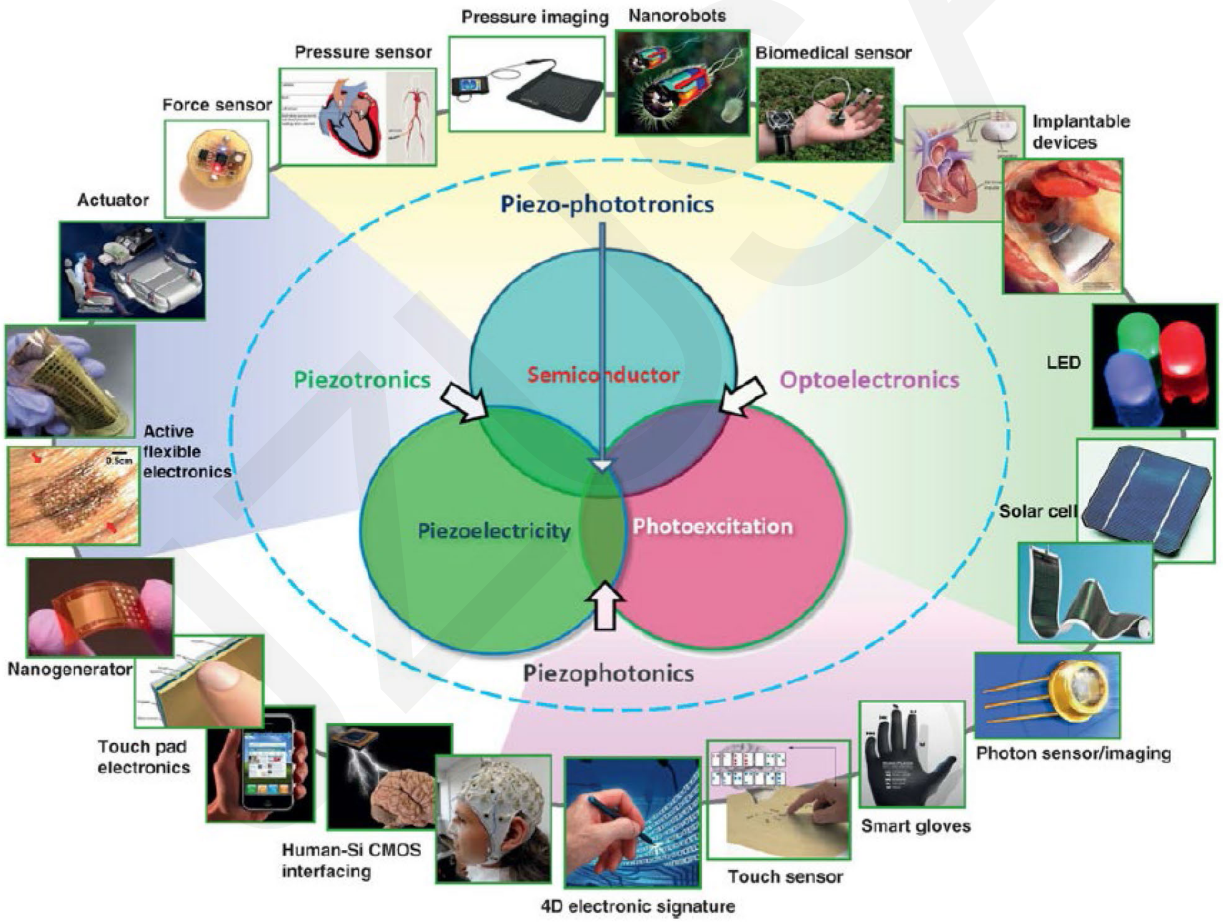
Journal of Zhejiang University-SCIENCE A
浙江大學
ZHEJIANG UNIVERSITY

Carrier distribution and electromechanical fields in a free piezoelectric semiconductor rod

Cited this as: Chun-li Zhang, Xiao-yuan Wang, Wei-qiu Chen, Jia-shi Yang, 2016. Carrier distribution and electromechanical fields in a free piezoelectric semiconductor rod. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 17(1):37-44. [doi:10.1631/jzus.A1500213]

Introduction

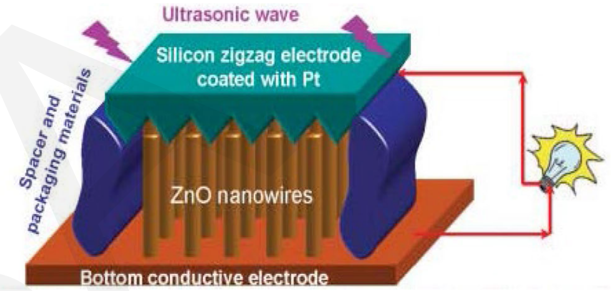
- **Piezoelectric semiconducting materials simultaneously possess piezoelectric and semiconducting properties. The interaction between the polarization field and charge carriers plays an important role in modern piezotronic and piezophotonic devices.**



Wang Z.L. , MRS Bulletin, 37(2012)p814

Introduction

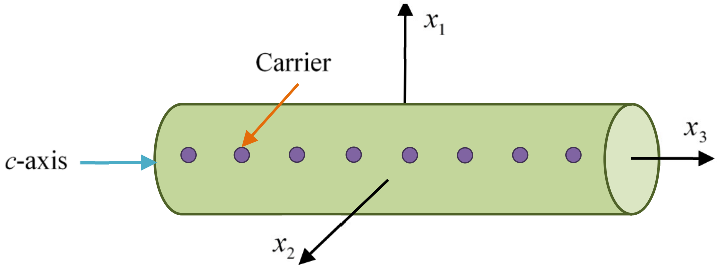
- **Piezoelectric semiconducting rod-type structures have recently sitimulated a great deal of research activities for their important technological promise in innovative muli-functional electronic and photonic devices.**



Ultrasonic wave energy harvester.

X.D. Wang, J.H. Song, J. Liu, Z.L. Wang, Science, 316 (2006) 102-105.

- **This paper is concerned with the carrier distribution and electromechanical fields in thea thin piezoelectric semiconductor rod which is often used in piezoelectric semiconductor devices. The rod is free from externally applied mechanical and electrical loads. This problem is fundamental to the applications of piezoelectric semiconductor rods or wires.**



The sketch of a piezoelectric semiconductor rod of crystals of 6mm

One-dimensional Model for a Rod

- **We performed a theoretical analysis using a one-dimensional model and obtained simple and useful results for the carrier distribution and electromechanical fields of a n-type piezoelectric semiconductor rod.**

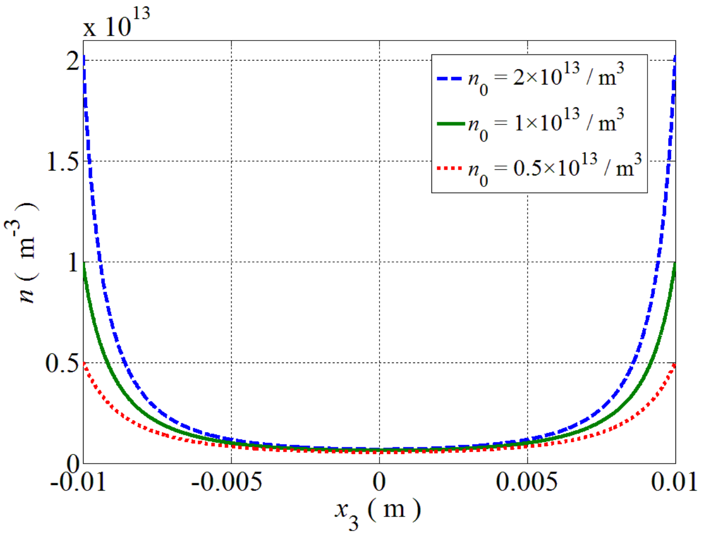
$$
\begin{aligned}
S_3 &= s_{33}T_3 + d_{33}E_3, & T_{33,3} &= 0,\\
D_3 &= d_{33}T_3 + \varepsilon_{33}E_3, & D_{3,3} &= q(-n + N_D^+),\\
J_3 &= qn\mu_{33}E_3 + qD_{33}n_{,3}, & J_{3,3} &= 0.
\end{aligned}
$$

$$
a = \frac{1}{2}\frac{\mu_{33}}{D_{33}} = \frac{1}{2}\frac{q}{kT}
$$

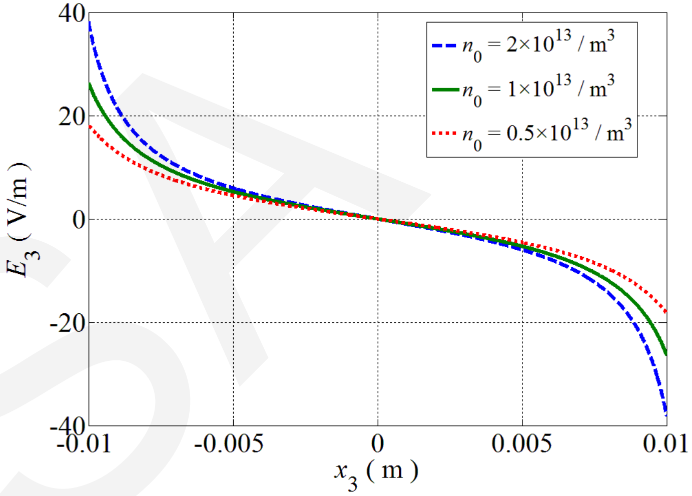
$$
u_3 = \frac{\bar{e}_{33}}{\bar{c}_{33}}\frac{1}{a}\ln\left[\cos\sqrt{ab}\,x_3\right], \quad S_3 = -\frac{\bar{e}_{33}}{\bar{c}_{33}}\frac{b\tan\sqrt{ab}\,x_3}{\sqrt{ab}}, \quad n = \frac{\varepsilon_{33}}{q}\frac{b}{\cos^2\sqrt{ab}\,x_3}, \quad T_3 = 0,
$$

$$
\phi = -\frac{1}{a}\ln\left[\cos\sqrt{ab}\,x_3\right], \quad E_3 = -\frac{b\tan\sqrt{ab}\,x_3}{\sqrt{ab}}, \quad D_3 = -\varepsilon_{33}\frac{b\tan\sqrt{ab}\,x_3}{\sqrt{ab}}, \quad J_3 = 0.
$$

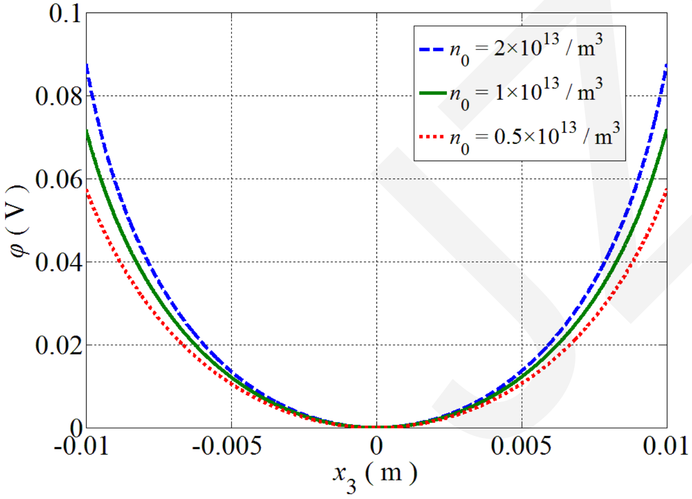
Results



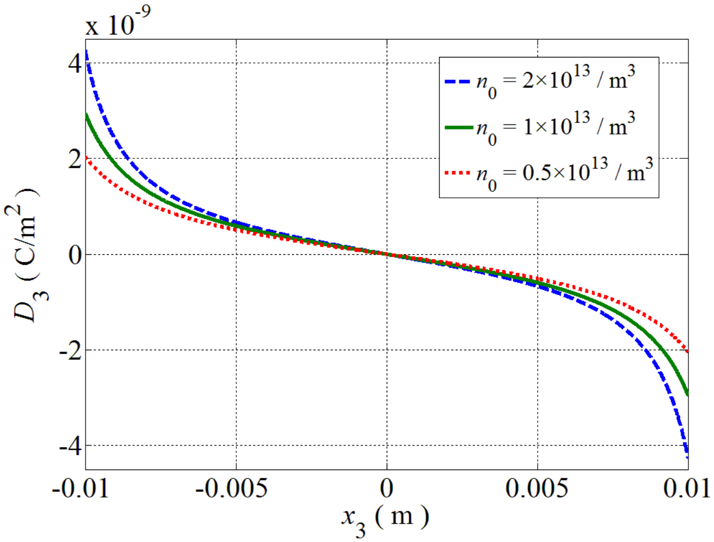
Carrier distribution along the rod.



Electric field distribution



Electric potential distribution.



(c) Electric displacement distribution

.

Conclusions

- Because of the presence of carriers and piezoelectric coupling, a thin piezoelectric semiconductor rod undergoes axial extension/contraction. The equations for determining the carrier density and electromechanical fields are nonlinear because of the drift current term.

- The carrier distribution and electromechanical fields are either symmetric or antisymmetric about the center of the rod. They are relatively stronger near the ends of the rod than at its central part. They are also sensitive to the numberamount of carriers. The effects of electrons and holes are qualitatively the same.