# Adjustment of electrical behaviors in a composite piezoelectric semiconductor structure through attaching non-uniform piezomagnetic layers

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**Abstract**

In order to control the magnetic field adjusted electrical behaviors in a composite piezomagnetic-piezoelectric semiconductor structure, non-uniform piezomagnetic layers are designed. After establishing the mathematical model, the effects of the non-uniform piezomagnetic layers on the electrical field quantities are investigated thoroughly. This work could be the guidance designing magneto-electric devices.

## 1 Introduction

Recent years, the adjustment of electrical behaviors through designing non-uniform cross section has been proposed [1]. Inspired by this concept, we attempt to design a composite structure with a uniform piezoelectric semiconductor core embedded between two non-uniform piezomagnetic layers, as shown in Figure 1. With the help of designed structure, the magnetic field adjusted electrical behaviors can be manipulated by changing the variation of cross section in piezomagnetic layers.

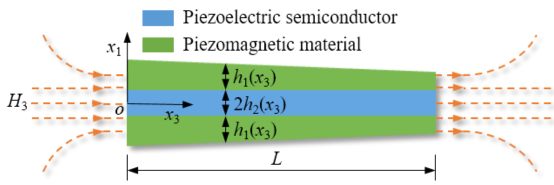



Figure 1: Sketch for a non-uniform composite serving in magnetic field.

## 2 Formulation and numerical analysis

Driven by axial magnetic field with constant $H_3$, the composite structure deforms along $x_3$ direction mainly. Resultantly, the mechanical displacement $u_3$, electric potential $\varphi$, and carrier concentration perturbation $\Delta n$ can be approximated by

$$u_3(x_1,x_2,x_3,t) \cong u_3(x_3,t), \quad \varphi(x_1,x_2,x_3,t) \cong \varphi(x_3,t), \quad \Delta n(x_1,x_3,t) \cong \Delta n(x_3,t). \tag{1}$$

Correspondingly, the relevant strain $S_{33}$ and electric field $E_3$ can be expressed by

$$S_{33} = u_{3,3}, \quad E_3 = -\varphi_{,3}. \tag{2}$$

The axial force $N_3$, electric displacement $\bar{D}_3$, and current density $\bar{J}_3^n$ are given by

$$N_3 = \bar{c}S_{33} - \bar{e}_{kij}E_3 - \bar{\beta}_{33}H_3, \quad D_3 = e_{33}S_{33} + \varepsilon_{33}E_3, \quad J_3^n = qn_0\mu_{33}^n E_3 + qd_{33}^n \Delta n_{,3}, \tag{3}$$

where $\bar{c} = c_{33}^{\mathrm{S}}A_2 + c_{33}^{\mathrm{M}}A_1(x_3)$, $\bar{e} = e_{33}^{\mathrm{S}}A_2$, $\bar{\varepsilon} = \varepsilon_{33}^{\mathrm{S}}A_2$, and $\bar{\beta}_{33} = \beta_{33}^{\mathrm{M}}A_1(x_3)$ are effective stiffness, piezoelectric constant, and dielectric constant. $A_1(x_3) = 4bh_1(x_3)$ and $A_2 = 4bh_2$ are the area of cross section. $q$ is the electronic charge. $\mu_{ij}^{n}$ and $d_{ij}^{n}$ represent the carrier mobility and carrier diffusion constants of electrons. $n_0$ is the initial concentration of electrons. The superscripts "S" and "M" denote the semiconductor and piezomagnetic layers, respectively.

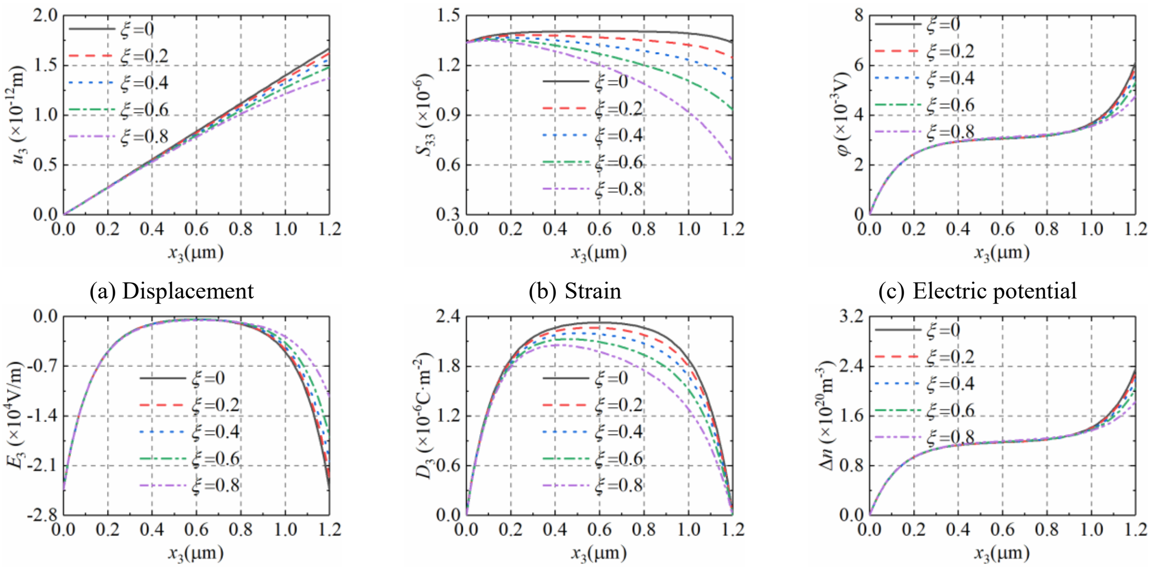
Based on these assumptions, one-dimensional governing equation can be developed, i.e.,

$$[\bar{c}_{33}u_{3,3}+\bar{e}_{33}\varphi_{,3}-\bar{\beta}_{33}H_3]_{,3}=0,\quad e_{33}u_{3,33}-\varepsilon_{33}\varphi_{,33}=-q\Delta n,\quad -n_0\mu_{33}^{n}\varphi_{,33}+d_{33}^{n}\Delta n_{,33}=0. \tag{4}$$

Here, we consider the entire structure is fixed at left end and free at right end. Besides, the boundaries are treated as electrically isolated. As a result, the boundary conditions are

$$u_3(0)=0,\ \ N_3(L)=0,\ \ D_3(0)=0,\ \ D_3(L)=0,\ \ J_3^{n}(0)=0,\ \ J_3^{n}(L)=0. \tag{5}$$

Applying differential quadrature method[2] to solve the complex governing equations with variable coefficients under the given boundary conditions, the effets of non-uniform piezomagnetic layers on the electrical behaviors can be analyzed.




(a) Displacement (b) Strain (c) Electric potential

(d) Electric field (e) Electric displacement (f) Perturbation carrier density

Figure 2: Effects of the variation in piezomagntic layers on the electrical field quantities.

Setting $h_1(x_3)=h_0(1-\xi x_3/L)$ and selecting the physcial parameters, Figure 2 gives the effects of the variation in piezomagntic layers on the electrical field quantities.

## 3 Conclusion

In this work, a composite structure which consists of piezoelectric semiconductor and non-uniform piezomagnetic layers is deigned. After establishing the mathematical model, the differential quadrature method is applied to calculate results. Furthermore, the Effects of the variation in piezomagntic layers on the electrical field quantities are investigated throughly.


## Acknowledgements

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## References


[1] K. Fang, P. Li, N. Li, et al, *Model and performance analysis of non-uniform piezoelectric semiconductor nanofibers, Appl. Math. Model.* **104** (2021) 628-643.

[2] Bert, C.W., Malik, M., *Differential quadrature method in computational mechanics: a review. Appl. Mech. Rev.* **49** (1996) 1-28.