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Fracture analysis in piezoelectric semiconductors under a thermal load

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ABSTRACT

In this paper, we solve the in-plane crack problem in piezoelectric semiconductors under a transient thermal load. General boundary conditions and sample geometry are allowed in the proposed formulation. The coupled governing partial differential equations (PDE) for stresses, electric displacement field and current are satisfied in a local weak-form on small fictitious subdomains. All field quantities are approximated by the moving least-squares (MLS) scheme. After performing the spatial integrations, we obtain a system of ordinary differential equations for the nodal unknowns. The influence of initial electron density on the intensity factors and energy release rate is investigated.

1. Introduction

Piezoelectric materials (PZ) have a wide range of engineering applications in smart structures and devices. Certain piezoelectric materials are also temperature sensitive, i.e. an electric charge or voltage is generated when temperature variations are exposed. This effect is called the pyroelectric effect. If a temperature load is considered in a piezoelectric solid it is needed to take into account the coupling of thermo-electro-mechanical fields. The theory of thermo-piezoelectricity was for the first time proposed by Mindlin [22]. The physical laws for thermo-piezoelectric materials were explored by Nowacki [23]. Dynamic thermoelasticity is relevant for many engineering problems since thermal stresses play an important role in the integrity of structures. The uncoupled thermoelasticity is considered here, since there is no heat production due to the strain rate, i.e. the thermoelastic dissipation. Thus, the temperature field is not influenced by mechanical deformation and the heat conduction equation can be solved first to obtain the temperature distribution. However, the coupling of mechanical and electric fields is still valid. Recently, Sladek et al. [39] analyzed non-conducting piezoelectric materials under a thermal load.

However, piezoelectric materials can be either dielectrics or semiconductors. Up to date dielectric materials are more intensively investigated than semiconductors. The analyzed problem for non-conducting PZ is simpler than for semiconductors. In piezoelectric semiconductors the induced electric field produces also the electric current. The interaction between mechanical fields and mobile charges in piezoelectric semiconductors is called the acoustoelectric effect [18,50]. An acoustic wave traveling in a PZ semiconductor can be amplified by application of an initial or biasing direct current electric field [44].

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Nomenclature

Latin symbols

a	crack-length
c	specific heat
c_{ijkl}	elasticity tensor
d_{ij}	carrier diffusion tensor
e_{ijk}	piezoelectric tensor
h_{ij}	dielectric tensor
k_{ij}	thermal conductivity
n_j	outward unit normal vector
p_j	pyroelectric material coefficients
$\mathbf{p}^{\mathbf{T}}$	vector of complete basis functions
q	electric charge of electron
t_i	traction vector
u_{i}	elastic displacements
u_{ik}^{*}	test function
w^{*}	test function
w^{a}	weight function
D_i	electric displacements
E_i	electric field
G	energy release rate
J_i	electric current
K_I, K_{II}	stress intensity factors
K_D	electric displacement intensity factor
K_γ	strain intensity factor
K_E	electric vector intensity factor
M	electron density
N^a	shape function associated with the node a

Greek symbols

β_{ij}	linear thermal expansion
δ_{ij}	Kronecker delta
ε_{ij}	strain tensor
ϕ	electric potential
λ_{ij}	stress-temperature modulus
μ_{ij}	electron mobility tensor
v^{*}	test function
ρ	mass density
σ_{ij}	stress tensor
τ	time
Γ_u	boundary with prescribed displacements
Γ_t	boundary with prescribed tractions
Γ_p	boundary with prescribed electric potential
Γ_q	boundary with prescribed normal component of the electric displacements
Γ_a	boundary with prescribed electron density
Γ_b	boundary with prescribed electric current flux
Γ_e	boundary with prescribed temperature
Γ_f	boundary with prescribed heat flux
Ω_S	local subdomain
$\partial\Omega_S$	boundary of the local subdomain

Other symbols

$f_{,\mathrm{i}}$	partial derivative of the function f
$\dot{f}$	time derivative of the function f

This phenomenon is utilized in many acoustoelectric devices [15,4]. In literature one can find also more sophisticated models of deformable piezoelectric semiconductors [52,53]. Lorenzi and Tiersten [52] derived governing equations for finitely deformable, polarized and magnetizable heat conducting and electrically semiconducting continuum. The model consists