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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 5×10^5 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 10^{12} W/cm^3. According to Einstein's well known formula, a cm^3 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).

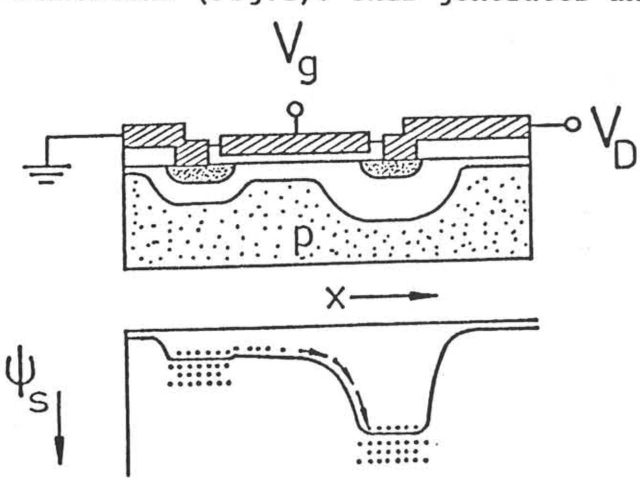

Fig. 1. Schematic cross-sectional view of a FET. The surface potential s changes rapidly near the drain. This is the region of the electric-field spike.

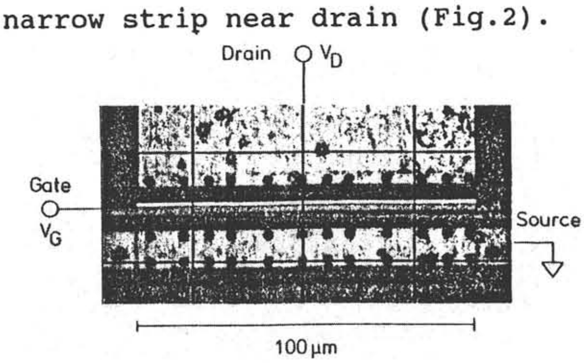

Fig. 2. Light emission from a Si MOSFET. The bright strip shows up on the drain contact side.

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

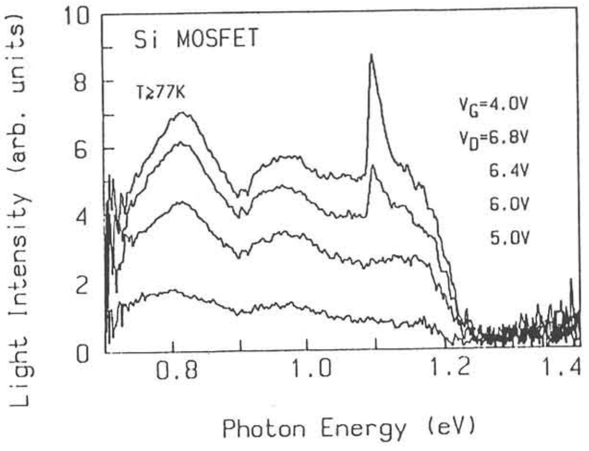

Fig. 3. Emission spectra of a Si MOS device operated at various V_D. The spike at 1.1eV of photon energy correlates with parasitic bipolar action in the MOSFET.

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 $\approx 10^{12}$ 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

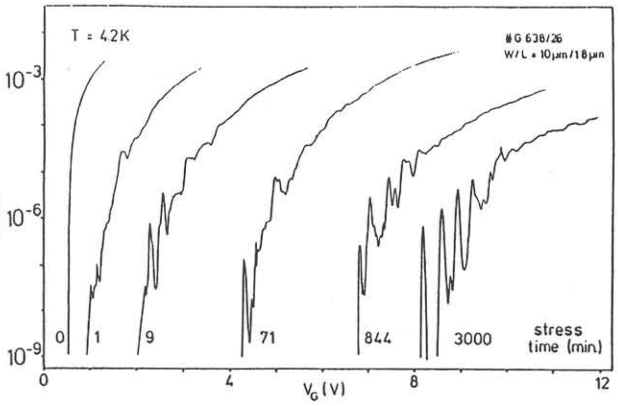

Fig. 4. Subthreshold conductance at 4.2K on a log scale after various stress cycles (V_g=3 V, V_D=8 V, T=65K). Device width is 10 μm; oxide thickness is 42 nm).

seen in the 4.2K characteristic is the result of resonant tunneling on a quantum-mechanical scale of lengths /4/. The T-dependent subthreshold current 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

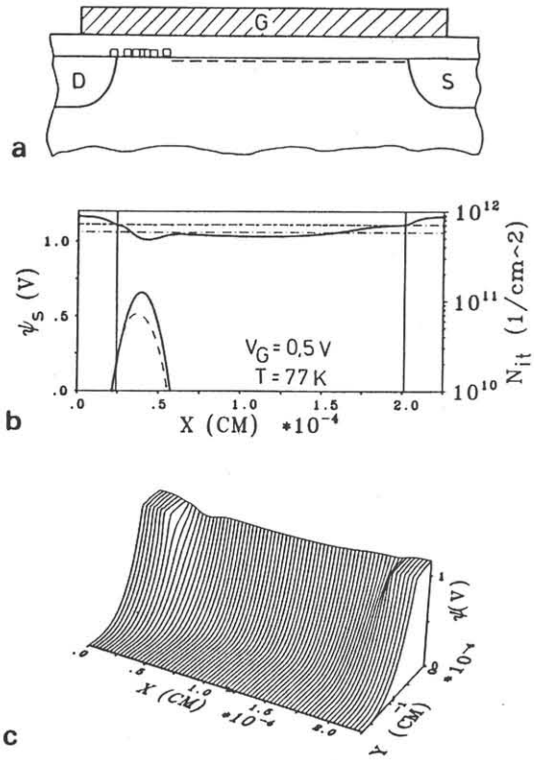

Fig. 5. Modelling results for a degraded device at T=77K showing
a) the FET in cross-section
b) the surface distribution of states N_{it} and the surface potential
c) the 2-dimensional potential surface.

the interface states have an energy distribution that increases steeply with energy approaching the band-edge. Similar observation have been made using charge-pumping experiments. The states are interfacial traps for electrons.

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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

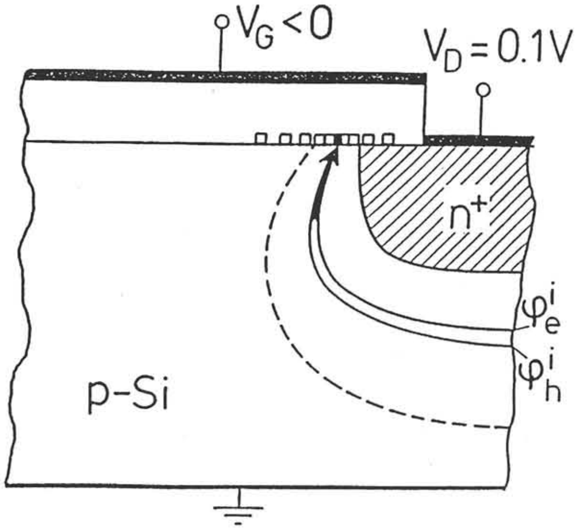

Fig. 6. Cross-sectional potential contours showing the depletion layer with the contours where the quasi-Fermi levels $_e$ and $_h$ equal the intrinsic Fermi energy ϵ_i.

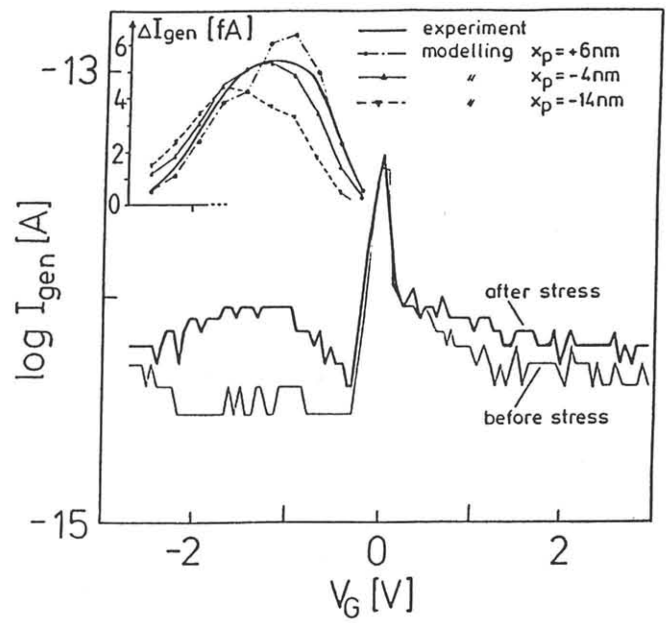

Fig. 7. Generation current in a gated-diode configuration before and after stress.

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 satisfactory 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.

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