The influence of the piezoelectric effect on stress distribution in semiconductor layers

A influência do efeito piezoelétrico na distribuição de tensão em camadas semicondutoras

Influencia del efecto piezoeléctrico en la distribución de tensiones en capas semiconductoras

DOI: 10.54021/seesv5n2-014

ABSTRACT

This study investigates thin structures by analyzing stress distribution in two different scenarios. In the first scenario, the absence of the $E_3$ and $d_{31}$ parameters is considered, while the second scenario examines their influence. The parameters vary according to a mixing rule based on thickness, with $h_1$, $h_2$, and $h_3$ representing the distinct layers of the structure. The coordinate origin is positioned on the lower surface of the structure. The piezoelectric effect in semiconductor layers refers to the phenomenon where mechanical stress within the material generates an electric charge due to the inherent piezoelectric properties of the material. This effect significantly influences the stress distribution in semiconductor layers, altering their mechanical and electrical behavior. Understanding this impact is crucial for...
optimizing the design and performance of semiconductor devices, as it affects the material's ability to handle stress and distribute it evenly, thereby enhancing the reliability and efficiency of electronic components. This comparative analysis enhances the understanding of the piezoelectric effect on stress distribution in semiconductor layers. By comparing these two scenarios, significant differences in stress distribution are observed when piezoelectric effects are considered. Understanding how piezoelectric effects influence stress distribution aids engineers in designing better semiconductor layers, enhancing both performance and reliability. This research underscores the critical importance of considering piezoelectric effects in the design and analysis of thin structures. By incorporating these effects, engineers can develop semiconductor devices that are not only more efficient but also significantly more robust. The study's findings highlight the necessity of integrating piezoelectric considerations into engineering practices to optimize material properties and structural integrity, ultimately leading to advancements in semiconductor technology and contributing to the development of high-performance, reliable electronic devices.

Keywords: Stress. Piezoelectric. Layers. Thin Structures.

RESUMO
Este estudo investiga estruturas finas por meio da análise da distribuição de tensões em dois cenários diferentes. No primeiro cenário, é considerada a ausência dos parâmetros E3 e d31, enquanto o segundo cenário examina sua influência. Os parâmetros variam de acordo com uma regra de mistura baseada na espessura, com h1, h2 e h3 representando as diferentes camadas da estrutura. A origem da coordenada está posicionada na superfície inferior da estrutura. O efeito piezoelétrico em camadas semicondutoras refere-se ao fenômeno em que a tensão mecânica dentro do material gera uma carga elétrica devido às propriedades piezoelétricas inerentes do material. Esse efeito influencia significativamente a distribuição de tensão nas camadas semicondutoras, alterando seu comportamento mecânico e elétrico. Compreender esse impacto é fundamental para otimizar o design e o desempenho dos dispositivos semicondutores, pois afeta a capacidade do material de lidar com a tensão e distribui-la uniformemente, aumentando assim a confiabilidade e a eficiência dos componentes eletrônicos. Essa análise comparativa aprimora a compreensão do efeito piezoelétrico na distribuição de tensão em camadas semicondutoras. Ao comparar esses dois cenários, são observadas diferenças significativas na distribuição de tensão quando os efeitos piezoelétricos são considerados. A compreensão de como os efeitos piezoelétricos influenciam a distribuição de tensão ajuda os engenheiros a projetar camadas semicondutoras melhores, aumentando o desempenho e a confiabilidade. Essa pesquisa ressalta a importância fundamental de considerar os efeitos piezoelétricos no projeto e na análise de estruturas finas. Ao incorporar esses efeitos, os engenheiros podem desenvolver dispositivos semicondutores que não são apenas mais eficientes, mas também significativamente mais robustos. As descobertas do estudo destacam a necessidade de integrar considerações piezoelétricas às práticas de engenharia para otimizar as propriedades do material e a integridade estrutural, o que, em última análise, leva a avanços na tecnologia de semicondutores e contribui para o desenvolvimento de dispositivos eletrônicos confiáveis e de alto desempenho.

RESUMEN
En este estudio se investigan estructuras delgadas analizando la distribución de tensiones en dos escenarios diferentes. En el primer escenario, se considera la ausencia de los parámetros E3 y d31, mientras que en el segundo se examina su influencia. Los parámetros varían según una regla de mezcla basada en el espesor, en la que h1, h2 y h3 representan las distintas capas de la estructura. El origen de coordenadas se sitúa en la superficie inferior de la estructura. El efecto piezoeléctrico en capas semiconductoras se refiere al fenómeno en el que la tensión mecánica dentro del material genera una carga eléctrica debido a las propiedades piezoeléctricas inherentes del material. Este efecto influye significativamente en la distribución de la tensión en las capas semiconductoras, alterando su comportamiento mecánico y eléctrico. Entender este impacto es crucial para optimizar el diseño y el rendimiento de los dispositivos semiconductoras, ya que afecta a la capacidad del material para manejar la tensión y distribuirla uniformemente, mejorando así la fiabilidad y la eficiencia de los componentes electrónicos. Este análisis comparativo mejora la comprensión del efecto piezoeléctrico sobre la distribución de la tensión en las capas semiconductoras. Al comparar estos dos escenarios, se observan diferencias significativas en la distribución de tensiones cuando se tienen en cuenta los efectos piezoeléctricos. Comprender cómo influyen los efectos piezoeléctricos en la distribución de tensiones ayuda a los ingenieros a diseñar mejores capas semiconductoras, mejorando tanto el rendimiento como la fiabilidad. Esta investigación subraya la importancia crítica de considerar los efectos piezoeléctricos en el diseño y análisis de estructuras delgadas. Al incorporar estos efectos, los ingenieros pueden desarrollar dispositivos semiconductoras que no sólo son más eficientes, sino también significativamente más robustos. Los resultados del estudio ponen de relieve la necesidad de integrar las consideraciones piezoeléctricas en las prácticas de ingeniería para optimizar las propiedades de los materiales y la integridad estructural, lo que en última instancia conduce a avances en la tecnología de semiconductoras y contribuye al desarrollo de dispositivos electrónicos fiables y de alto rendimiento.


1 INTRODUCTION

Composites are composed of more than one material to leverage complementary characteristics. Three widely used fiber-reinforced composites are reinforced concrete, reinforced rubber, and carbon-fiber epoxy[1].

Reinforced concrete combines the low cost and compressive strength of concrete with the ductility and tensile strength of steel. Reinforced rubber merges the high deformability of rubber, which absorbs dynamic energy, with the strength
and rigidity of steel. The carbon-fiber epoxy composite uses the matrix to bind the carbon fibers together[2].

The mechanical analysis of fiber-reinforced composites is divided into three main levels: macro-level, meso-level, and nano-level. The macro-level focuses on the overall behavior of structural components. The meso-level examines the interdependent behavior of the fiber and matrix, including interfacial stress and slippage[3]. The nano-level investigates the nanometric structure of the fibers and matrix themselves and their influence on the meso- and macro-levels[4-5].

Cellular materials have garnered significant research interest due to their exceptional energy absorption and attenuation capabilities. A significant improvement in crushing stress has been observed in dynamic impact experiments on wood. The critical role of transverse and normal shear stresses in identifying damage mechanisms in laminated composite plates, combined with the structural optimization demands of modern industries, has driven the application of models incorporating complete 3D kinematics and constitutive relationships.

Furthermore, the analysis of plates with cracks, holes, fillets, notches, and other geometric discontinuities requires high accuracy in predicting stress fields. A comprehensive literature review revealed a wide range of scientific articles addressing various aspects of determining the ultimate tensile strength of materials, particularly brittle materials, using the Brazilian test. These studies highlight the evolution of the state of the art on this topic, analyzing what the authors consider the 43 most significant works[6].

The displacement field in the flow around a circular cylinder is of significant interest due to its relevance in various engineering applications. These include vortex-induced vibration on risers and pipelines, inertia and damping forces on platform columns, and other cylindrical structures [7]. Researchers have been driven to investigate the behavior of flow around circular cylinders due to its impact on offshore structures like wind turbines and spar platforms, emphasizing the importance of accurately assessing wave loads for safety [8].

As dimensions shrink to the nanometer scale, continuum mechanics is increasingly explored for modeling materials. The mechanical behavior of these nanostructures is heavily influenced by size effects when dimensions become comparable to molecular distances. Non-local continuum theories were introduced
to address such behaviors, where stress at a reference point is a function of strain throughout the body [9-13].

In the context of cylindrical structures, non-local elastic beam and shell models have been developed to explore small-scale effects on the buckling analysis of carbon nanotubes (CNTs) under axial compression. The Eringen model, for example, has been applied to analyze Euler-Bernoulli micro and nano beams. The significance of the small-scale effect is evident in studies of CNTs, such as the elastic buckling of multi-walled carbon nanotubes (MWCNTs) under uniform external radial pressure [14-20].

Recent research has also focused on functionally graded material (FGM) plates. Using refined plate theories, including those with four variables, studies have examined axial buckling under various load conditions without the need for shear correction factors.

2 THEORETICAL CONTRIBUTION

This study establishes a framework for analyzing stress distribution in layered structures, incorporating the effect of piezoelectricity. This approach enhances our understanding of the interplay between mechanical and electrical properties in these materials.

3 PRACTICAL CONTRIBUTION:

The findings provide engineers with valuable insights for designing more robust and efficient semiconductor devices. By understanding how the piezoelectric effect alters stress distribution, engineers can:

- optimize material selection and layer configurations to achieve better stress management;
- enhance the reliability of electronic components by preventing stress-induced failures.
4 SIGNIFICANCE

Highlighting the critical role of piezoelectricity in stress distribution underscores the need to integrate this factor into the design process. This ultimately leads to advancements in:

- semiconductor technology through the development of high-performance materials;
- electronic device reliability by ensuring structural integrity under various operational conditions.

This research offers a significant contribution by bridging the gap between the theoretical understanding of the piezoelectric effect and its practical implications in the design and optimization of next-generation semiconductor devices.

These theories accommodate porosity and other imperfections in the thermo-mechanical behavior of such structures.

Figure 1: Homogeneous composite structure for each layer

![Homogeneous composite structure for each layer](source: The authors)

In our study, the structure under investigation consists of three layers with different thicknesses, denoted as $h_1$, $h_2$, and $h_3$. The top surface is at $z=h$, and the bottom surface is at $z=0$. Under the given conditions, the layers are invariant in both the x and y directions. Therefore, our focus is on the stress distribution along the z direction.

\[
(N_z, M_z) = \int_A \sigma_z(1, z) dA = 0
\]

We work with isotropic elastic materials. The relationship between strain, stress, temperature, and piezoelectric parameters is expressed as follows:
\[ \varepsilon(z) = \frac{1}{E(z)} \sigma(z) + \alpha(z) \Delta T - E_3 d_{31} \]  \hspace{1cm} (2) \\

Or \\
\[ \bar{E}(z) = \frac{E(z)}{1-\nu(z)} \]  \hspace{1cm} (3) \\

such as:

\( E(z) \) is the elastic modulus. \\
\( \nu(z) \) is the Poisson's ratio. \\
\( \alpha(z) \) is the thermal expansion coefficient, which is a continuous function of \( z \). \\
\( \Delta T \) is the temperature. \\
\( E_3 \) is the electric field. \\
\( d_{31} \) piezoelectric coefficient.

5 STEPS FOR ANALYSIS

1. define layer boundaries: identify the boundaries of each layer at \( h_1 \), \( h_2 \) and \( h_3 \); 
2. apply stress-strain relationship: use the given stress-strain relationship to express the strain in terms of stress, temperature change, and piezoelectric effects for each layer; 
3. integrate across layers: integrate the stress equation across the thickness of each layer to determine the overall stress distribution; 
4. consider boundary conditions: apply the appropriate boundary conditions at \( z=0 \) and \( z=h \) to solve for unknowns and obtain the stress distribution in each layer; 
5. evaluate the impact of variations: analyze how variations in material properties, temperature changes, and electric fields affect the stress distribution in the composite structure.

To calculate all parameters along the \( z \)-axis, we utilize the function \( P(z) \), taking into account the heights \( h_1 \), \( h_2 \) and \( h_3 \), as well as the initial deformation. The variation in deformation is expressed as:
\[ \delta \varepsilon (z) = \frac{1}{E(z)} \sigma (z) + \alpha (z) \Delta T - E_3 d_{31} - \varepsilon_e (z) \] (4)

**6 STRESS VARIATION**

The stress varies proportionally with \( z \), considering both the temperature and the initial deformation effects. We denote this proportionality as:

\[ \delta \varepsilon (z) = k (\bar{z} - z) \] (5)

The relationship between stress and the other factors is given by:

\[ \sigma (z) = E(z) [k (\bar{z} - z) - \alpha (z) \Delta T - E_3 d_{31} + \varepsilon_e (z)] \] (6)

**7 DETERMINATION OF CONSTANTS**

The constants \( k \) and \( \bar{z} \) are derived from the equations of force (\( N \)), moment (\( M \)), and the stress equation. These relationships can be expressed as follows:

\[ I_n = \int_0^h z^n \overline{E}(z) \, dz \text{ Avec } n=0,1,2. \] (7)

\[ I_0 = \int_0^h \overline{E}(z) \, dz \] (8)

\[ I_1 = \int_0^h z \overline{E}(z) \, dz \] (9)

\[ I_2 = \int_0^h z^2 \overline{E}(z) \, dz \] (10)

\[ J_m = \int_0^h z^m \overline{E}(z) \left[ \alpha (z) \Delta T - E_3 d_{31} + \varepsilon_e (z) \right] dz \text{ With } m=0,1 \] (11)

\[ J_0 = \int_0^h \overline{E}(z) \left[ \alpha (z) \Delta T - E_3 d_{31} + \varepsilon_e (z) \right] dz \] (12)

\[ J_1 = \int_0^h z \overline{E}(z) \left[ \alpha (z) \Delta T - E_3 d_{31} + \varepsilon_e (z) \right] dz \] (13)
8 INTEGRATION OF THE STRESS EQUATION

Initially, we integrate the stress equation once, resulting in:

\[
\int_0^h \sigma(z) \, dz = \int_0^h \overline{E}(z) k \bar{z} \, dz - \int_0^h \overline{E}(z) kz \, dz - \int_0^h \overline{E}(z) \alpha(z) \Delta T \, dz - \int_0^h \overline{E}(z) E_3 d_{31} \, dz + \int_0^h \overline{E}(z) \varepsilon_e(z) \, dz = 0 
\]  

(14)

Substituting each integral with its respective expression yields:

\[
k \bar{z} l_0 - k l_1 - J_0 - E_3 d_{31} l_0 = 0 
\]  

(15)

Similarly, we multiply the stress equation by \(zzz\) and integrate to get:

\[
\int_0^h \sigma(z) z \, dz = \int_0^h \overline{zE}(z) k \bar{z} \, dz - \int_0^h \overline{zE}(z) kz \, dz - \int_0^h \overline{zE}(z) \alpha(z) \Delta T \, dz - \int_0^h \overline{zE}(z) E_3 d_{31} \, dz + \int_0^h \overline{zE}(z) \varepsilon_e(z) \, dz = 0 
\]  

(16)

From this integration, we derive:

\[
k \bar{z} l_1 - k l_2 - J_1 + E_3 d_{31} l_1 = 0 
\]  

(17)

The solution to these equations provides us with:

\[
k = \frac{l_0 l_1 + 2 E_3 d_{31} l_0 + l_1 l_0}{- l_1^2 + l_0 l_2} 
\]  

(18)

\[
\bar{z} = \frac{l_2 l_0 + E_3 d_{31} l_0 l_2 + l_1 l_1 + E_3 d_{31} l_1^2}{2 E_3 d_{31} l_0 l_1 - l_0 l_1 + f_0 \Gamma_1} 
\]  

(19)

We use a variation law for all parameters that change along the \(z\)-axis, expressed as:
where:

$P_1$ and $P_2$ are constants.

This relationship can be extended to all variable parameters as follows:

$$
P(z) = \begin{cases} 
P_1 \left(\frac{h_1 + h_2 - z}{h_2}\right) + P_2 \left(\frac{z - h_1}{h_2}\right) & \text{pour} \quad 0(z<h_1) \\
\text{pour} \quad h_1(z<h_1+h_2) \\
\text{pour} \quad h_1 + h_2(z<h_1+h_2+h_3)
\end{cases}
$$
\hfill (20)

9 DISCUSSION AND RESULTS

$E_{33}=75$kV/cm, $\varepsilon_1=0$, $\varepsilon_3=-0.00074799$, $d_{31}=-21$, $h_1=0.1\text{mm}$, $h_3=0.01\text{mm}$,
$\alpha_1=0.415220698\times10^{-5}$ $\alpha_3=0.8\times10^{-5}$ $u_1 =0.312$ $u_3=0.36$, $\Delta T =1100^\circ\text{C}$ $E_1=85.30$ N/mm$^2$ $E_3=81.10$ N/mm$^2$
Table 1: Variation of Stress as a Function of \( z \) (\( h_2<0.09 \text{mm} \))

<table>
<thead>
<tr>
<th>( z ) (mm)</th>
<th>( \sigma(z) ) (GPa) for ( h_2 = 0.01 )</th>
<th>( \sigma(z) ) (GPa) for ( h_2 = 0.03 )</th>
<th>( \sigma(z) ) (GPa) for ( h_2 = 0.05 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>-0.05</td>
<td>-0.04</td>
<td>-0.03</td>
</tr>
<tr>
<td>0.02</td>
<td>-0.04</td>
<td>-0.03</td>
<td>-0.02</td>
</tr>
<tr>
<td>0.04</td>
<td>-0.03</td>
<td>-0.02</td>
<td>-0.01</td>
</tr>
<tr>
<td>0.06</td>
<td>-0.02</td>
<td>-0.01</td>
<td>0.00</td>
</tr>
<tr>
<td>0.08</td>
<td>0.00</td>
<td>0.00</td>
<td>0.01</td>
</tr>
<tr>
<td>0.10</td>
<td>0.01</td>
<td>0.02</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Source: Authors

Table 2: Variation of Stress as a Function of \( z \) (\( h_2>0.09 \text{mm} \))

<table>
<thead>
<tr>
<th>( z ) (mm)</th>
<th>( \sigma(z) ) (GPa) for ( h_2 = 0.10 )</th>
<th>( \sigma(z) ) (GPa) for ( h_2 = 0.14 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>-0.05</td>
<td>-0.04</td>
</tr>
<tr>
<td>0.02</td>
<td>-0.04</td>
<td>-0.03</td>
</tr>
<tr>
<td>0.04</td>
<td>-0.03</td>
<td>-0.02</td>
</tr>
<tr>
<td>0.06</td>
<td>-0.02</td>
<td>-0.01</td>
</tr>
<tr>
<td>0.08</td>
<td>-0.01</td>
<td>0.00</td>
</tr>
<tr>
<td>0.10</td>
<td>0.00</td>
<td>0.01</td>
</tr>
<tr>
<td>0.12</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>0.14</td>
<td>0.02</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Source: Authors

Table 3: Variation of Stress as a Function of \( z \) (\( h_2<0.09 \text{mm} \)) with the Presence of \( E_3 \) and \( d_{31} \)

<table>
<thead>
<tr>
<th>( z ) (mm)</th>
<th>( \sigma(z) ) (GPa) for ( h_2 = 0.01 )</th>
<th>( \sigma(z) ) (GPa) for ( h_2 = 0.03 )</th>
<th>( \sigma(z) ) (GPa) for ( h_2 = 0.05 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>-1.4 \times 10^7</td>
<td>-1.3 \times 10^7</td>
<td>-1.2 \times 10^7</td>
</tr>
<tr>
<td>0.05</td>
<td>-0.5 \times 10^7</td>
<td>-0.6 \times 10^7</td>
<td>-0.7 \times 10^7</td>
</tr>
<tr>
<td>0.10</td>
<td>0.6 \times 10^7</td>
<td>0.4 \times 10^7</td>
<td>0.3 \times 10^7</td>
</tr>
<tr>
<td>0.15</td>
<td>1.2 \times 10^7</td>
<td>1 \times 10^7</td>
<td>0.8 \times 10^7</td>
</tr>
<tr>
<td>0.20</td>
<td>3 \times 10^7</td>
<td>2 \times 10^7</td>
<td>1.5 \times 10^7</td>
</tr>
<tr>
<td>0.25</td>
<td>4.5 \times 10^7</td>
<td>2 \times 10^7</td>
<td>1.5 \times 10^7</td>
</tr>
</tbody>
</table>

Source: Authors

Table 4: Variation of Stress as a Function of \( z \) (\( h_2>0.09 \text{mm} \)) with the Presence of \( E_3 \) and \( d_{31} \)

<table>
<thead>
<tr>
<th>( z ) (mm)</th>
<th>( \sigma(z) ) (GPa) for ( h_2 = 0.10 )</th>
<th>( \sigma(z) ) (GPa) for ( h_2 = 0.14 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>-5.5 \times 10^7</td>
<td>-5.5 \times 10^7</td>
</tr>
<tr>
<td>0.05</td>
<td>-5 \times 10^7</td>
<td>-5 \times 10^7</td>
</tr>
<tr>
<td>0.10</td>
<td>-2.5 \times 10^7</td>
<td>-2.5 \times 10^7</td>
</tr>
<tr>
<td>0.15</td>
<td>2.5 \times 10^7</td>
<td>2.5 \times 10^7</td>
</tr>
<tr>
<td>0.20</td>
<td>5.5 \times 10^7</td>
<td>5.5 \times 10^7</td>
</tr>
</tbody>
</table>

Source: Authors
These tables provide a clear and structured reading of the stress variations as a function of z for different thicknesses $h_2$ and the presence or absence of the parameters $E_3$ and $d_{31}$.

9.1 INTERPRETATION OF TABLE 1: VARIATION OF STRESS AS A FUNCTION OF Z ($H_2 < 0.09\text{MM}$)

Table 1 provides the variation of stress, $\sigma(z)$, in (GPa) as a function of the position, $z$, in millimeters (mm), for three different values of $h_2$ (0.01 mm, 0.03 mm, and 0.05 mm). The stress values are presented for each $h_2$ at various positions along the $z$-axis from 0.00 mm to 0.12 mm.

- for all three values of $h_2$, the stress $\sigma(z)$ increases as $z$ increases from 0.00 mm to 0.12 mm;
- the stress changes from negative to positive values as $z$ increases, indicating a transition from compressive to tensile stress.

**Impact of $h_2$ on Stress Variation:**

- higher $h_2$ values result in less negative compressive stresses at lower $z$ values and more positive tensile stresses at higher $z$ values;
- the rate of change from compressive to tensile stress is influenced by the value of $h_2$, with larger $h_2$ leading to a quicker transition. The data presented in Table 1 illustrates the variation in stress along the $z$-axis for different values of $h_2$. As $z$ increases, stress transitions from compressive to tensile, with the magnitude and transition rate dependent on the specific $h_2$ value. Smaller $h_2$ values exhibit greater initial compressive stresses, while larger $h_2$ values show higher tensile stresses at increased $z$ values.

This detailed analysis provides a comprehensive understanding of the stress distribution influenced by the parameter $h_2$.

9.2 INTERPRETATION OF TABLE 2: VARIATION OF STRESS AS A FUNCTION OF Z ($H_2 > 0.09\text{MM}$)

Table 2 presents the variation of stress, $\sigma(z)$, in (GPa) as a function of the position, $z$, in millimeters (mm), for two different values of $h_2$ (0.10 mm and 0.14
mm). The stress values are shown for each \( h_2 \) at various positions along the z-axis from 0.00 mm to 0.14 mm.

For both values of \( h_2 \), the stress \( \sigma(z) \) increases as \( z \) increases from 0.00 mm to 0.14 mm.

- the stress changes from negative (compressive) to positive (tensile) values as \( z \) increases, indicating a transition from compressive to tensile stress.

Impact of \( h_2 \) on Stress Variation:

- higher \( h_2 \) values result in less negative compressive stresses at lower \( z \) values and more positive tensile stresses at higher \( z \) values;
- the rate of change from compressive to tensile stress is influenced by the value of \( h_2 \), with larger \( h_2 \) leading to a quicker transition.

The data presented in Table 2 illustrates the variation in stress along the z-axis for different values of \( h_2 \). As \( z \) increases, stress transitions from compressive to tensile, with the magnitude and transition rate dependent on the specific \( h_2 \) value. Smaller \( h_2 \) values exhibit greater initial compressive stresses, while larger \( h_2 \) values show higher tensile stresses at increased \( z \) values. This detailed analysis provides a comprehensive understanding of the stress distribution influenced by the parameter \( h_2 \).

### 9.3 INTERPRETATION OF TABLE 3: VARIATION OF STRESS AS A FUNCTION OF Z (\( H_2 < 0.09 \text{MM} \)) WITH THE PRESENCE OF \( E_3 \) AND \( D_{31} \)

Table 3 presents the variation of stress, \( \sigma(z) \), in (GPa) as a function of the position, \( z \), in millimeters (mm), for three different values of \( h_2 \) (0.01 mm, 0.03 mm, and 0.05 mm) with the presence of the parameters \( E_3 \) and \( d_{31} \).

- for all three values of \( h_2 \), the stress \( \sigma(z) \) increases as \( z \) increases from 0.00 mm to 0.10 mm;
- the presence of \( E_3 \) and \( d_{31} \) introduces additional stress factors.

Impact of \( E_3 \) and \( d_{31} \):

- the parameters \( E_3 \) and \( d_{31} \) likely introduce piezoelectric or electro-mechanical effects that influence the stress distribution;
- these effects can cause significant variations in stress, leading to higher tensile stresses as seen in the increasing trend at \( z=0.05 \text{ mm} \) and \( z=0.10 \text{ mm} \).
The data presented in Table 3 illustrates the variation in stress along the z-axis for different values of $h_2$ with the presence of $E_3$ and $d_{31}$. The stress transitions from compressive to tensile as z increases, with the magnitude of the tensile stress increasing for larger $h_2$. The presence of $E_3$ and $d_{31}$ adds complexity to the stress distribution, indicating significant piezoelectric or electro-mechanical influences. The provided data highlights the need for further points to complete the analysis beyond $z=0.10$ mm. This detailed interpretation offers a comprehensive understanding of the stress distribution influenced by the parameters $h_2$, $E_3$ and $d_{31}$.

9.4 INTERPRETATION OF TABLE 4: VARIATION OF STRESS AS A FUNCTION OF Z ($H_2 > 0.09$MM) WITH THE PRESENCE OF $E_3$ AND $D_{31}$

Table 4 presents the variation of stress, $\sigma(z)$, in (GPa) as a function of the position, z, in millimeters (mm), for two different values of $h_2$ (0.10 mm and 0.14 mm) with the presence of the parameters $E_3$ and $d_{31}$.

- for both values of $h_2$, the stress $\sigma(z)$ increases as z increases from 0.00 mm to 0.10 mm;
- the stress changes from highly negative (compressive) to highly positive (tensile) as z increases, indicating a significant transition in stress state.

Impact of $E_3$ and $d_{31}$:

- the presence of $E_3$ and $d_{31}$ likely introduces significant piezoelectric or electro-mechanical effects that influence the stress distribution;
- these effects contribute to the high variation in stress values, leading to substantial compressive stresses initially and transitioning to high tensile stresses.

The data presented in Table 4 illustrates the variation in stress along the z-axis for different values of $h_2$ with the presence of $E_3$ and $d_{31}$. As z increases, the stress transitions from highly compressive to highly tensile, with the magnitude of both compressive and tensile stress increasing for larger $h_2$. The presence of $E_3$ and $d_{31}$ introduces substantial electro-mechanical influences, causing significant variations in stress. The provided data highlights the need for further points to complete the analysis beyond $z=0.10$ mm. This detailed interpretation offers a
comprehensive understanding of the stress distribution influenced by the parameters $h_2$, $E_3$ and $d_{31}$.

10 CONCLUSION

In various fields of research, the study of stress distribution in structures under varying parameters is of paramount importance. This investigation focused on analyzing the stress distribution within a composite material of three different thicknesses, with a particular emphasis on the influence of the piezoelectric effect.

Our analysis revealed several key insights:

- **Stress Distribution at the Neutral Axis**: For all cases studied, at $z=0$ (the neutral axis of the composite), the stress variation is negative. This indicates that at the central plane of the composite, the stress is typically compressive.

- **Zero stress point**: as we move away from $z=0$, there exists a specific value of $z$ at which the stress neutralizes. This zero-stress point is crucial as it signifies the transition from compressive to tensile stresses across the thickness of the composite;

- **Stress reversal**: beyond this neutral point, the stress distribution changes its sign. This change indicates a shift from compressive to tensile stress or vice versa, depending on the direction of traversal through the composite’s thickness;

- **Impact of piezoelectric effect**: one of the most significant findings of this study is the substantial influence of the piezoelectric effect on the stress distribution. The presence of this effect markedly amplifies the stress values within the composite material. This amplification underscores the necessity of considering piezoelectric properties in the design and analysis of composite materials, especially in applications where mechanical performance is critical.

- **Sign change in stress distribution**: beyond the neutral stress point, the stress distribution alters its sign, denoting a reversal from compressive to tensile stress or vice versa depending on the direction through the material’s thickness. The tables provided in this study vividly illustrate these phenomena,
showing how the stress distribution varies with different thicknesses and the
presence of the piezoelectric effect. The piezoelectric effect, in particular, plays
a crucial role in magnifying the stress values, making it a pivotal factor in the
engineering and optimization of composite structures.

11 SOCIETAL IMPACT

- development of advanced materials: by understanding how stress is
distributed and how the piezoelectric effect influences it, engineers can
design new composite materials with tailored properties. These materials
could be stronger, lighter, and more efficient, leading to advancements in
various fields such as:
  - aerospace engineering: lighter and stronger aircraft components;
  - civil engineering: more robust and earthquake-resistant structures;
  - biomedical engineering: improved prosthetics and implants.
- enhanced device performance: the knowledge gained can be used to
create more reliable and efficient electronic devices that utilize piezoelectric
materials. This could lead to:
  - smaller and more powerful electronic components;
  - improved energy harvesting technologies;
  - more durable and reliable sensors and actuators.

12 ACADEMIC IMPACT

- deeper understanding of stress distribution: this research provides a
framework for analyzing stress distribution in composite materials,
considering the piezoelectric effect. This approach can be further explored
and refined to gain a deeper understanding of the complex interactions
between mechanical and electrical properties in these materials;
- guiding future research: the findings provide valuable insights for future
research directions. Here are some potential areas of exploration:
  - the dynamic response of these materials under varying loads;
  - the long-term durability of piezoelectric composites;
• their performance under extreme environmental conditions.

Overall, this research contributes to both the development of new and improved materials for society and the advancement of knowledge within academia.

Understanding the interplay between stress distribution and the piezoelectric effect in composite materials offers valuable insights for engineering applications. These findings can guide the development of advanced materials with tailored mechanical properties for specific applications. Future research could explore the dynamic response of such materials under varying load conditions, the long-term durability of piezoelectric composites, and their performance under extreme environmental conditions.

In conclusion, this study underscores the crucial role of piezoelectricity in stress distribution within semiconductor devices. By analyzing structures with and without this effect, we unveil its significant impact on stress patterns. This newfound knowledge equips engineers to design better performing and more reliable semiconductor layers. By integrating piezoelectric considerations, the development of high-performance and robust electronic devices becomes a reality.
REFERENCES


