PARTYK, Z. SZEDLÁK, R. REDHAMMER

Microelectronics Department, Slovak Technical University,
Ilkovičova 3, 81219 Bratislava, Slovak Republic

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The charge pumping current results from recombination associated with the SiO2-
Si interface traps under the gate of a MISFET when a voltage pulse is applied to the
gate. The modified Kaw's model is proposed which predicts this current as a function of
frequency, amplitude and average voltage of pulses with peak-to-peak amplitudes larger
than the difference between the flatband and inversion voltages and with pulse transitions
fast enough so that negligible capture or emission occurs during the transition. The
presented modification of Kaw's model of the charge pumping effect enables to compute
the dependences of the charge pumping current for various types of MIS transistors with
different dimensions manufactured by different technologies.

1. Introduction

Ageing phenomena in MIS transistors are ever more studied because of their
increasing influence on reliability of small size components. They have been shown
to be due, in a great part, to the degradation of the insulator layer — semiconductor
interface, by generation of new interface traps. Only a few techniques are available
to measure Si-SiO2 interface trap densities directly on MIS transistors: the weak
inversion method, deep level transient spectroscopy, 1/f noise measurements, and
charge pumping measurement. This latter technique appears to be the only one
which can be used for small sized components and can detect surface trap densities
as low as $10^{13} \text{m}^{-2}\text{eV}^{-1}$.

The charge pumping phenomenon was developed by Brugler and Jespers in 1969
[1]. Figure 1 shows their basic setup for the charge pumping experiment. The
source and drain of the transistor under test are connected together and held at
a certain reverse bias voltage $U_R$ with respect to the substrate. A rectangular
pulse train with amplitude $U_G$ and a defined offset voltage level $U_{GO}$ is applied at
the gate of the transistor. When the transistor is pulsed into inversion, electrons
will flow from the source and drain into the channel, where some of them will be
captured by interface traps. When the gate is driving the semiconductor surface
to accumulation, the mobile charges will flow back to the source and drain, but
the charges trapped in the interface traps will recombine with the majority carriers
from the substrate; this flow of charge (d.c. current) is called the charge pumping
current $I_{cp}$. The charge pumping current is directly correlated with the interface
trap density $N_{it}$ and is proportional to the pulse frequency $f$ and gate area $A_G$. 
At larger gate pulse voltages, the charge pumping current $I_{cp}$ saturates (Fig. 2) and the interface trap density $N_{it}$ is determined from this value of current $I_{cp}$ by the following equation [1]:

$$I_{cp} = qfA_GN_{it},$$

where $q$ is the electronic charge.

2. Models of the charge pumping effect

In the modelling of semiconductor structures one usually starts from a set of formulae, well-known in semiconductor physics, which can be derived from the Maxwell equations. By simplifying the Maxwell equations, the Poisson equation is derived which describes the potential distribution in MIS transistors. Some two-dimensional forms of this equation can be solved by applying the Fourier transform or can be converted into an integral form and solved by the Green’s function method. Our approach consists in solving a one-dimensional Poisson equation. Improvements have been made in the physical model and also in the numerical treatment.