Shock acoustical waves on linear and non-linear dielectric and flexoelectric materials

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Intersonic shear cracks and fault ruptures

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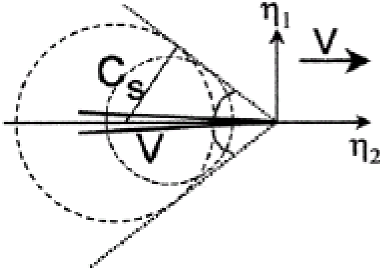
$$\sin\theta = \frac{c_s}{V}$$



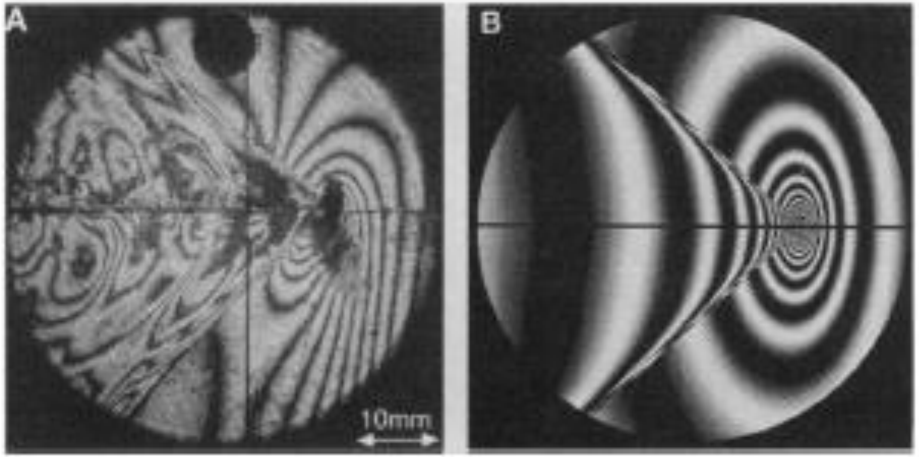
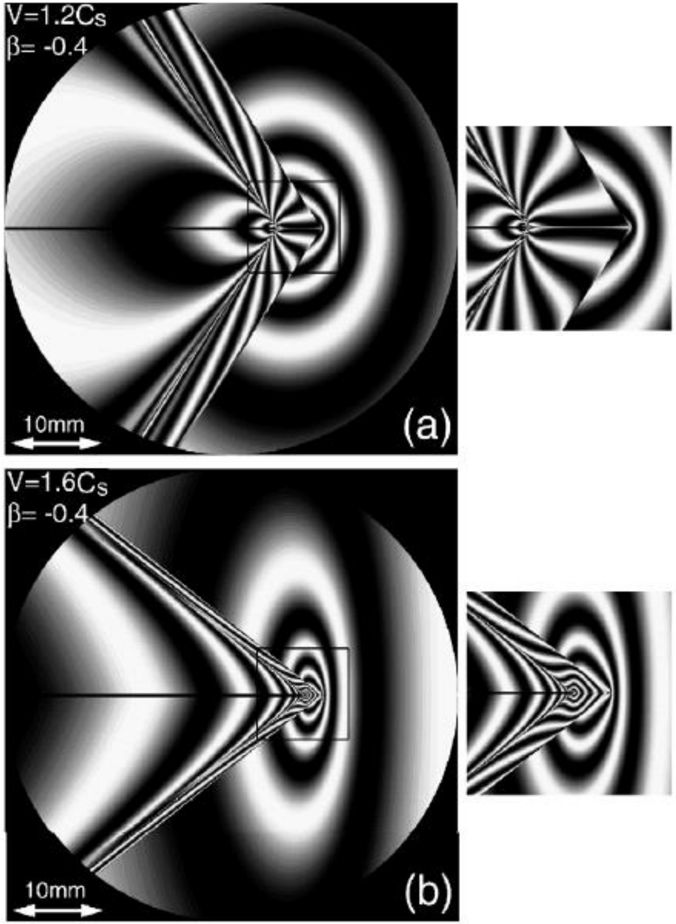
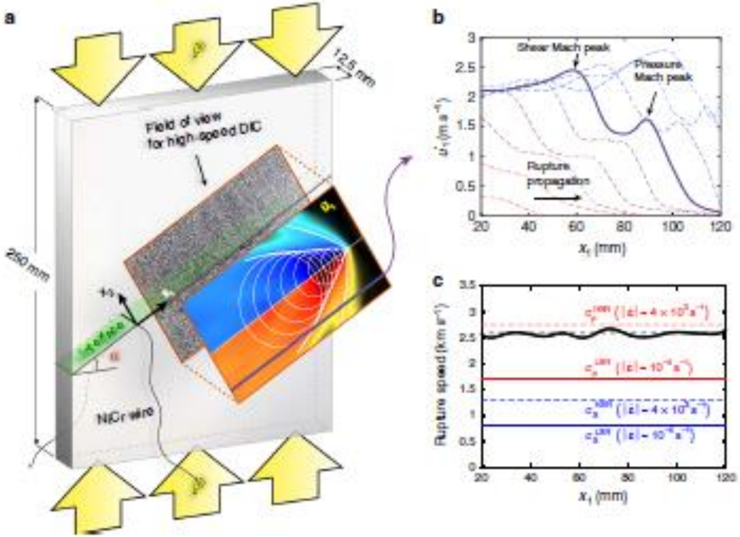
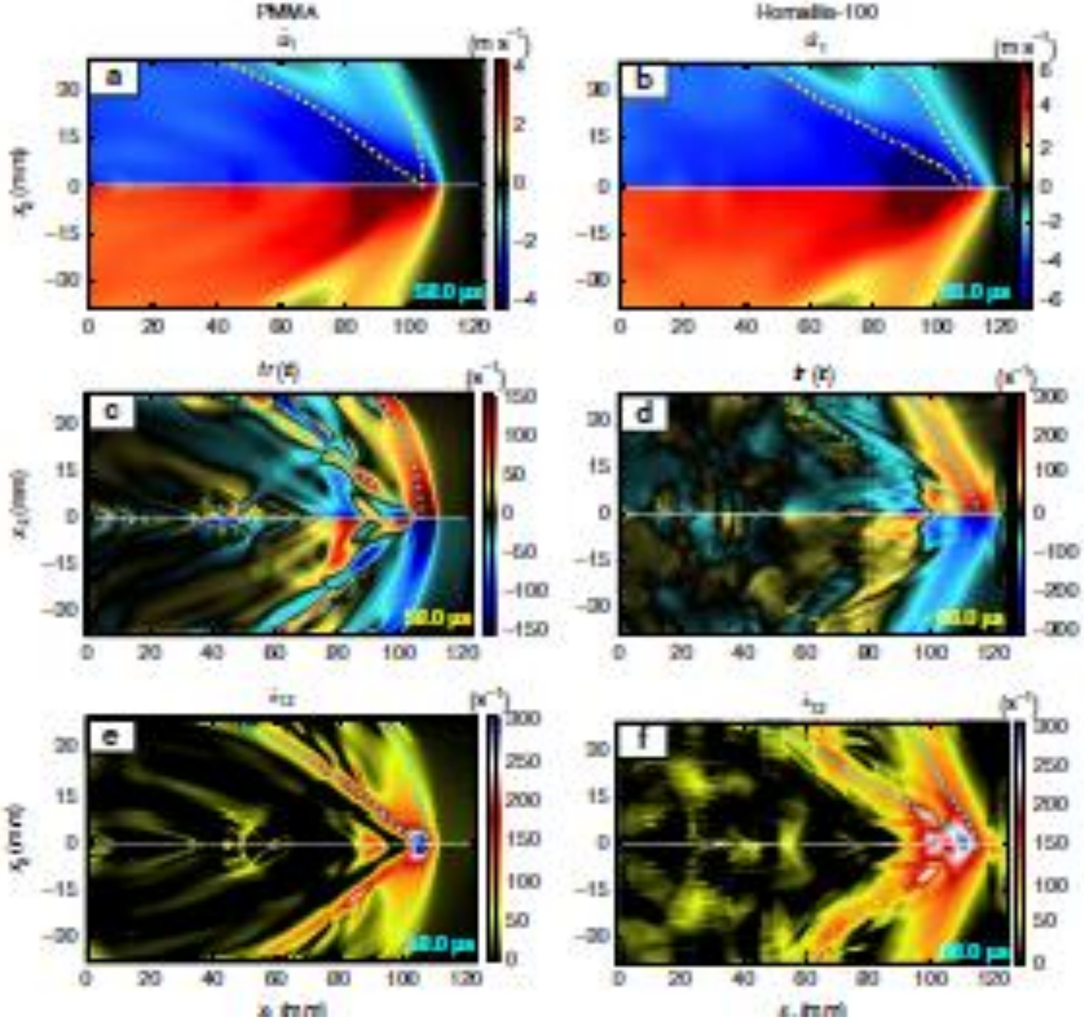


Fig. 4. Enlarged view of the isochromatic fringe pattern around a steady-state mode II intersonic crack along a weak plane in Homalite-100. (A) Experimental pattern. (B) Freund's theoretical prediction (13). For both cases, $\beta = 43°$ and $v = 1.47c_s$.



ure 21. Synthetic isochromatic patterns constructed using the steady state velocity weakening cohesive zone model of reference [58].


a
b
c
Field of view
for high-speed DIC
12.5 mm
250 mm
Interface
NiCr wire
Shear Mach peak
Pressure
Mach peak
Rupture
propagation
Rupture speed (km s⁻¹)


PMMA
Homalite-100
a
b
c
d
e
f

Lattice wave emission from a moving dislocation

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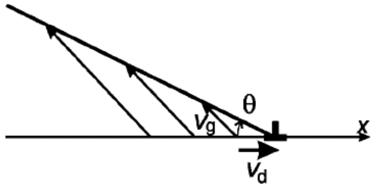

FIG. 15. A dislocation moving with velocity $\mathbf{v}_d$ emits lattice waves that propagate with group velocity $\mathbf{v}_g$. The successively emitted waves with a certain $\mathbf{k}$ vector leave a line behind the dislocation. The angle between the line and the $-x$ direction is $\theta = \tan^{-1}[v_{gy}/(v_d - v_{gx})]$.

$$\sin\theta = \frac{\ell\sqrt{6}}{H}\frac{c_s}{V}$$

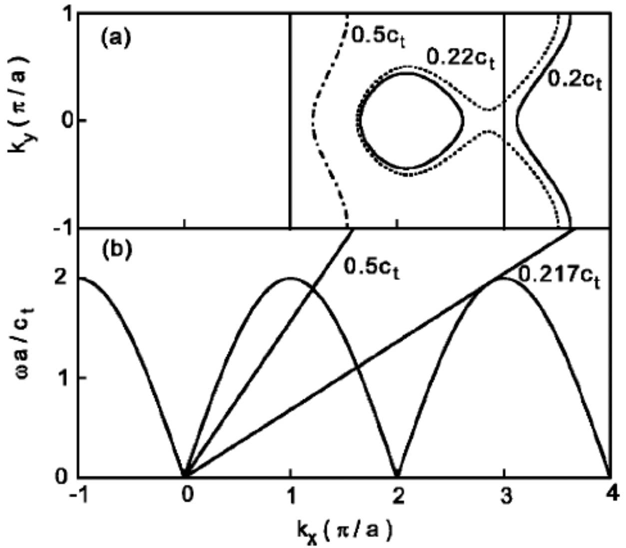

FIG. 13. (a) Wave vector $\mathbf{k}$ that satisfies $\omega(k_x, k_y) = \mathbf{k}\cdot\mathbf{v}_d$ and (b) phonon-dispersion curve along the axis $k_y = 0$, $\omega(k_x, 0)$ for the square lattice.

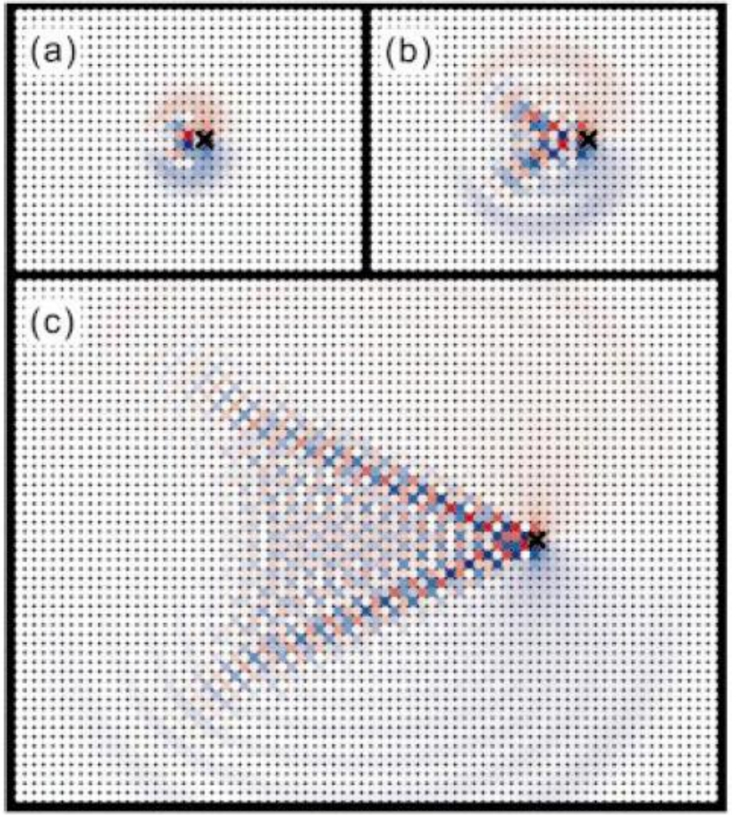

FIG. 4. (Color) Emitted waves from a moving dislocation with a velocity of $0.51c_t$ under the applied stress $F = 0.051G$. (a) $t = 6.36a/c_t$, (b) $t = 6.95a/c_t$, (c) $t = 37.69a/c_t$. The meaning of the colors and the contrast are the same as in Fig. 3. The maximum velocity $v_{\max}$ of the atomic rows is $0.125c_t$, $0.176c_t$, and $0.201c_t$ in the cases (a), (b), and (c), respectively. The position of the dislocation is indicated with a cross.

Compressional and shear wakes in a two-dimensional dusty plasma crystal

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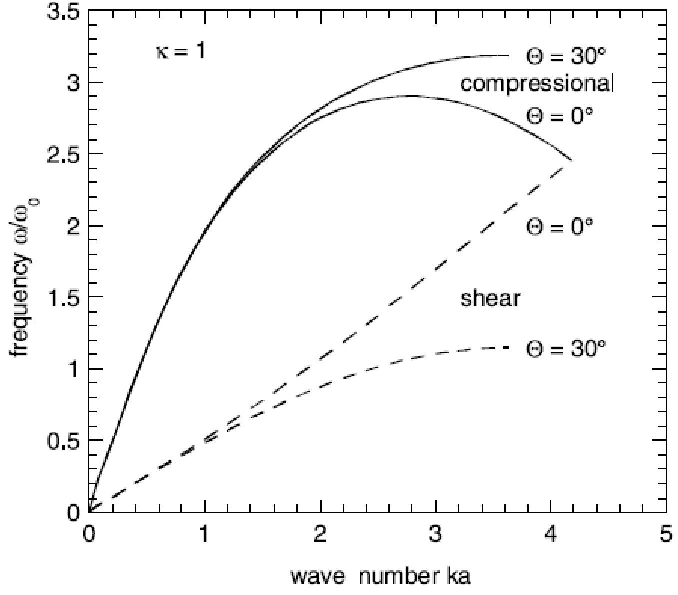
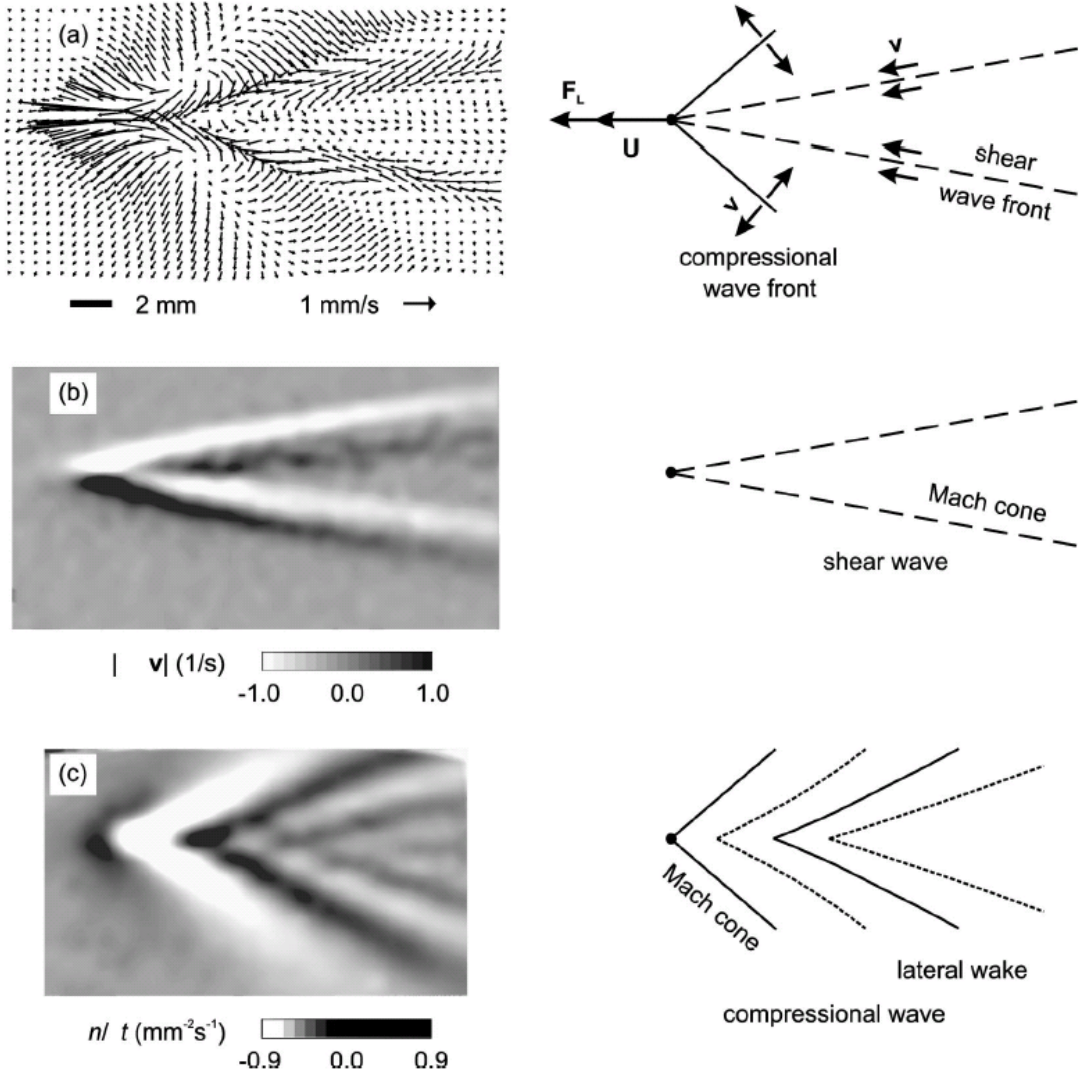


FIG. 3. Theoretical dispersion relation for a 2D triangular Yukawa lattice. It has two modes, compressional and shear. The shear wave has less dispersion, i.e., ω is more nearly $\propto k$ over a wide range of k than the compressional wave. The wave's propagation direction Θ is measured with respect to the primitive vector of the lattice. Reproduced from Fig. 3 of Ref. [12].



Motivation – Outline:

- Seismology
- Activation of Faults
- Fracture Mechanics
- Dielectricity combined with flexoelectricity
- Elimination of polarization
- Dynamic anti-plane problem
- Dispersion relation
- Theoretical and FEM analysis
- Nonlinearities and soliton waves

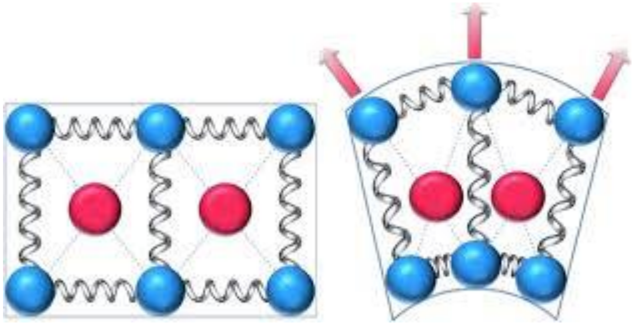
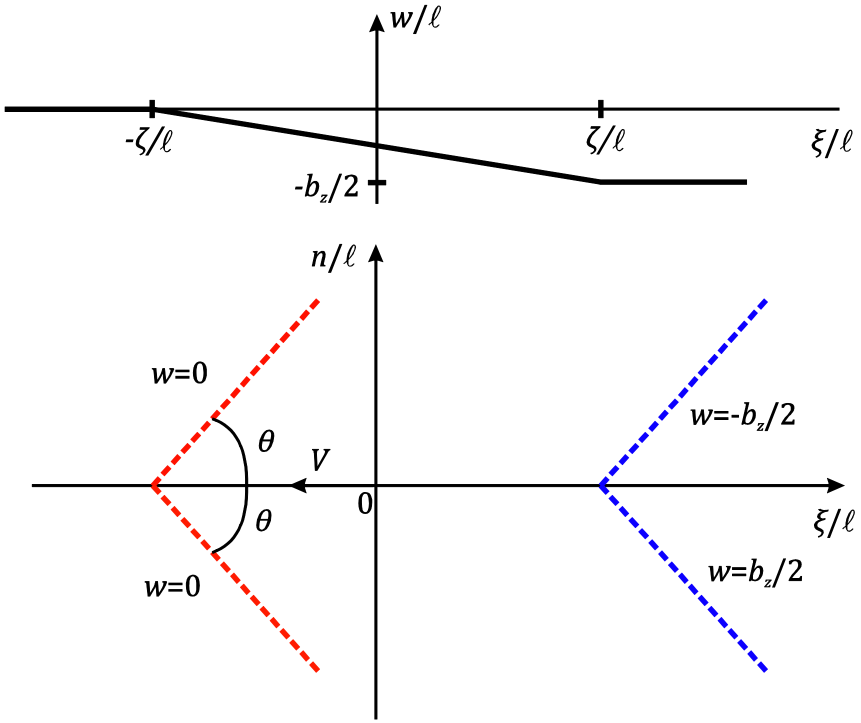


Illustration of induced polarization due to non-uniform bending deformation of a centro-symmetric (non-piezoelectric) material. Krichen and Sharma (2016)

Mach lines



$$\sin\theta = \frac{c_s}{V}$$

$$w = f(\Xi) = f\left(\xi \pm \eta\sqrt{\frac{V^2}{c_s^2} - 1}\right)$$

$$\sin\theta = \frac{\ell\sqrt{6}}{H}\frac{c_s}{V}$$

$$\bar{\eta} = \frac{\xi}{\ell} \pm \frac{\eta}{\ell}\sqrt{\frac{H^2V^2}{6\ell^2 {c_s}^2} - 1}$$

Isotropic anti-plane dielectric flexoelectric: $\boxed{\beta = 0}$

Assume: $X_z = 0,\ \Phi_{,z} = 0,\ E_z^0 = 0$

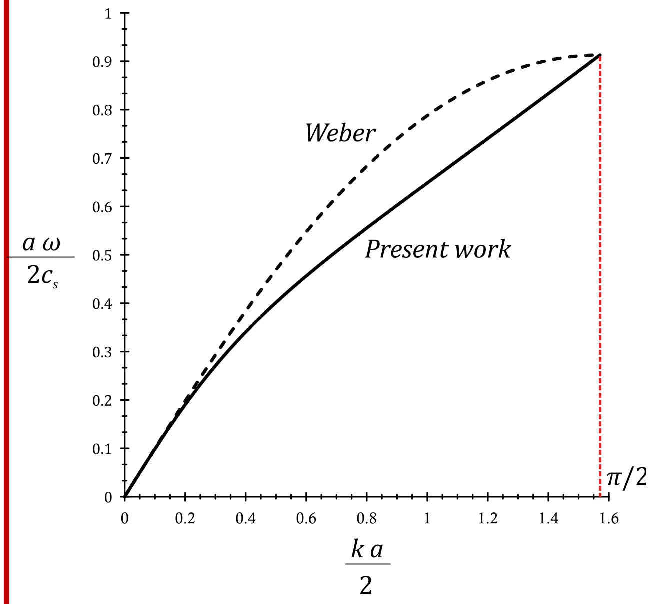
$$\mu \nabla^2 u_z - \underbrace{\left(\frac{\mu(b_{44} + b_{77})}{a} - \frac{(e_{44} - f_{12})^2}{a} \right)}_{\boxed{\frac{\mu \ell^2}{2}}} \nabla^4 u_z = \rho \ddot{u}_z - \underbrace{\frac{(b_{44} + b_{77})}{a}}_{\boxed{\frac{1}{12} H^2}} \rho \nabla^2 \ddot{u}_z$$

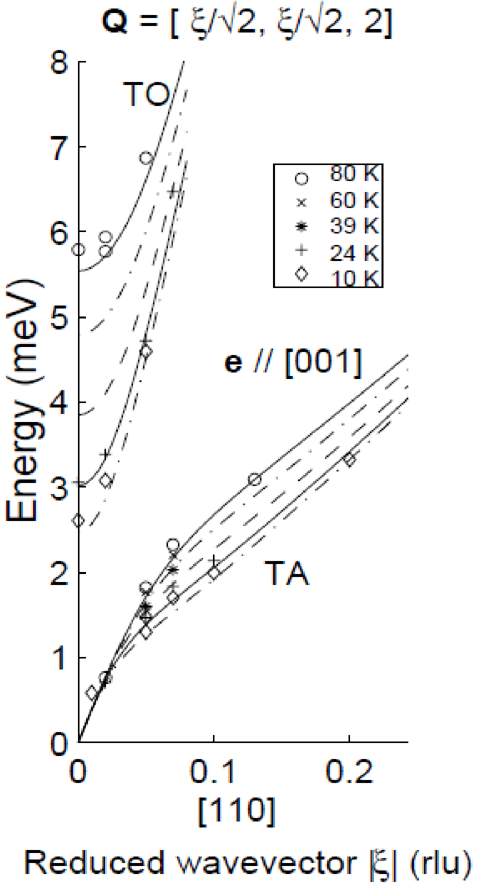
$$\mu > 0,\quad a > 0,\quad f_{44} > 0,\quad e_{44} > 0,\quad b_{44} + b_{77} > 0,\ \mu(b_{44} + b_{77}) - e_{44}^2 > 0$$

$$\frac{\ell^2}{2} = \frac{(b_{44} + b_{77}) - (e_{44} + f_{12})^2 / \mu}{a} > 0$$

$$\frac{H^2}{12} = \frac{(b_{44} + b_{77})}{a} > 0$$

Dispersion relation:





$$\frac{\omega}{k} = c_s \left(\frac{1 + \dfrac{\ell^2}{2} k^2}{1 + \dfrac{H^2}{12} k^2} \right)^{1/2}$$

$$a^2 \omega^2 = c_s^2 \frac{\sin^2(ka/2)}{1 + 2(f'/f)\sin^2(ka/2)}$$

$$k \to 0, \quad \frac{dw}{dk} = c_s$$

$$k \to \infty, \quad \frac{dw}{dk} = c_s \frac{\ell\sqrt{6}}{H}$$

$H/(\ell\sqrt{6}) = 1.938 \longrightarrow V/c_s \approx 0.67$

$a/2 = \ell/\sqrt{2}$: Atomic dimension

$0 \le ka/2 \le \pi/2$: Wave number

$f'/f = 0.1$: ionic/bond forces

E. Farhi *et al.*, Eur. Phys. J. B (2000)

Isotropic anti-plane dielectric flexoelectric: $\boxed{\beta = 0}$

Typical material constants (Maraghandi et al., 2006):

$$c_{44} = \mu = 0.325 \cdot 10^{-2} \left[\frac{dyne}{nm^2} \right]$$

$$e_{44} = 0.356 \cdot 10^{15} \left[\frac{dyne\ nm}{C} \right]$$

$$f_{12} = 0.01125 \cdot 10^{7} \left[\frac{dyne\ nm}{C} \right]$$

$$b_{44} = 0.5255 \cdot 10^{32} \left[\frac{dyne\ nm^4}{C^2} \right]$$

$$b_{77} = 1.921 \cdot 10^{32} \left[\frac{dyne\ nm^4}{C^2} \right]$$

$$a = 8.767 \cdot 10^{33} \left[\frac{dyne\ nm^2}{C^2} \right]$$

$$\varepsilon_0 = 8.854 \cdot 10^{-35} \left[\frac{C^2}{dyne\ nm^2} \right]$$

$$\Rightarrow$$

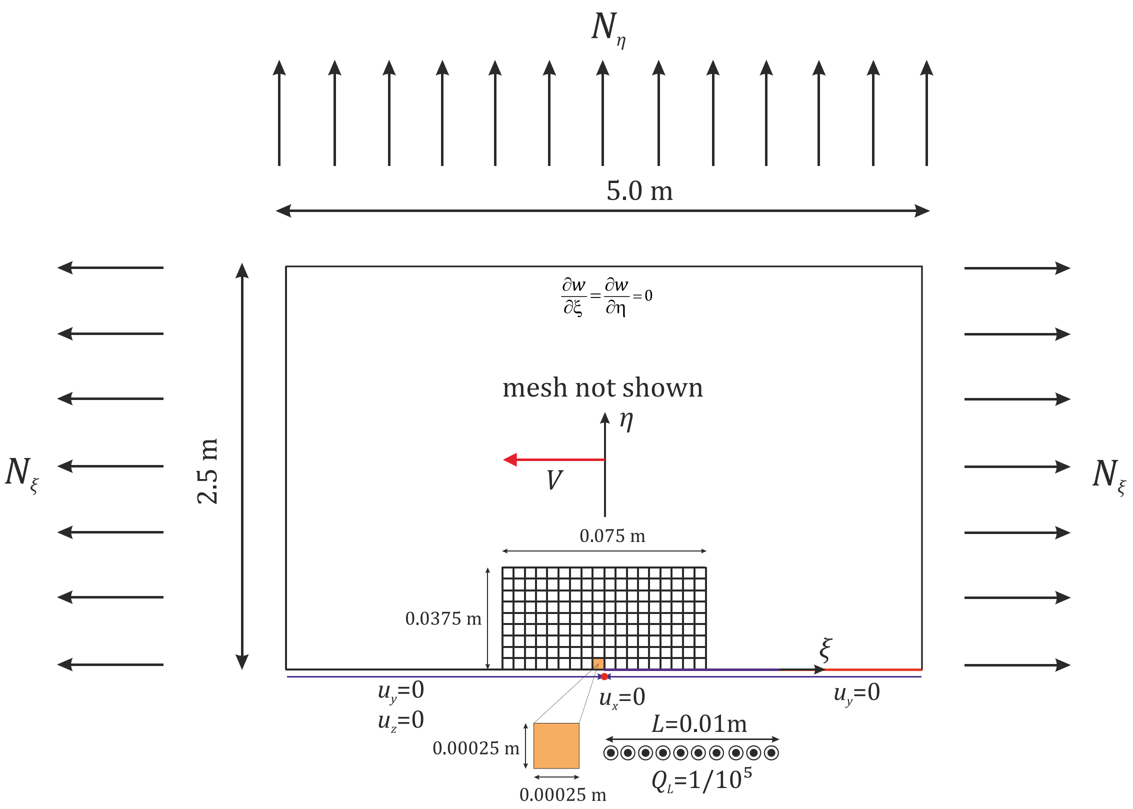
$$\frac{\ell}{\sqrt{2}} = \sqrt{\frac{(b_{44} + b_{77})}{a} - \frac{(e_{44} - f_{12})^2}{\mu a}} = 0.1532\ nm$$

$$\frac{H}{\sqrt{12}} = \sqrt{\frac{12(b_{44} + b_{77})}{a}} = 0.1671\ nm$$

$$\rho = 5.3176 \left[\frac{g}{cm^3} \right]$$

$$strain\ gradient\ length = 0.049 - 0.14\ [nm]$$

Isotropic anti-plane dielectric flexoelectric: FEM model

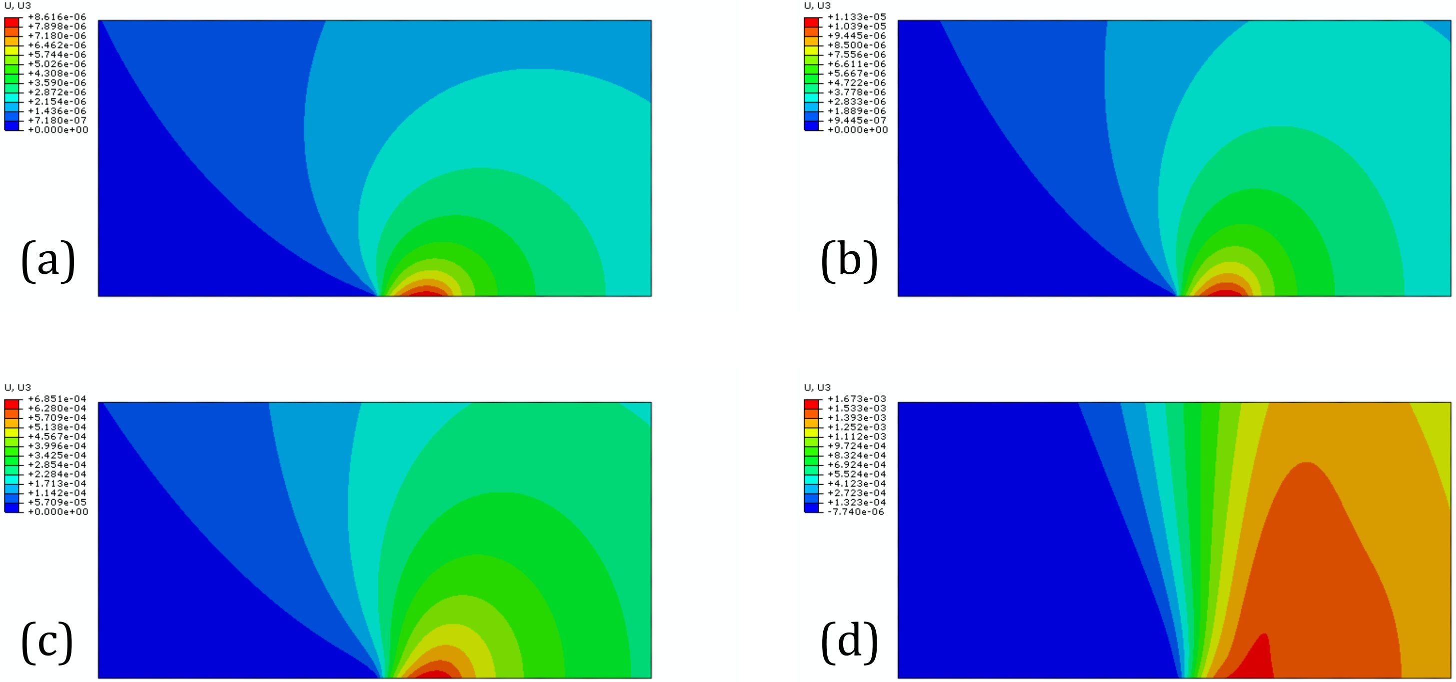


- We model the anti-plane space as a thin plate which extends multiple times the characteristic lengths of the problem.
- The plate's Poisson ratio is set to zero and orthotropic elasticity was tuned to capture the micro-inertia length.
- Pre-stretching was applied according to the crack velocity and the micro-structural length of the problem.
- Only half the space is discretized by 100000 linear quadrilateral elements (S4R in ABAQUS notation) and 600 linear triangular elements (S3 in ABAQUS notation).

Contour fields of out of plane displacements: Influence of velocity

$(V/c_s)^2 = 0,\ H^2/(6\ell^2) = 0,\ \ell/(L\sqrt{2}) = 0$

$(V/c_s)^2 = 0.5,\ H^2/(6\ell^2) = 0,\ \ell/(L\sqrt{2}) = 0$



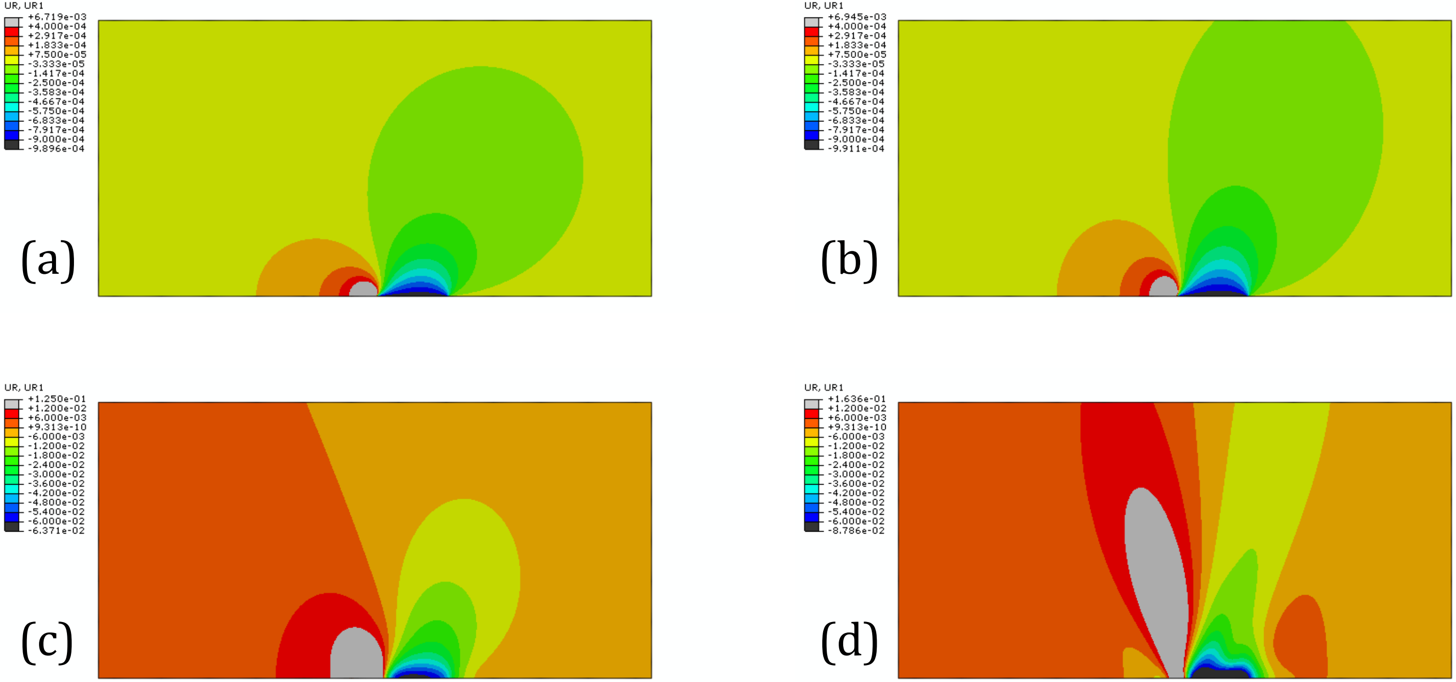
$(V/c_s)^2 = 0.5,\ H^2/(6\ell^2) = 0,\ \ell/(L\sqrt{2}) = 0.003$

$(V/c_s)^2 = 0.95,\ H^2/(6\ell^2) = 0,\ \ell/(L\sqrt{2}) = 0.003$

Contour fields of rotations $w_{,2}$: Influence of velocity

$(V/c_s)^2 = 0,\; H^2/(6\ell^2) = 0,\; \ell/(L\sqrt{2}) = 0$

$(V/c_s)^2 = 0.5,\; H^2/(6\ell^2) = 0,\; \ell/(L\sqrt{2}) = 0$



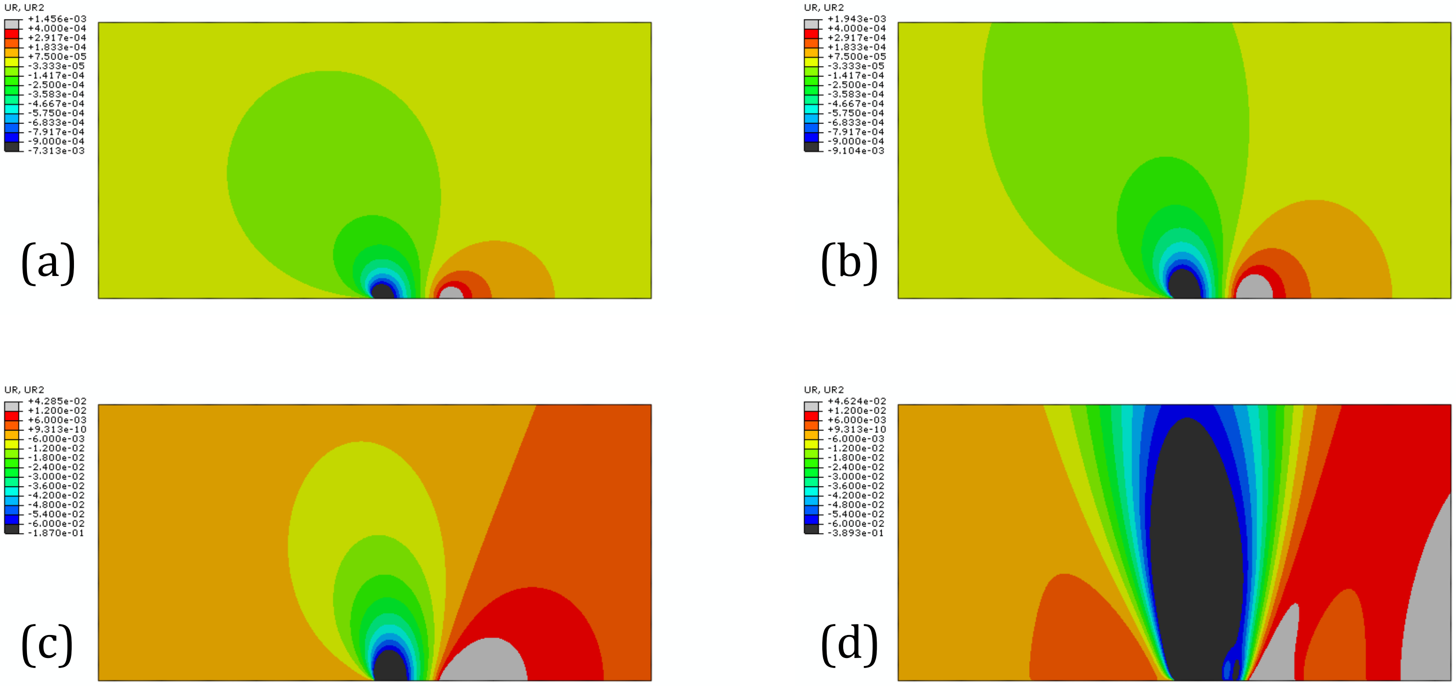
$(V/c_s)^2 = 0.5,\; H^2/(6\ell^2) = 0,\; \ell/(L\sqrt{2}) = 0.003$

$(V/c_s)^2 = 0.95,\; H^2/(6\ell^2) = 0,\; \ell/(L\sqrt{2}) = 0.003$

Contour fields of rotations $w_{,1}$: Influence of velocity

$(V/c_s)^2 = 0,\ H^2/(6\ell^2) = 0,\ \ell/(L\sqrt{2}) = 0$

$(V/c_s)^2 = 0.5,\ H^2/(6\ell^2) = 0,\ \ell/(L\sqrt{2}) = 0$



$(V/c_s)^2 = 0.5,\ H^2/(6\ell^2) = 0,\ \ell/(L\sqrt{2}) = 0.003$

$(V/c_s)^2 = 0.95,\ H^2/(6\ell^2) = 0,\ \ell/(L\sqrt{2}) = 0.003$

Conclusions:

- Antiplane problems in flexoelectricity
- Couple stress (micro-structural length, micro-inertia length)
- Prestressed plate analogue and FEM methodology
- Steady state results
- Dispersion analysis
- Facture faults
- Anharmonic elasticity
- Viscosity
- Solitons