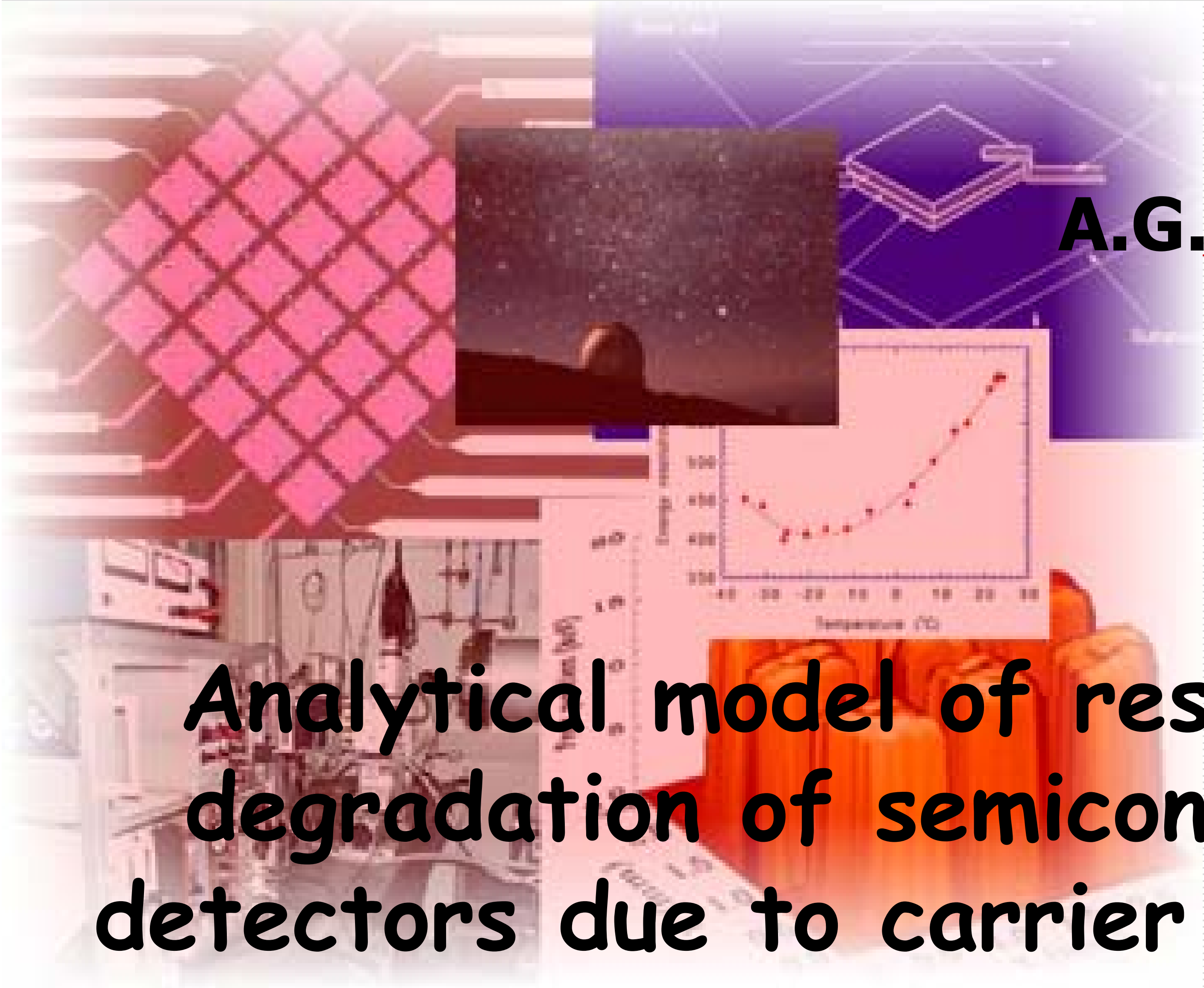
Lancaster University

esa



A.G.Kozorezov

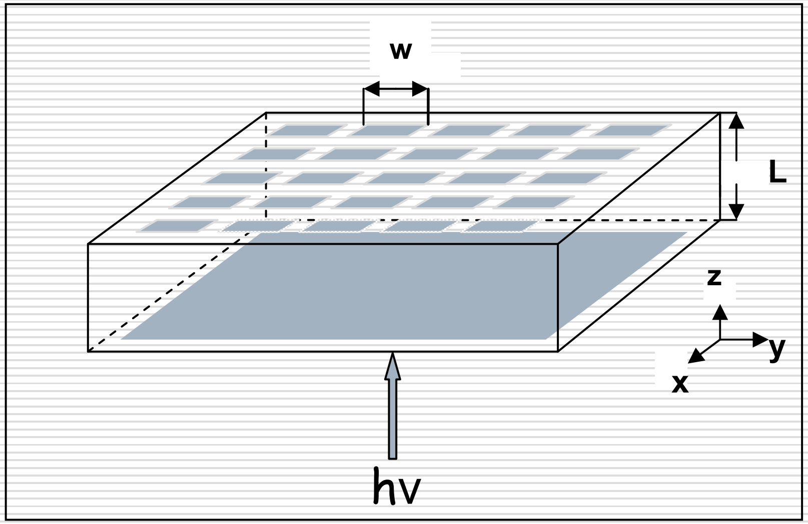
A.Owens,
R. den Hartog,
J.K.Wigmore,
A.Peacock
Hala Al Jawhari

Analytical model of resolution degradation of semiconductor detectors due to carrier trapping

Overview

- Detector resolution
- Analytical expression for carrier trapping contribution to signal broadening
- Asymptotic behaviour at small photon energy.
- Asymptotic behaviour at high photon energy
- Dependence on electron and hole transport. Optimisation
- TlBr data

Detector resolution



Square matrix on a pixelated plane

$z=0$: $V=0$

$z=L$: $V=V_b$

$$\Delta E = 2.355\sqrt{\varepsilon F E + \sigma_e^2 + \alpha_1 E^{\alpha_2}}$$

A.G.Kozorezov

Analytical expression for carrier trapping contribution to signal broadening

$$\Delta E = 2.355\sqrt{\varepsilon F E + \sigma_e^2 + G(E)E^2}$$

ε is e-h pair creation energy, F-Fano-factor, σ_e is electronic noise

$$G(E) = \frac{1-\exp(-\Gamma(E)L)}{\Gamma(E)} \frac{\int_0^L dz \exp(-\Gamma(E)z) Q^2(\vec{r}_a, z)}{\left[\int_0^L dz \exp(-\Gamma(E)z) Q(\vec{r}_a, z)\right]^2} - 1$$

E is the photon energy, and $\Gamma(E)$ is the X-ray absorption coefficient

$$Q(\vec{r}_a, z_a) = \exp\left(-\frac{L-z_a}{l_e}\right) + \frac{1}{l_e}\left[L - z_a + \int_{z_a}^{L} dz \Phi_w(\vec{r}_a, z)\right] + \frac{1}{l_h}\int_0^{z_a} dz \Phi_w(\vec{r}_a, z)$$

$l_{e,h}$ are electron (hole) mean drift paths, Φ_w is the weighting potential

A.G.Kozorezov

Asymptotic behaviour at small photon energy

$$E \to 0, \quad \Gamma L >> 1$$

Absorption close to cathode

$$G(E) \to \frac{1}{\Gamma^2(E) l_e^2} (<< 1)$$

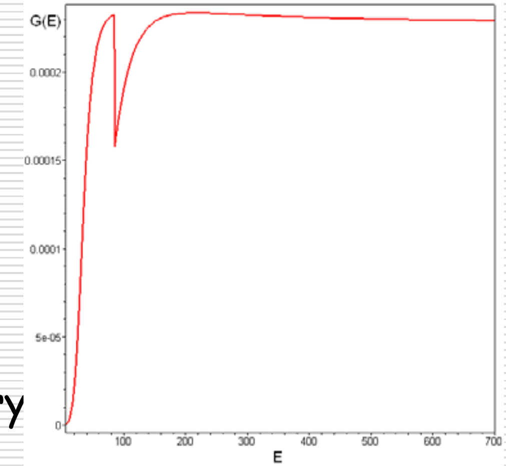
At small photon energy trapping strength factor G(E) shows universal behaviour. It does not depend on both pixel geometry and lateral co-ordinates of the photon absorption site.
Its energy dependence is determined by that of the absorption coefficient

A.G.Kozorezov

Asymptotic behaviour at high photon energy

$E \to \infty, \quad \Gamma L << 1$ Uniform in-depth absorption

$$\Delta E = 2.355\sqrt{\varepsilon F E + \sigma_e^2 + \alpha(l_e, l_h, L, R_0, \vec{r}_a)E^2}$$



For $l_{e,h}$ >>L the expression for α is simplified:

$$\alpha_{single} = \alpha_{single}(l_e, l_h, L) = \frac{L^2}{45}\left(\frac{1}{l_e}+\frac{1}{l_h}\right)^2 - \frac{L^2}{12 l_e^2}$$

for single pixel geometry

for small pixel geometry R_0<<L

$$\alpha_{small} = \frac{1}{12}\left(\frac{L}{l_e}\right)^2\left(1+O\left(\frac{R_0}{L}\right)\right) \approx \frac{1}{12}\left(\frac{L}{l_e}\right)^2 = \alpha_{small}(l_e, L)$$

→ no dependence on pixel size and on absorption site location

For $l_e=l_h=l$ >> L

$$\alpha_{single}(l, l, L) = \frac{1}{180}\left(\frac{L}{l}\right)^2 << \alpha_{small}(l, L)$$

→ **Small pixel geometry is worse than single pixel !!**
No volume averaging, stronger fluctuations in near field region

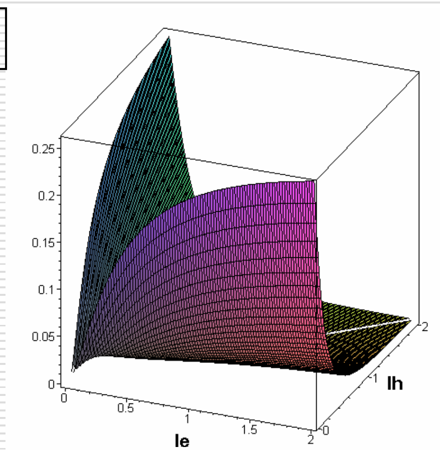
However for $l_e \geq (11/4) l_h$ >> L

$$\alpha_{single}(l_e, l_h, L) \geq \alpha_{small}(l_e, L)$$

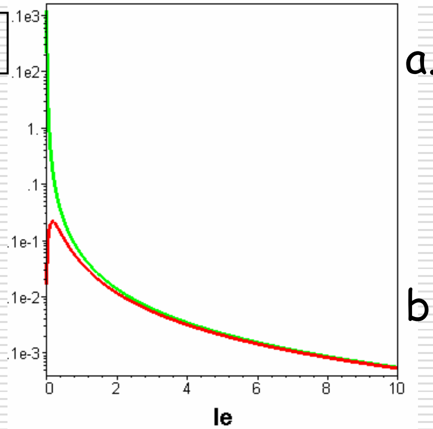
→ **Small pixels are better again**

Dependence on electron and hole transport. Optimisation

a



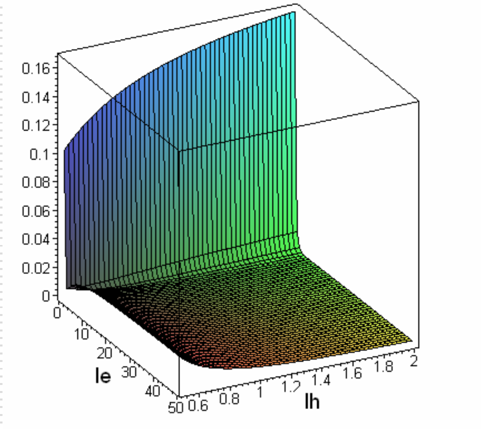
b



a. $G_\infty(l_e,l_h,L)$ as a function of electron and hole transport parameters for a single pixel geometry (l_e and l_h are in units of L);

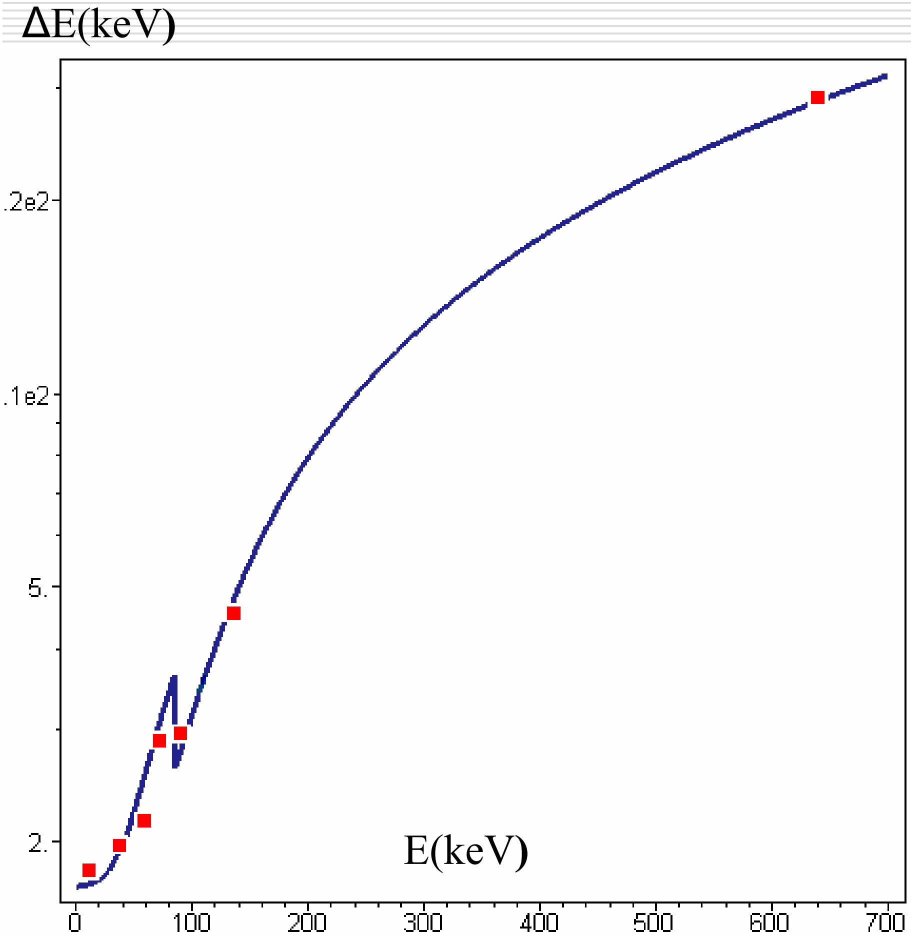
b. $G_\infty(l_e,l_e,L)$ vs l_e.
Upper curve: $1/180(L/l_e)^2$

c



c. $G_\infty(l_e,l_h,L,R_0)$ as a function of electron and hole transport parameters for a small pixel geometry (l_e and l_h are in units of L), R_0=0.05L;

TlBr: Experiment



TlBr detector resolution
3x3 square matrix array
$L=1000\mu m$, $R_0=350\mu m$, $V_b=300V$
$\mu_e\tau_e=5\cdot10^{-4}cm^2V^{-1}$
$\mu_h\tau_h= 3\cdot10^{-6}cm^2V^{-1}$
Solid curve – theory,
Squares – experiment.

Onodera et al (2004) TlBr
3x3 square matrix array
$L=1.8mm$, $R_0=570\mu m$, $V_b=1800V$
$\mu_e\tau_e=1.7\cdot10^{-4}cm^2V^{-1}$
$\mu_h\tau_h= 6.4\cdot10^{-5}cm^2V^{-1}$
$\Delta E_{experiment}$ =9.7keV at E=660keV
ΔE_{theory}=34.4keV. However, for
$\mu_e\tau_e=5\cdot10^{-4}cm^2V^{-1}$ ΔE_{theory}=9.7keV

Summary

- The noise due to incomplete charge collection because of carrier trapping results in the resolution degradation described by the $G(E)E^2$ variance.
- G(E) has universal low energy asymptotic with no dependence on pixel geometry
- In the opposite limit of high photon energies G is a constant depending on both pixel geometry and carrier transport parameters
- Theoretical resolution curve shows an excellent agreement with experiment for TlBr detector in the range 5-660 keV without any fitting parameters.