QUANTUM 1/f NOISE IN SOLID STATE DEVICES
IN PARTICULAR Hg$_{1-x}$Cd$_x$Te N$^+$-P DIODES

FINAL REPORT

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The research results are documented in the fourteen reports and publications issued under this contract.

Quantum 1/f Noise in Solid State Devices in Particular Hg1-xCdTeX-N-P

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ABSTRACT (Continued on reverse if necessary and identify by block number)

The research results are documented in the fourteen reports and publications issued under this contract.

Alternatively, the abstract is mentioned as:

The quantum 1/f noise in solid state devices, particularly in Hg1-xCdTe-N-P, is documented in the fourteen reports and publications issued under this contract.
Papers published under the contract July 1, 1985 to date

A. Early papers on which the present contract is based.

2. A. van der Ziel and P. H. Handel, "Quantum partition 1/f noise in pentodes," Physica, vol. 125B, p. 286, 1984. These were the first two papers that indicated the presence of quantum partition 1/f noise in pentodes.

B. Early papers under the contract

Tables of the Hooge parameter of Hg$_{1-x}$Cd$_x$Te $n^+$-p diodes versus composition $x$ and temperature $T$.

C. Papers mentioned in the progress reports

Relativistic effects become important if $m < 0.02m_0$.

Extensive review of the status of quantum 1/f noise. Still uses wrong estimated values of $\tau$ in Hg$_{1-x}$Cd$_x$Te.

Interprets Schwantes' secondary emission 1/f noise as quantum 1/f noise.

Uses the measured values for $\tau$. Finds from this value $\alpha_H = (3-5) 10^{-3}$ (coherent state) or $\alpha_H = 5x10^{-5}$ (Umklapp).

Expands and slightly corrects earlier work. Most data agree with the quantum 1/f noise theory, but in one noisy device the quantum 1/f noise seems to be masked by noise of non-quantum origin.

Shows that the devices have coherent state 1/f noise.

Gives a survey of quantum 1/f noise experiments.

First semiclassical interpretation of quantum 1/f noise in terms of Bremsstrahlung fluctuations.


26. A. van der Ziel, "Generalized semiclassical quantum $1/f$ noise theory; acceleration $1/f$ noise in semiconductors," J. Applied Physics, 63, 903 (1988). Extends the theory to the acceleration $1/f$ noise process and shows that in the latter the Hooge parameter varies as the square of the device length $L$ for intermediate values of $L$.


D. Papers written during the last eight months of the contract

SECONDARY EMISSION 1/f NOISE REVISITED

by A. van der Ziel, P. Fang and A. D. van Rheenen

Abstract

Fang and van der Ziel's analysis of secondary emission 1/f noise in secondary emission pentodes is extended to 16 individual data points. It is found that by proper choice of the secondary electron path length $d_{da}$, good agreement between the experimental values of the Hooge parameter $\alpha_H$ and the theoretical values predicted by Handel's quantum 1/f noise theory is obtained for 14 data points. Handel's equations for the Hooge parameter of the tubes thus seem to have heuristic validity. The values of the secondary electron path length $d_{da}$ differ somewhat from tube to tube and may also depend slightly on bias; these effects are attributed to the electron-optical system formed by screen grid, dynode and anode.

* Accepted for publication in Journal of Applied Physics.

EXTENSIONS OF HANDEL'S 1/f NOISE EQUATIONS AND THEIR SEMICLASSICAL THEORY

by A. van der Ziel, A. D van Rheenen, and A. N. Birbas

Abstract

By replacing the change in velocity $\Delta V$ by the low frequency Fourier transform $F(o)$ of the electron acceleration $\dot{a}(t)$, Handel's equations for the Hooge parameter $\alpha_H$ are put in equivalent forms that are not only applicable to collision 1/f noise in semiconductors but also to acceleration 1/f noise in long devices. When the power spectrum $S_p(f)$ of the emitted Bremsstrahlung is evaluated, it contains already the two terms $(q/e)^2$ and $|F(o)|^2/c^2$ found in Handel's extended expressions for the Hooge parameter $\alpha_H$. Going over to elementary events and defining the spectrum of the quantum emission rate $S_q^e(f)$ per elementary event by the equation $S_q^e(f) = S_q^e(f)/[hf\tau_3]$, where $\tau_3$ is the duration of the Bremsstrahlung pulse, the expression also contains the factor $4\alpha_0/(3\pi)$ found in Handel's expression for $\alpha_H$. It thus seems that the Hooge parameter depends only on the Bremsstrahlung emission process but not on the details of the electron-photon interaction. This may explain why Handel's expressions for $\alpha_H$ so often agree with experiment. Introducing the current spectrum $S_I(f) = S_I(f)/\lambda$ per elementary event where $\lambda = N/\tau_3$ and $N$ the number of carriers, and bearing in mind that $S_I(f)$ and $S_q^e(f)$ come from the same quantum process and are therefore proportional, it is highly likely that the proportionality factor corresponds to the shot noise of an elementary event. This leads immediately to the Hooge equation and to the Hooge parameter $\alpha_H$.

**Accepted for publication in Physical Review B.
EXTENSION OF THE HOOGÉ EQUATION AND OF THE HOOGÉ PARAMETER CONCEPT*

by A. van der Ziel and A. D. van Rheenen

Abstract

The Hoogé equation is extended to the case where the noise spectrum is of the form $1/f^\gamma$ with $\gamma$ slightly different from unity. This leads to a generalization of the Hoogé parameter that corrects an earlier ambiguity.

* Accepted for publication in Solid-State Electronics.

GENERATION-RECOMBINATION-TYPE 1/f NOISE IN n-i-p DIODES**

by A. van der Ziel, L. He, A. D. van Rheenen, and P. Fang

Abstract

It is shown for p-i-n diodes, in which the current flow is by hole-electron pair generation and (or) recombination, that the $1/f^\gamma$ noise is due to generation-recombination processes involving traps and (or) recombination centers and that the spectrum may be written as $S_1(f) = \frac{q_H e |I|}{f^\gamma \tau}$, where $q_H$ is the Hoogé parameter, $e$ the electron charge, $|I|$ the absolute current, $\tau$ the time constant associated with the pair generation and pair recombination process, $f$ the frequency and $\gamma$ is the exponent of the spectrum. This is studied experimentally and the Hoogé parameters of various devices are determined.

**Accepted for publication in Solid-State Electronics.
Abstract

1/f noise measurements at forward bias are reported on double heterojunction AlGaAs-GaAs laser diodes fabricated on GaAs and on Si substrates. The noise spectrum is of the form $1/f^\beta$ with $\beta$ close to unity. $S_1(f)/I$ is roughly independent of current for $I < 1 \text{ mA}$ and decreases with increasing current for $I > 1 \text{ mA}$. This means that the Hooge equation is valid for $I < 1 \text{ mA}$ with constant $a_H/\tau$, whereas $a_H/\tau$ decreases with increasing current for $I > 1 \text{ mA}$. Here $a_H$ is the Hooge parameter and $\tau$ the carrier lifetime.

The values of $a_H/\tau$ for devices on a Si-substrate (#1 and #3) are 20-50 times larger than for devices on a GaAs substrate (#5, 6, and 7); this is attributed to the fact that the diodes on a Si-substrate have a much larger dislocation density than the diodes on a GaAs substrate. The current dependence of $a_H/\tau$ is a high injection effect. For $I \ll 1 \text{ mA}$ the carrier density in the active region is equal to the equilibrium density $N_0$, and $a_H = a_{Ho}$ and $\tau = \tau_0 = 2 \times 10^{-9} \text{ s}$ are constants; for $I \gg 1 \text{ mA}$ there is high injection so that $N \gg N_0$. $a_H$ and $\tau$ now decrease with increasing $I$, and the data require that $a_H$ decreases faster than $\tau$. The diodes with a silicon substrate have $a_{Ho} = (2.5-5.0) \times 10^{-3}$ for $I < 1 \text{ mA}$; this value for $a_H$ is probably accidental and does not indicate Hooge type 1/f noise.

*To be submitted to Journal of Applied Physics.*