# A comprehensive model using Stark effect for failure analysis of double-heterostructure light emitting diodes


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## Abstract


This paper shows the great interest to study the electroluminescence spectrum for ***reliability investigations*** of double-heterostructure AlGaAsGaAs commercial Light Emitting Diodes. Based on the ***superposition theory of the electronic transition, spontaneous, Stark effects and stimulated recombination can be separated***. The internal ***piezoelectric field*** can be estimated and thus the amplitude of ***residual stresses of the active zone*** can be extracted. The main interest of the methodology consists in the ***determination of the failure mechanisms*** coming from increase of ***defects density and internal active zone mechanical stresses*** gradual changes. The determination of degradation laws is thus physical and improves the study of the ageing of the material.


## Context and objectives

**Basic Stark effect (S.E) model with Airy function (wave function)**

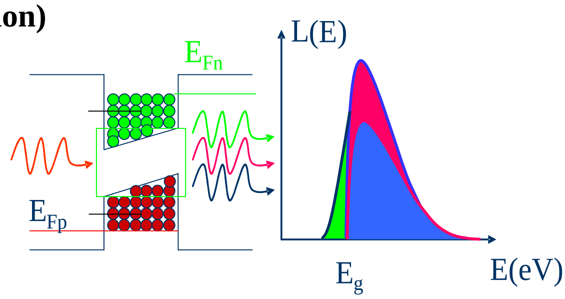
Wave function of electron

$$\begin{cases} \dfrac{d^2 Ai(z)}{dz^2} - zAi(z) = 0 \\ Ai(z) \approx \dfrac{1}{2\sqrt{\pi} z^{1/4}} \exp\left(-\dfrac{2}{3} z^{3/2}\right) \end{cases}$$

Spectral model of recombination by S.E

$$R_{stark}(\xi) = r_0 \sqrt{\beta}\pi \left[ \left( \frac{dAi(-\xi)}{dz} \right)^2 + \xi Ai^2(-\xi) \right]$$

$$\beta = \left( \frac{2m_r}{\hbar^2 q^2 F^2} \right)^{-1/3} ; \xi = \frac{h\nu - E_g}{\beta}$$




**Basic Spontaneous (a) and Stimulated (b) emissions**

(a)

$$R_{spon}(E) = K_{spon}(E - E_g)^{1/2} \exp\left(-\frac{E - E_g}{kT}\right)$$

$$K_{spon} = \frac{(2m_r)^{3/2}}{\pi\hbar^2 \tau_R} \exp\left(\frac{\Delta E_F - E_g}{kT}\right)$$

(b)

$$\gamma(h\nu) = K_{spon}(h\nu - E_g)^{1/2}[f_c(h\nu) - f_v(h\nu)]$$

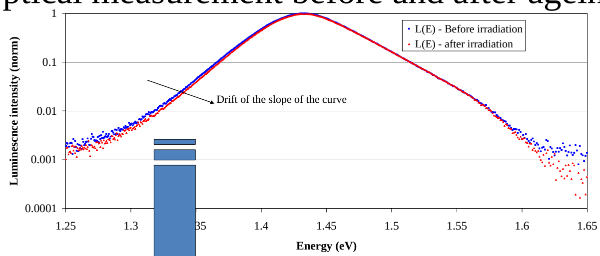
$$R_{stim} = \int_{E_g}^{\Delta E_F} \gamma(E) dE$$

- Spontaneous emission
- Stimulated emission
- Stark effect

$$J = qdA_{nr}n + qdBn^2 + qdR_{stark}n^2 + qdR_{stim}s$$

## Results and discussion

Optical measurement before and after ageing test



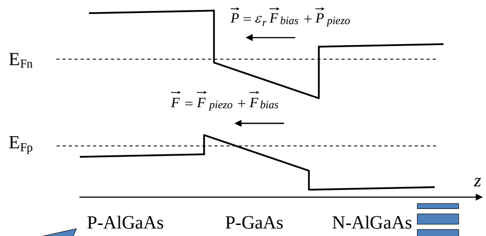

Physical model (in relation with S.E model

$$\left| \langle k,v | \vec{p}.\vec{P} | k,c \rangle \right|^2 = \frac{3}{2} \chi_{vc}^2 = \frac{\kappa}{\tau_R}$$

$$\vec{P} = \varepsilon_r \vec{F}_{bias} + \alpha \vec{F}_{piezo} = \varepsilon_r \vec{F}_{bias} + \kappa' . \vec{\sigma_\perp}$$

$$\frac{1}{\tau_R} = \frac{1}{\tau_{R0}} - \eta \left| \vec{\sigma}_\perp \right|$$

Localization of failure mechanisms




$$P = \frac{\eta_{tot} n^2 E_c N_j}{N_c N_v} \left[ \frac{1}{\tau_{R0}} - \frac{\eta \sigma_0}{2} \left( 1 - \exp\left[ \frac{D}{D_0} \right] \right) \right]$$

Degradation law determination

## Conclusion

In this paper, we extract degradation laws of double heterostructure light emitting diodes adapted for space mission profile. For this kind of critical mission the knowledge of degradation laws and then the lifetime distribution is crucial. We extract from the experimental measurements the failure signature induced by Gamma irradiations. Those ones are related to the degradation mechanisms. We can engage a new study to estimate degradation laws in spatial environment in which we will compare degradation made by particles irradiations with thermal storage.