Invited

Hot Carriers in FETs —
Light Emission and Degradation Physics

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Abstract

We consider FET-devices operated under hot electron conditions. The spectrally resolved emission of electromagnetic radiation is measured and related to the electron energy distribution in the device. We discuss degradation effects and experiments designed to study the energy-distribution and spatial location of defect states produced by hot carriers.

Where there is fire sparks will fly. Inside a micrometer-sized FET device there is a lot of fire. Several Volts drop in a distance of order 0.1 µm near the drain contact of a device under typical operating conditions (Fig.1). This generates an electric-field spike with peak fields of order 5x10⁵ V/cm. The energy dissipated in the volume of the field spike, which extends only a few hundred Å into the semiconductor, is of order 10¹² W/cm³. According to Einstein's well known formula, a cm³ of material generating such a amount of energy by nuclear fusion would consume itself in 100 sec! Sparks do fly. In FETs there is observed emission of visible light in the narrow strip near drain (Fig.2).

Fig. 1. Schematic cross-sectional view of a FET. The surface potentials change rapidly near the drain. This is the region of the electric-field spike.

Fig. 2. Light emission from a Si MOSFET. The bright strip shows up on the drain contact side.
It is of particular interest today to use the spectral characteristic of the emissions as a measure of the electron energies /1,2,3/. The Si spectrum in Fig.3 shows a several band structure-related features even below $E_g$. The sharp spike near $E_g$ comes at such voltage where parasitic bipolar action occurs. It signals the recombination of comparatively cold carriers. In GaAs MESFETs a continuum of radiation is seen for below $E_g$ (0.7-1.2 eV). The photon density decreases exponentially with rising energy. It has been speculated that this is Bremsstrahlung from carriers stopped in the drain /3/.

It is surprising how well the Si-SiO$_2$ interface stands up to the $10^{12} \text{ W/cm}^3$ stress that is periodically switched on and off in a Megabit-RAM circuit. Nevertheless, with time a cumulative type of damage does occur. It is concentrated in the region of the field spike. Defect state are created which degrade the electrical performance of the device. In particular, at low temperatures (4.2K) there is found to occur a very sizeable shift in the threshold onset of conductance. The subthreshold current-gate voltage characteristic changes dramatically with stress (Fig.4). The fluctuation signature seen in the 4.2K characteristic is the result of resonant tunneling on a quantum-mechanical scale of lengths /4/. The T-dependent subthreshold characteristic has been modelled in terms of interface states with a spatial distribution that is sharply peaked at the position of the
field-spike during the degradation cycle /5/ (Fig. 5). It is found that

![Diagram](image)

made using charge-pumping experiments. The states are interfacial traps for electrons.

A basic problem in the study of the defects has been that in FET-devices they are located only in a narrow range of the channel. There are many techniques that have been used to provide homogeneously distributed damage. There are various irradiations, avalanche injection and bias-temperature stress. A technique that has been used to simulate the high lateral fields in a MOSFET has been a microwave (~3 GHZ), magnetron-pulse experiment /6,7/. The evolution of interface damage has been followed in temperature-annealing cycles.

In an effort to observe and spatially locate the mid-gap deep-level states that are responsible for generation and recombination in Shockley-Read-Hall processes, we have recently studied the reverse-bias, generations currents in the gated-diode configuration /8/. Fig. 6 shows

![Graph](image)
how in this measurement the effective generation zone (the space between the \( i_e \) and \( i_h \) contours) scans the interface region like a pointer when \( V_g \) is swept from threshold into strong accumulation. In this way one samples the defect distribution. The modelling in terms of a sharply peaked distribution of deep-level interface defects can satisfactorily fit the generation current as observed in Fig. 7. Such experiments also point to the creation of some bulk-type defects near the drain contact during the degradation.

REFERENCES