Thermal impact on DC characteristics of GaN HEMT devices

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GaN HEMT devices

GaN High Electron-Mobility Transistors (HEMTs): basic structure and formation of the two dimensional electron gas (2DEG) [1].

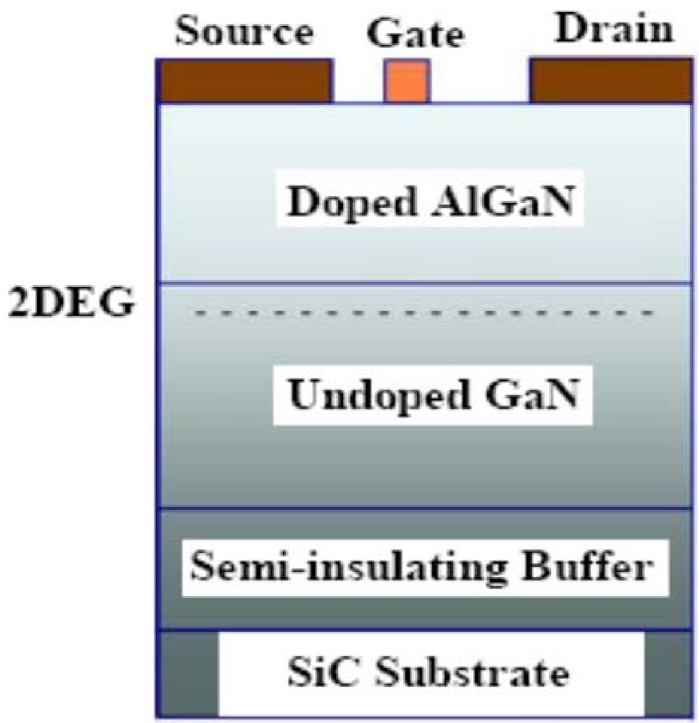


Figure 1.a AlGaN/GaN HEMT Structure

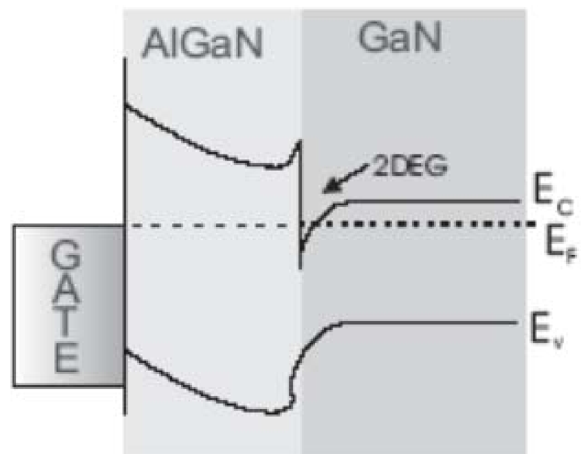


Figure 2.a Band Diagram of AlGaN/GaN HEMT at zero gate voltage.

GaN HEMT devices

Advantages of GaN HEMT devices:

- High breakdown voltage, low on-state resistance, fast switching speed, high-temperature operation capability.

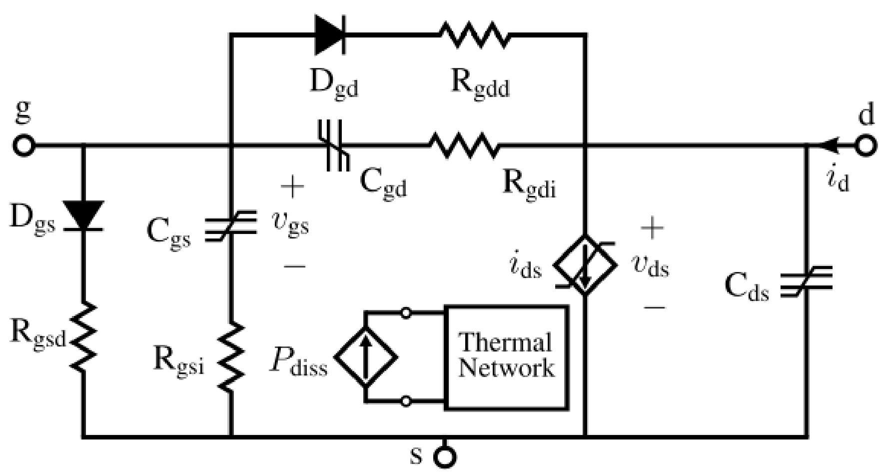
GaN HEMT applications:

- Power electronic systems (converters, motor drives, etc)
- RF applications

Electro-thermal model [2]

During normal operation, the junction temperature of the device will increase, bringing about changes to the device parameters. For example, the self-heating effect is a local increase in junction temperature due to dissipated Joule electric power [3].

Thus, in order to model the device during operation accurately, the need to do electro-thermal modeling is naturally raised.



Temperature-dependent parameters of GaN HEMT [1]

To calculate Ids [4]:

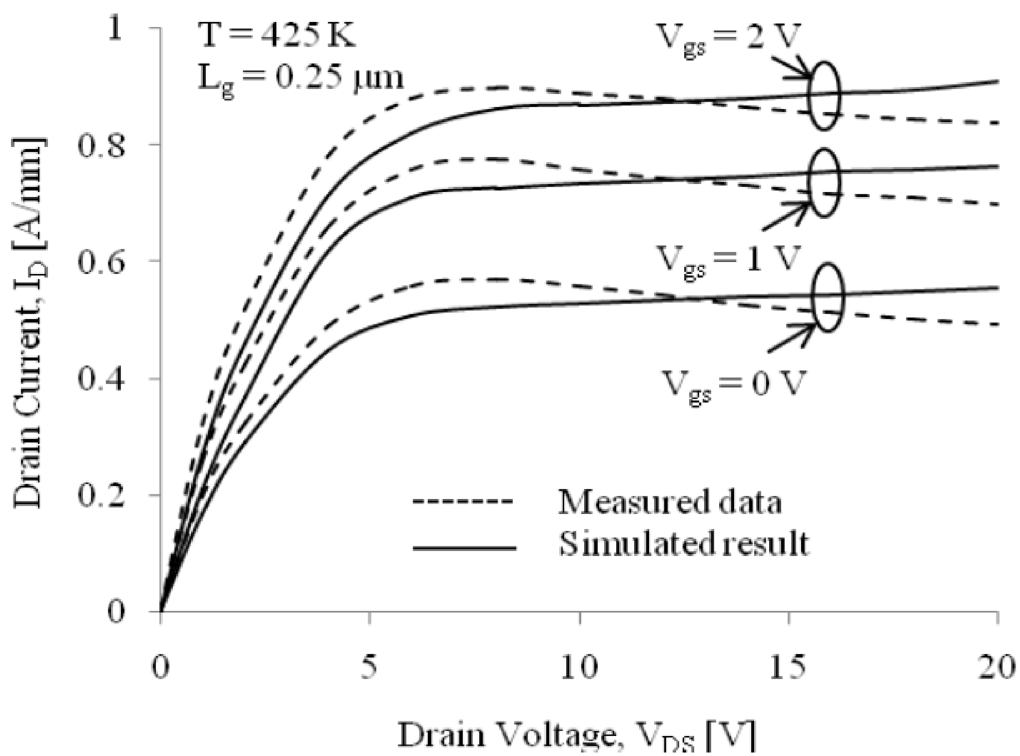
- Ids = wqv(x)ns(x)

Thus, we should consider the temperature impact on:

- Carrier mobility μ
- Bandgap and Carrier concentration n_s

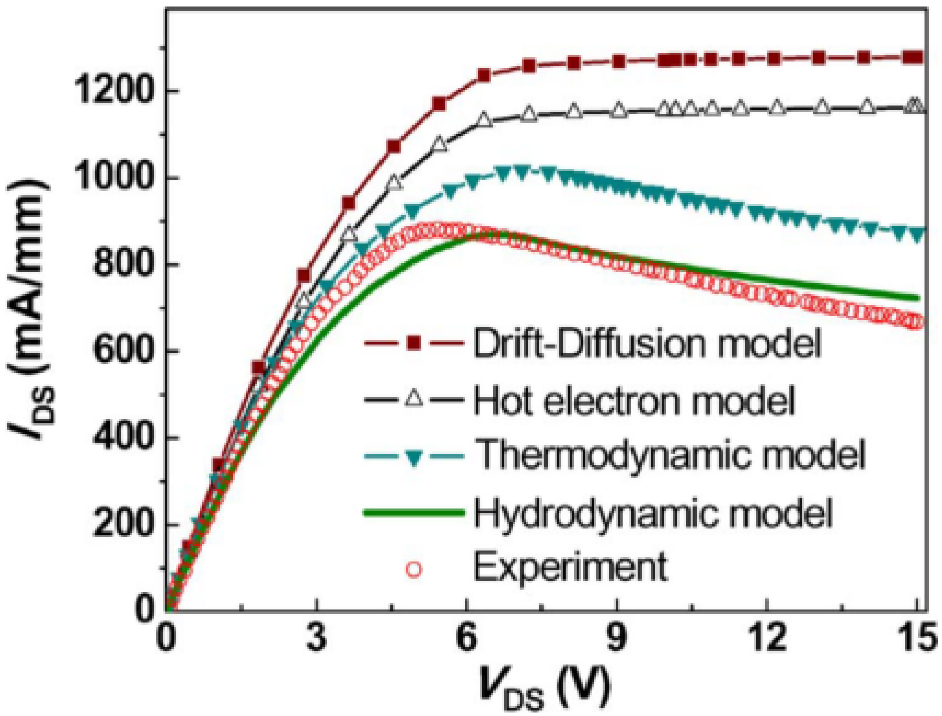
Carrier mobility: NDC phenomena

Negative Differential output Conductance (NDC) phenomena [1]



Carrier mobility: NDC phenomena

Cause of NDC phenomena: Self-heating or hot electron effect? [3]



Carrier mobility: NDC phenomena

NDC is actually caused by change in carrier mobility, as shown below [3]. When T goes up, the carrier mobility goes down.

$$\mu(F) = \frac{\mu_{\text{low}}}{\left[1 + \left(\frac{\mu_{\text{low}} F}{\nu_{\text{sat}}}\right)^{\beta}\right]^{\frac{1}{\beta}}}$$

where

$$\mu_{\text{low}} = \mu_{300}(300/T_L)^{\varsigma}$$

$$v_{\text{sat}} = v_{300}(300/T_L)^{\delta}$$

$$\beta = \beta_0 (T_L/300)^{\beta_{\text{exp}}}$$

2DEG Carrier concentration

Generally speaking, the density of the 2DEG in GaN devices is becoming smaller in the temperature range of normal operation [5].

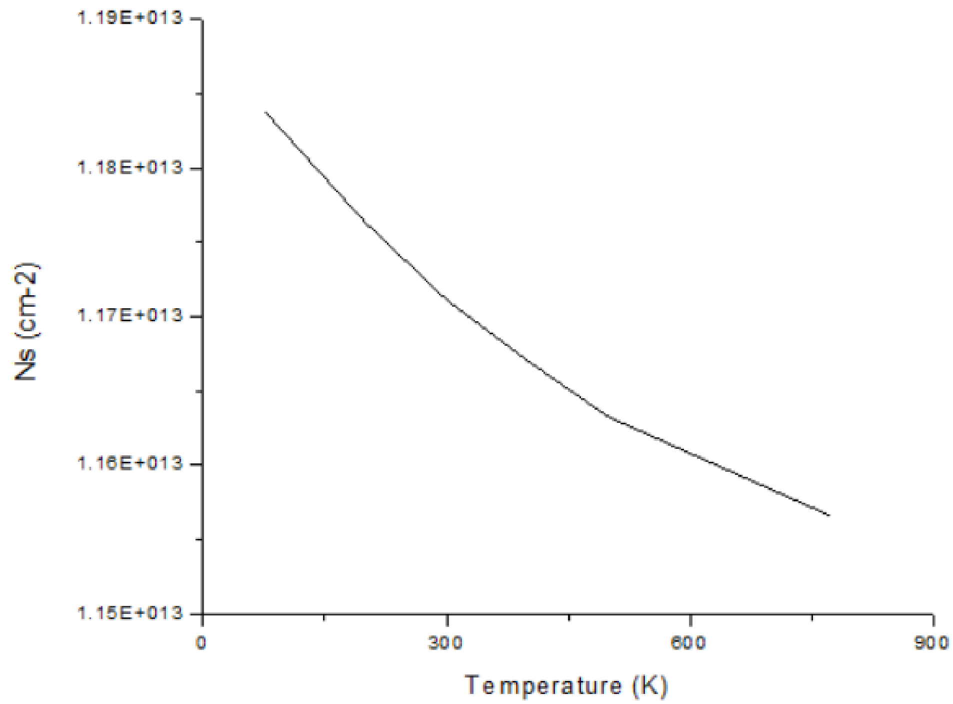


Fig. 9. Calculated sheet charge density inside the 2D well with respect to temperature.

Bandgap change

There are changes in the bandgap of GaN brought by the temperature [1],

$$E_g = E_{g,0} - \frac{\alpha_g T_L^2}{\beta_g + T_L}$$

The same method is used to calculate bandgap of AlN.

For AlGaN, the bandgap is calculated as [1]

$$E_g^{AlGaN} = E_g^{AlN}(1-\chi) + E_g^{GaN}\chi + C_g(1-\chi)\chi$$

2DEG Carrier concentration [5]

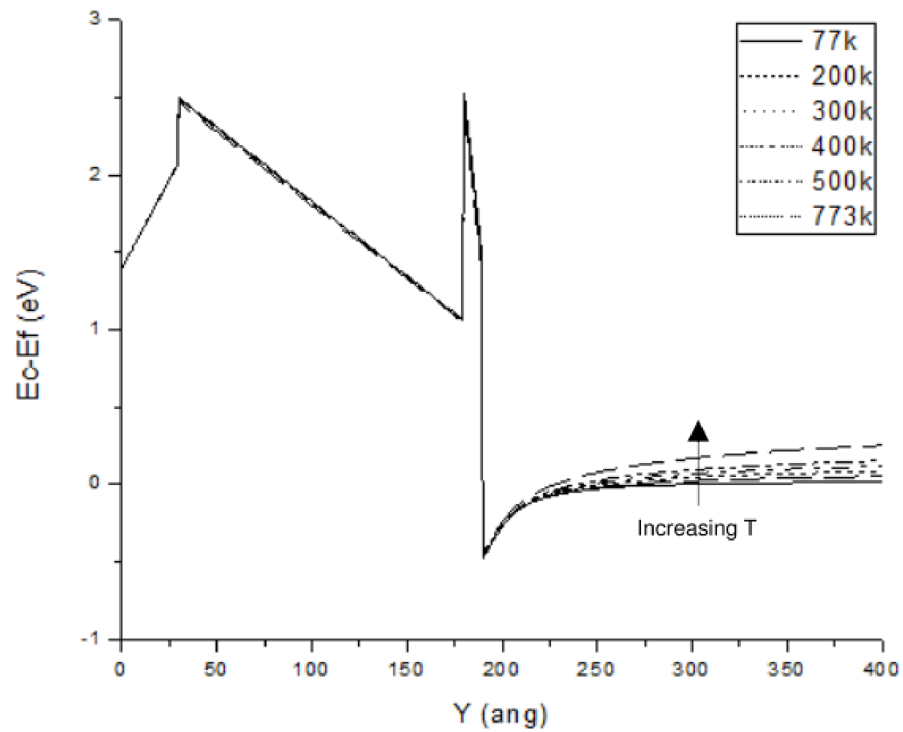


Fig. 6. Calculated conduction band edge along the growth dere-ction with respect to temperature.

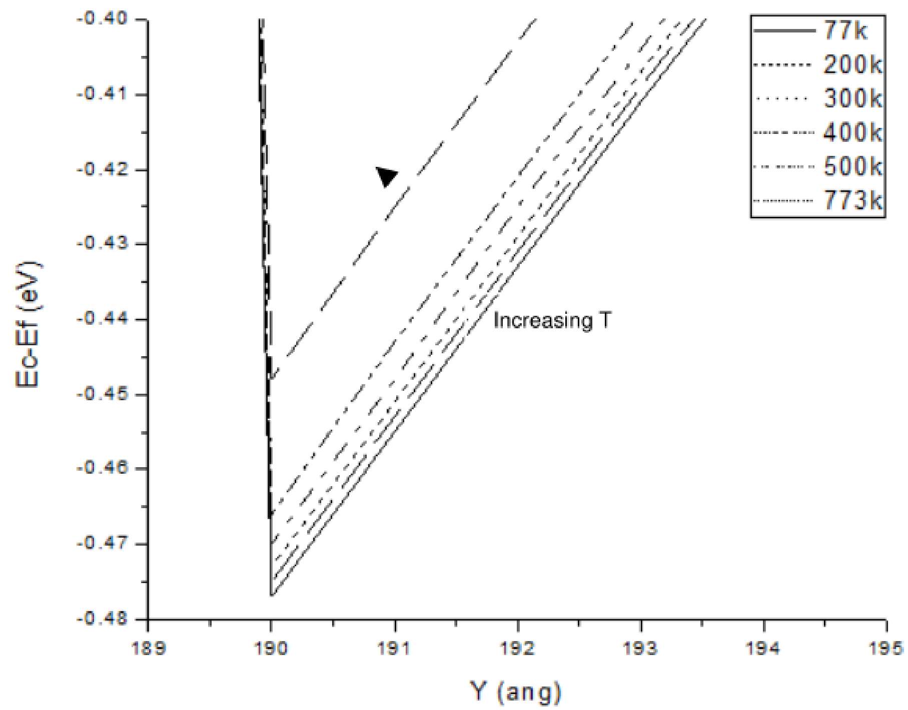


Fig. 7. Calculated conduction band edge inside the well with respect to temperature.

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References

[1]Balwant Raj, and Sukhleen Bindra, "Thermal Analysis of AlGaN/GaN HEMT: Measurement and Analytical Modeling Techniques," *Int. J. Comput. Appl* 75 (2013): 4-13.

[2] Justin B. King, and Thomas J. Brazil, "A comprehensive electrothermal GaN HEMT model including nonlinear thermal effects," In Microwave Symposium Digest (MTT), 2012 IEEE MTT-S International, pp. 1-3. IEEE, 2012.

[3]X. D. Wang, W. Da Hu, X. S. Chen, and W. Lu, “The study of self-heating and hot-electron effects for AlGaN/GaN double-channel HEMTs,” *IEEE Trans. Electron Devices*, vol. 59, no. 5, pp. 1393–1401, 2012.

[4]X. Cheng, M. Li, and Y. Wang, “Physics-Based Compact Model for AlGaN / GaN MODFETs With Close-Formed I – V and C – V Characteristics,” *IEEE Trans. Electron Devices*, vol. 56, no. 12, pp. 2881–2887, 2009.

[5] Ashraf Khan, Faisal Shah, Jafar Siddiq, and Tim Vasen, "High Temperature Transport Properties of AlGaN/GaN Heterostructures.”