113, 203109 (2013)

Negative differential resistance induced by thermalization of two-dimensional electrons in terahertz quantum-well photodetectors

X. G. Guo,[1,a)] L. L. Gu,[1] M. Dong,[1] J. C. Cao,[1] H. C. Liu,[2] and F. M. Guo[3]
[1]Key Laboratory of Terahertz Solid-State Technology, Shanghai Institute of Microsystem and Information Technology, Chinese Academy of Sciences, 865 Changning Road, Shanghai 200050, China
[2]Key Laboratory of Artificial Structures and Quantum Control, Ministry of Education, Department of Physics, Shanghai Jiao Tong University, 800 Dongchuan Road, Shanghai 200240, China
[3]Key Laboratory of Polar Materials and Devices, Ministry of Education, East China Normal University, 500 Dongchuan Road, Shanghai 200241, China

(10 A 2013; 16 y 2013; 31 y 2013)

[illegible] (2) [illegible] 2 [illegible] 2 [illegible] 2 [illegible]

/10.1063/1.4808343

I. INTRODUCTION

[illegible] ( ).[1] [illegible] 1.5 [illegible] *et al.*[2] [illegible] *et al.* [illegible] [3] [illegible] ;[4] [illegible] (2) [illegible] [4–6] [illegible] 2 [illegible] 2 [illegible] 2 [illegible] 2 [illegible] 3 [illegible] 2 [illegible] 2 [illegible] .[7] [illegible] [8] [illegible] 2 [illegible]

II. THEORETICAL MODEL

[illegible] 2 [illegible] T_e [illegible] $dT_e/dt = S(E_k, J) - R(T_e, T_L)$, w [illegible] $S(E_k, J)$ [illegible] 3 [illegible] 2 [illegible] 3 [illegible] $E_k J$ wt [illegible] E_k [illegible] 3 [illegible] J [illegible] $R(T_e, T_L)$ [illegible] 2 [illegible] wt T_L [illegible] T_e [illegible] S [illegible] R [illegible] T_e. [illegible] $E_{ki} = F_{i-1} v_d \tau + E_b - E_1$. [illegible] $v_d = uF_{i-1}/[1 + (uF_{i-1}/v_{sat})^2]^{1/2}$ [illegible] wt F_{i-1} [illegible] μ [illegible] v_{sat} [illegible] τ [illegible] E_b [illegible] E_1 [illegible] 2 [illegible] [8] [illegible] $R(T_e, T_L) = A(T_e^{\gamma} - T_L^{\gamma})$, w [illegible] A [illegible] γ [illegible] [9] [illegible] T_{ei} [illegible] 2 [illegible]

[a)] [illegible]

$$T_{ei} = \begin{cases} \sqrt[\gamma]{T_L^{\gamma} + aE_{ki}J}, & ei < \\ T, & T_{ei} \geq T \end{cases} \quad (1)$$

a, γ, T ... (1), ... $\rightarrow$ ... 2 ... $\rightarrow$ ... T_e ... T ... (1) ... *et al.*[10] ... 2 ... J ... J_{inj} ...), ... [10–13] ... [9]

$$\rho_i = \rho_d + \frac{\varepsilon_0 \varepsilon_r}{q}(F_i - F_{i-1}), \quad (2)$$

$$p_c J_{inj}(F_0, T_L, T_e) = J_{th}(\rho_i, F_i, T_e), \quad (3)$$

$$V = L_b F_0 + \sum_{i=1}^{N}(L_b + L_w)F_i, \quad (4)$$

ρ_i ... 2 ... ρ_d ... ε_0 ... ε_r ... q ... p_c ... F_{i-1} (F_i) ... J_{th} ... V ... N ... L_b ... L_w ... J_{inj} ... [10,11]

$$J_{inj} = \frac{qm^* kT_L}{2\pi^2\hbar^3}\int_{E_c}^{\infty} T(E_z, F_0) \times \left[\frac{1 + \quad((E_{Fc} - E_z)/kT_L)}{1 + \quad((E_{Fw} - E_z - qF_0L_b)/kT_e)}\right], \quad (5)$$

m^* ... k ... E_c ... E_z ... E_{Fc} ... E_{Fw} ... [9,10] ... $T(E_z, F_0)$

$$T(E_z, F_0) = \begin{cases} 1, & E_z \geq E_b \\ [(-4/3qF_0)(2m^*/\hbar^2)^{1/2}(E_b - E_z)^{3/2}], & E_b - qF_0L_b \leq E_z < E_b \\ [(-4/3qF_0)(2m^*/\hbar^2)^{1/2}(E_b - E_z)^{3/2} - (E_b - E_z - qF_0L_b)^{3/2}], & E_z < E_b - qF_0L_b \end{cases} \quad (6)$$

... J_{th} ... (5).

III. NUMERICAL RESULTS AND DISCUSSIONS

... 265 ... 8 ... 14. ... 400 ... 1.0×10^{17} ... 3, 40 ... $L_w = 11.9$ ... A ... $L_b = 55.2$ ... $A_{0.05}$ ... $_{0.95}A$ ... 800 ... 1.0×10^{17} ... 3. ... 10 ... $\rho_d = 1.0 \times 10^{11}$/ ... 2. ... [2,15] ... (1) (6) ... $|\rho_{i,n} - \rho_{i,n-1}|/\rho_d$ ... 1.0×10^{-4} ... n ... n ... 0.067 m_0 ... m_0 ... A (0.05) ... A $\varepsilon_r = 10.88$

0.84 $x = 0.042$ ... x ... A ... [10] ... $T_L = 4.0$ ... μ ... v_{sat} ... p_c ... 5000 ... 2/ / , 1.0×10^{7} / , 0.03, 8.0 ... 1 ... 3 ... $a = 1.0 \times 10^{10}$, $\gamma = 4.0$, T = 14, 20, 22 ... a ... γ. ... T ... T < 15 ... T ... a, γ, T ...

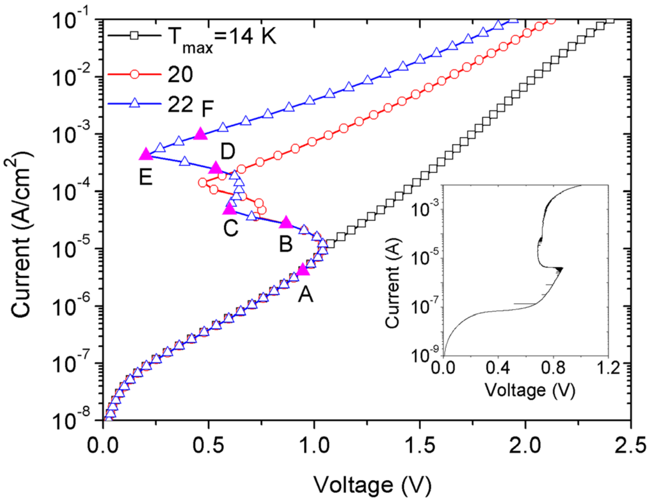


FIG. 1. [illegible] 265 [illegible] 12 [illegible] 13 [illegible] 4.0 [illegible] $a = 1.0 \times 10^{10}$, $\gamma = 4.0$, [illegible] $T_{max} = 14, 20,$ [illegible] 22 [illegible] [3]

[illegible] (1) [illegible] 2 [illegible] A, [illegible] $T_{max} = 22$ [illegible] 1. [illegible] 2 [illegible] (point A), [illegible]

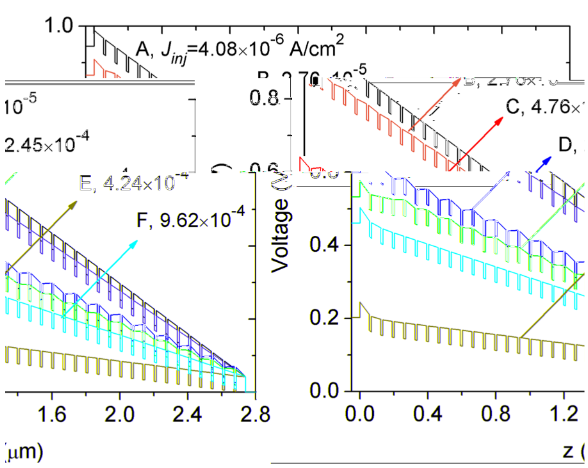
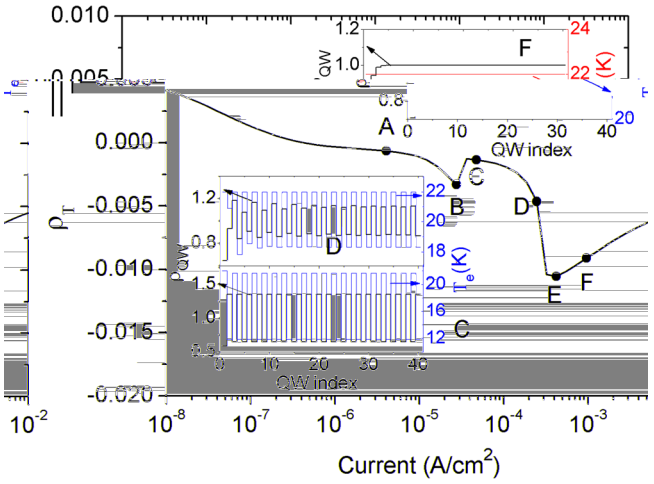


FIG. 2. [illegible] A, [illegible] 1 [illegible] $T_{max} = 22$ [illegible]

[illegible] A [illegible] (1), [illegible] T_e [illegible] 2 [illegible] 2 [illegible] $J_{inj} = 2.76 \times 10^{-5}$ A/cm^2, [illegible] J_{inj}, [illegible] *et al.*[16] [illegible] T_e [illegible] 2 [illegible] $T_{max} = 22$ [illegible] T_e [illegible] T_{max} [illegible] 2 [illegible] 2 [illegible] T_e [illegible] T_{max} [illegible]

[illegible] $\rho_T = \sum_{i=1}^{N}(\rho_i - \rho_d)/N\rho_d$ [illegible] 3. [illegible] $J_{inj} > 3.0 \times 10^{-7}$ A/cm^2, [illegible] 2 [illegible] 2 [illegible] 3 [illegible] 2 [illegible] $T_{max} = 22$ [illegible] 2 [illegible]



. 3. t tt t t ty ρ_T f t f t t. t: t f t ty t t, t T_e ρ f t , , w . 1.

IV. CONCLUSIONS

, w t t t t- t f t t . A - t t t- t t f 2 t t . f - t. f t . t t t t f 2 t tw -t . t t t, t ff t t f t 2 t t t T_e . t t , t 2 t t y t . t t. f t - t 2 t t f t .

ACKNOWLEDGMENTS

t . A. f t - t t w t t f . 1. w w t y t 863 f (t . 2011AA010205), t t t t t f (t . 61176086, 61131006, 60721004), t t t t f t t t . t (t . 2011 150021), t t t t y t (t . 2011 02707), t t t (2011 932903), t t (t . - 1123-1), t t t f t A y f . . . . w t t y t t (2011 925603) t t t f (91221201 61234005).

1 . . . . . , *Quantum Well Infrared Photodetectors: Physics and Applications* (, w , 2007).
2A. , . . -A , . A. , A y . tt . **92**, 202110 (2008).
3A. y tt , A. ff , . . . t , . A. . . . . A y . **110**, 013714 (2011).
4A. . . , . t , . t , . . . , . ff , - t t t . **45**, 1121 (2001).
5 . . . t , . t , . , A. , . . **19**, 219 (2004).
6 . . . . . A y . **111**, 034504 (2012).
7 . . tt . , A y . tt . **78**, 2902 (2001).
8 . . . . . , A. . . . . , A y . tt . **84**, 4068 (2004).
9 . . t , . . A. y , . . **17**, 18 (2002).
10 . . . . . A y . **79**, 446 (1996).
11 . . . . . t , A y . tt . **61**, 468 (1992).
12 . . , A y . tt . **60**, 1507 (1992).
13 . . . A y . **74**, 1 (1993).
14 . . . . . w , A y . tt . **86**, 231103 (2005).
15 . . . . . , A y . tt . **94**, 201101 (2009).
16 . y , . y , . . , y . . **61**, 2742 (2000).