Stability of charge-controlled dielectric plates

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Soft Dielectrics

Soft dielectric materials are smart materials that deform elastically in the presence of an electric field.

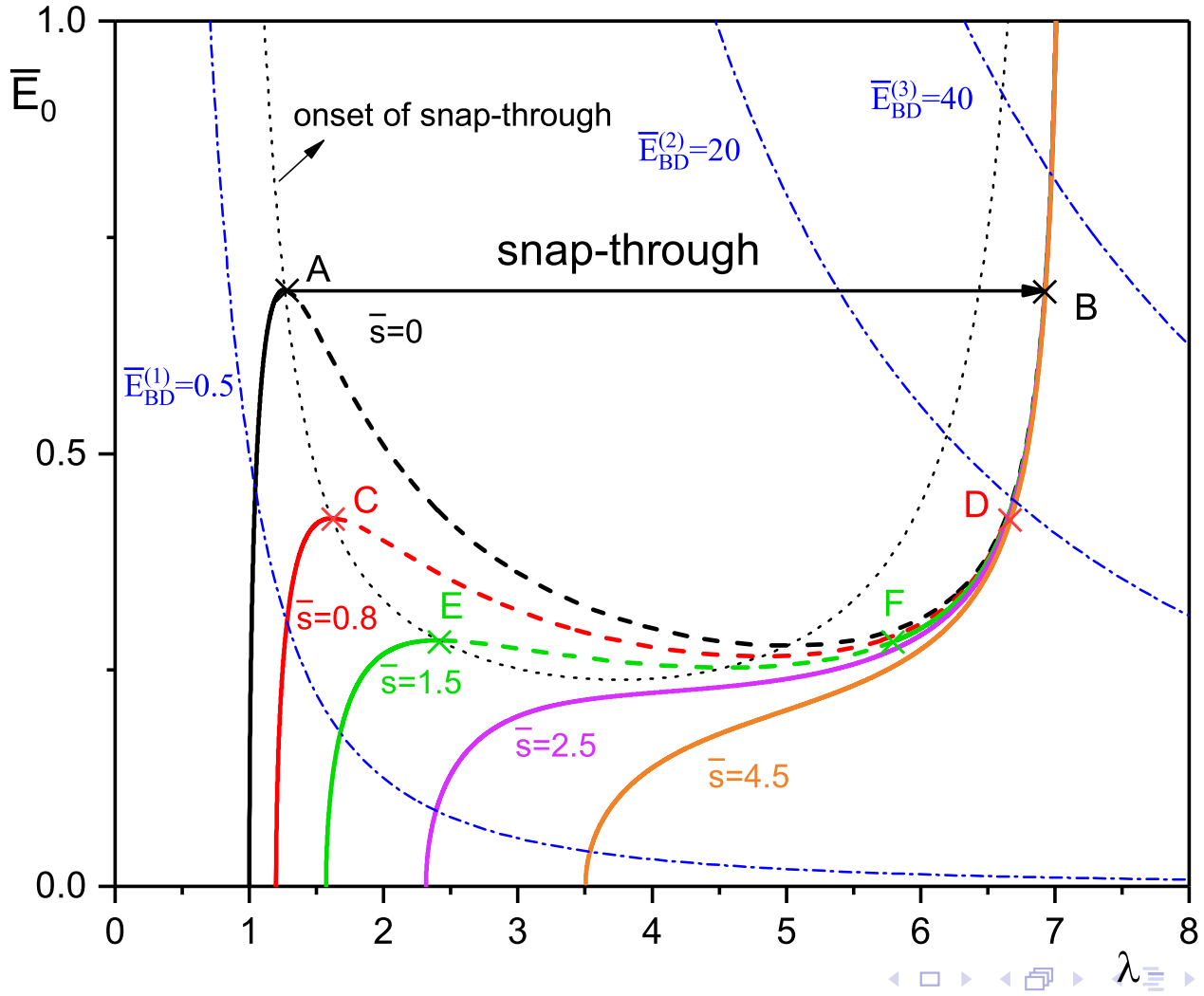
These materials can be used to produce actuators, artificial muscles or wearable electronics.

They are modelled by coupling the equations of electrostatics with those of non-linear elasticity.

Instabilities in soft dielectrics can cause material breakdown or be exploited for some applications.

Snap-through

The **snap-through** instability can be used to generate a large deformation, if it occurs before the material breaks down.



Wrinkling

However this is difficult to achieve in practice, as the material first breaks down or **wrinkles** form.

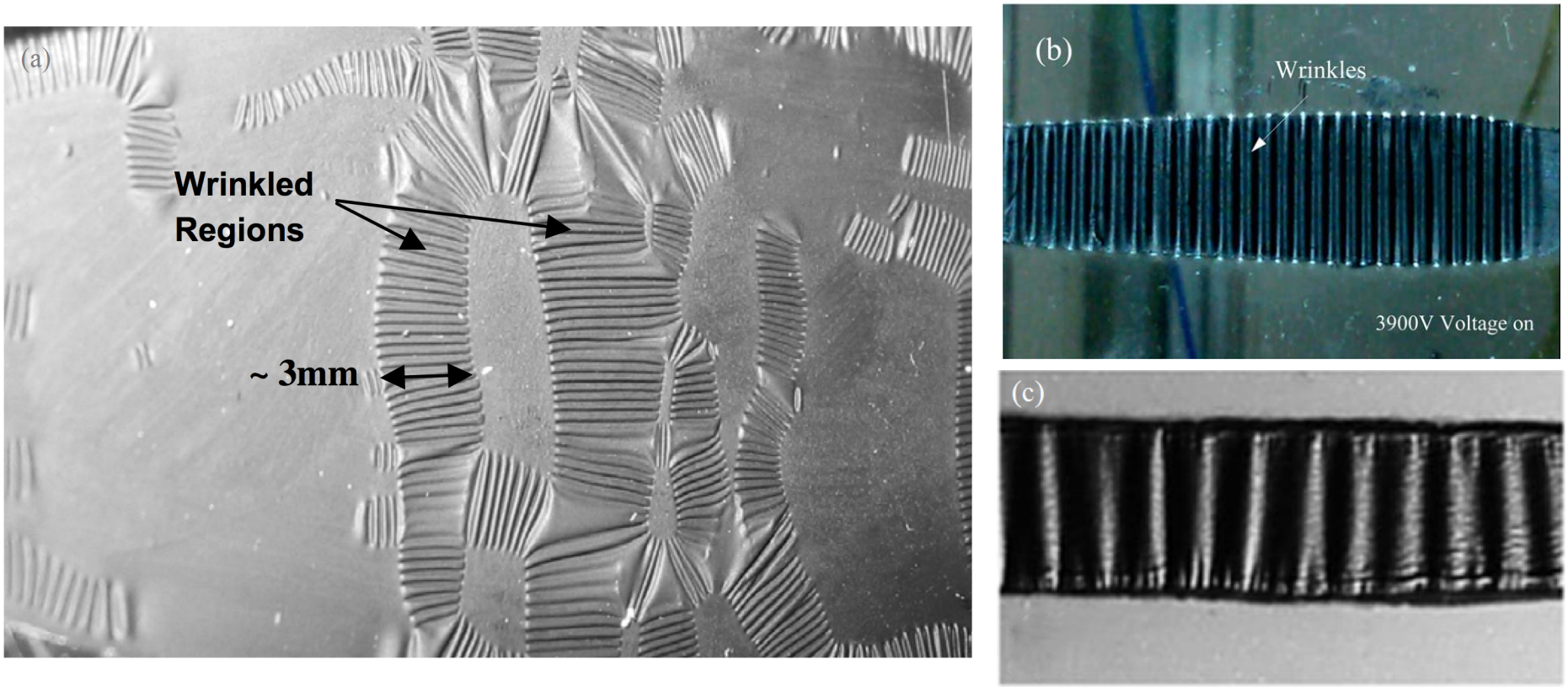
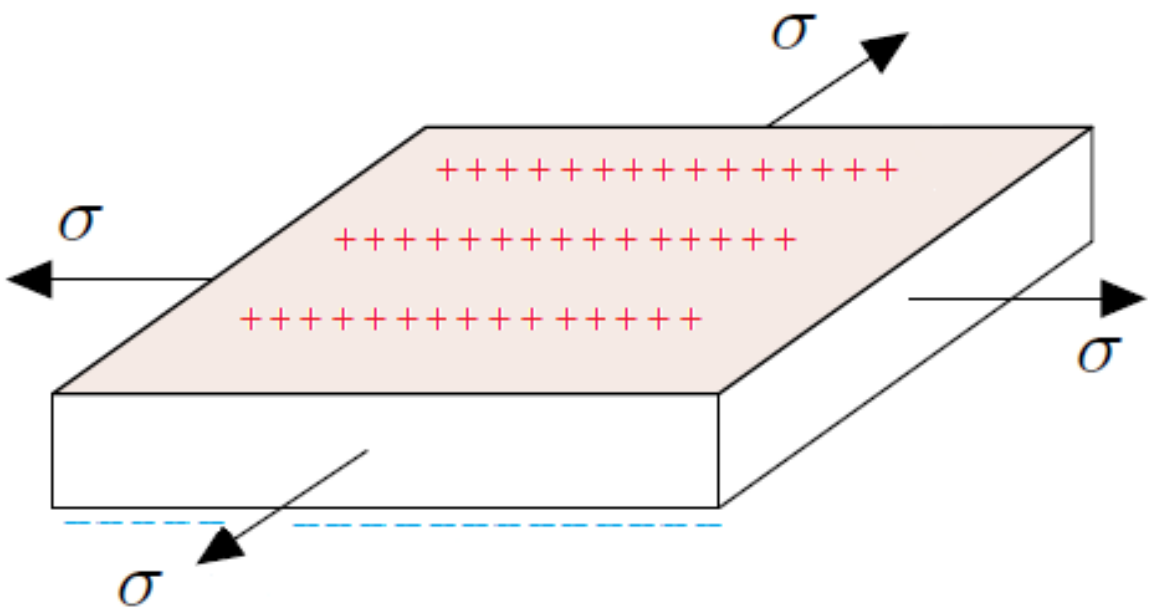


Figure: Experimental evidence of electro-mechanical wrinkling [2, 3, 4]

Setup of Model

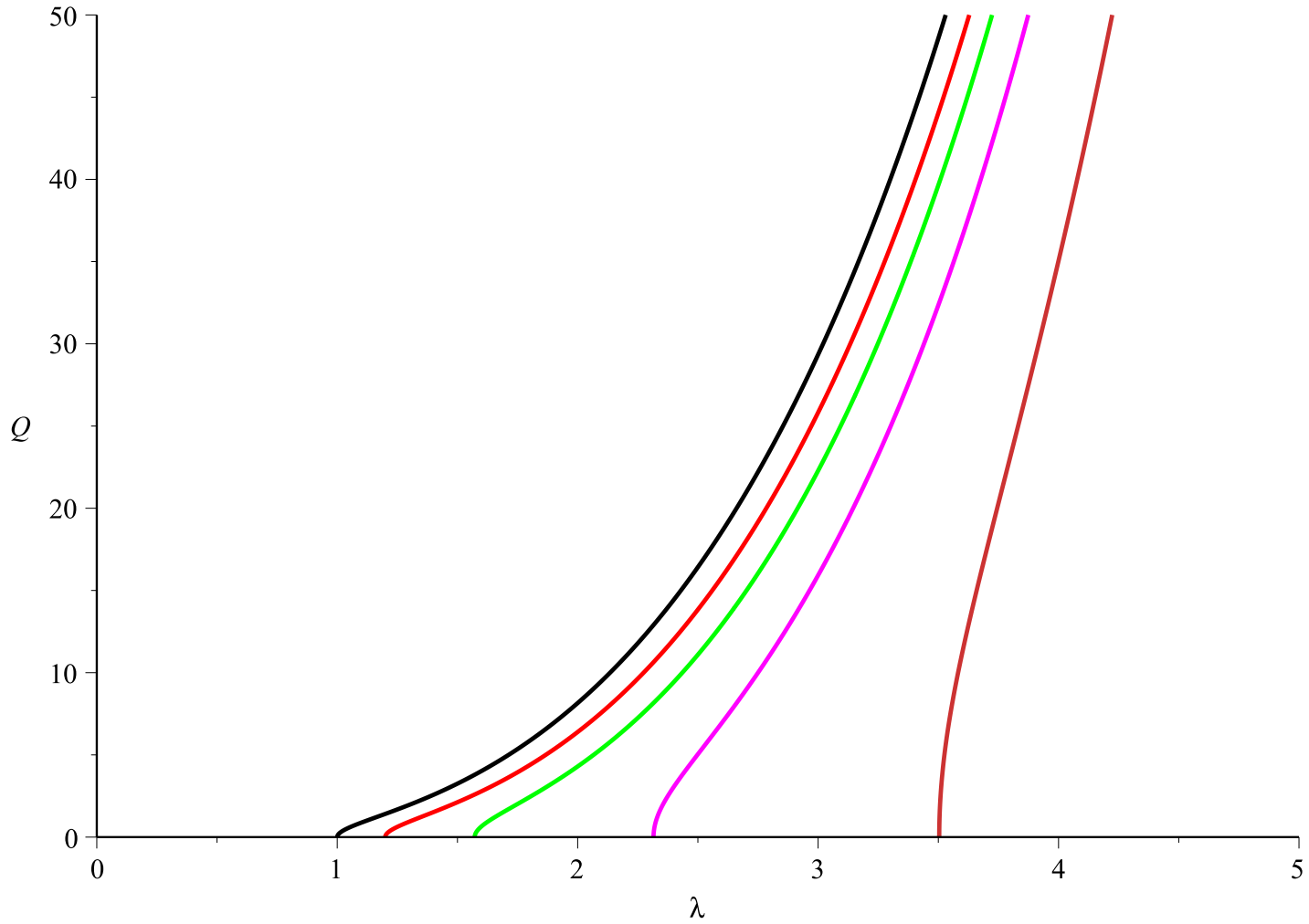
We consider a rectangular plate of soft dielectric material that is **stretched equally** along its lateral directions. We denote the principal stretches by $\lambda_1 = \lambda_3 = \lambda$, $\lambda_2 = \lambda^{-2}$.



We apply charges $\pm Q$ to the lateral faces of the dielectric. This induces a voltage V across the thickness.

Charge-control

Charge-controlled actuation does not exhibit the snap-through instability, and so is considered stable.



Incremental Deformations

We look for solutions in the neighbourhood of the deformation.

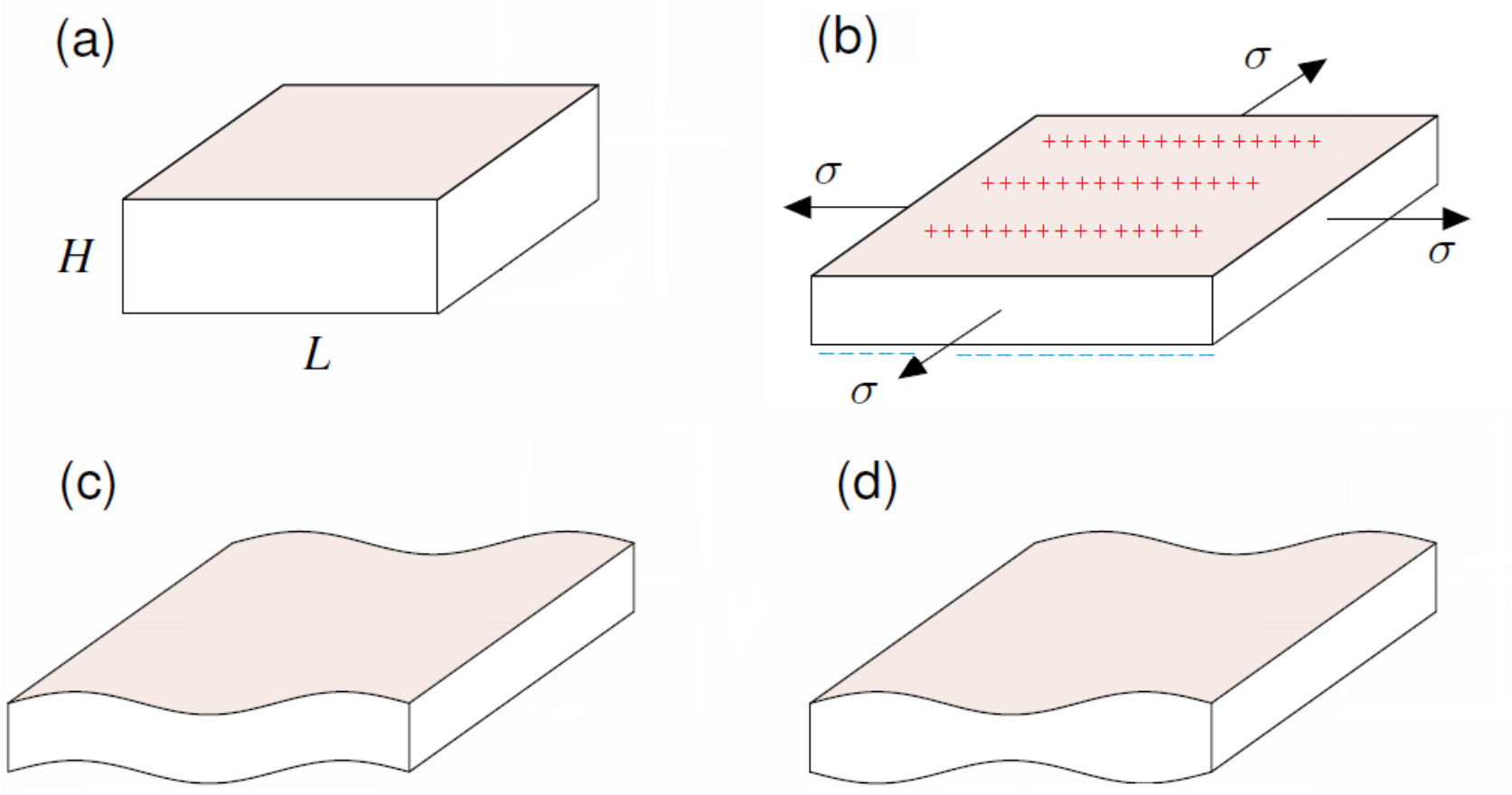


Figure: Antisymmetric and symmetric wrinkles in a soft dielectric plate

Results

We solve the incremental equations for the **Gent dielectric**

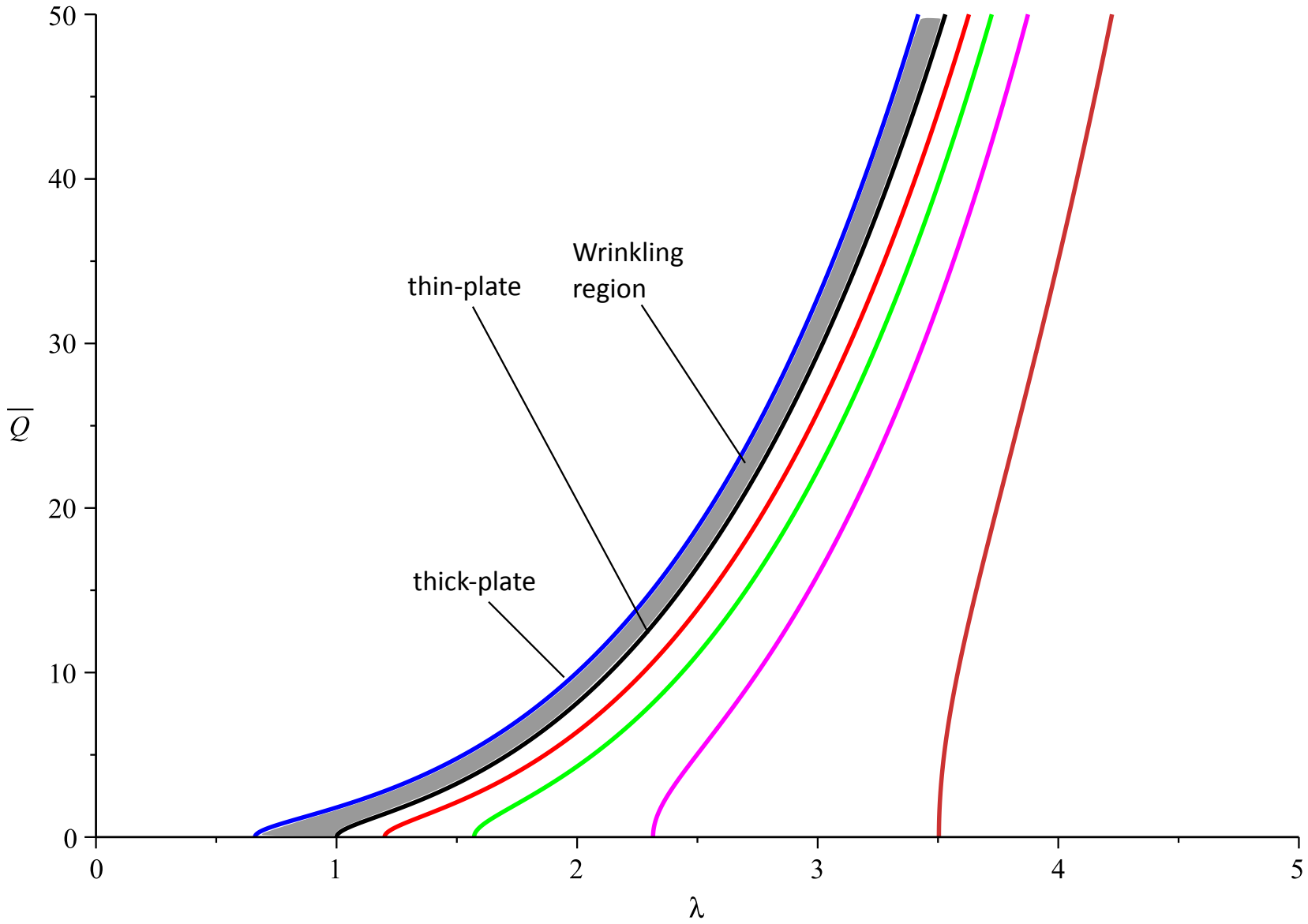
$$\Omega(\lambda, \overline{E}_0) = -\frac{J_m}{2} \ln\left(1 - \frac{(2\lambda^2 + \lambda^{-4} - 3)}{J_m}\right) - \frac{1}{2}\lambda^4 \overline{E}_0^2,$$

where $\overline{E}_0$ is a non-dimensional measure of the voltage and J_m is a material parameter.

We also note that the charge Q is related to $\overline{E}_0$ by,

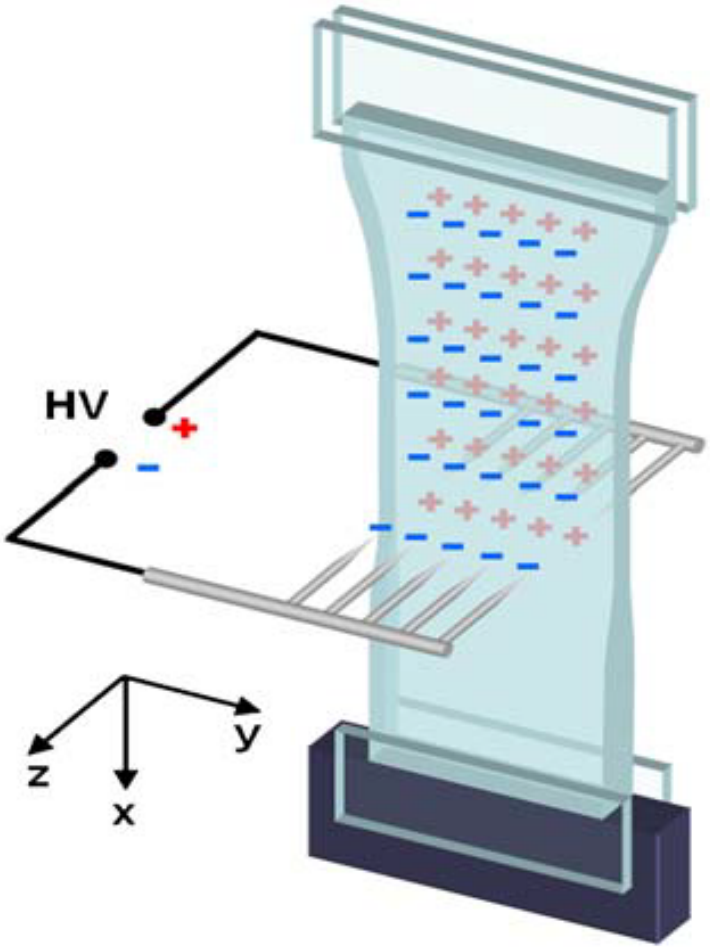
$$\overline{Q} = \lambda^4 \overline{E}_0.$$

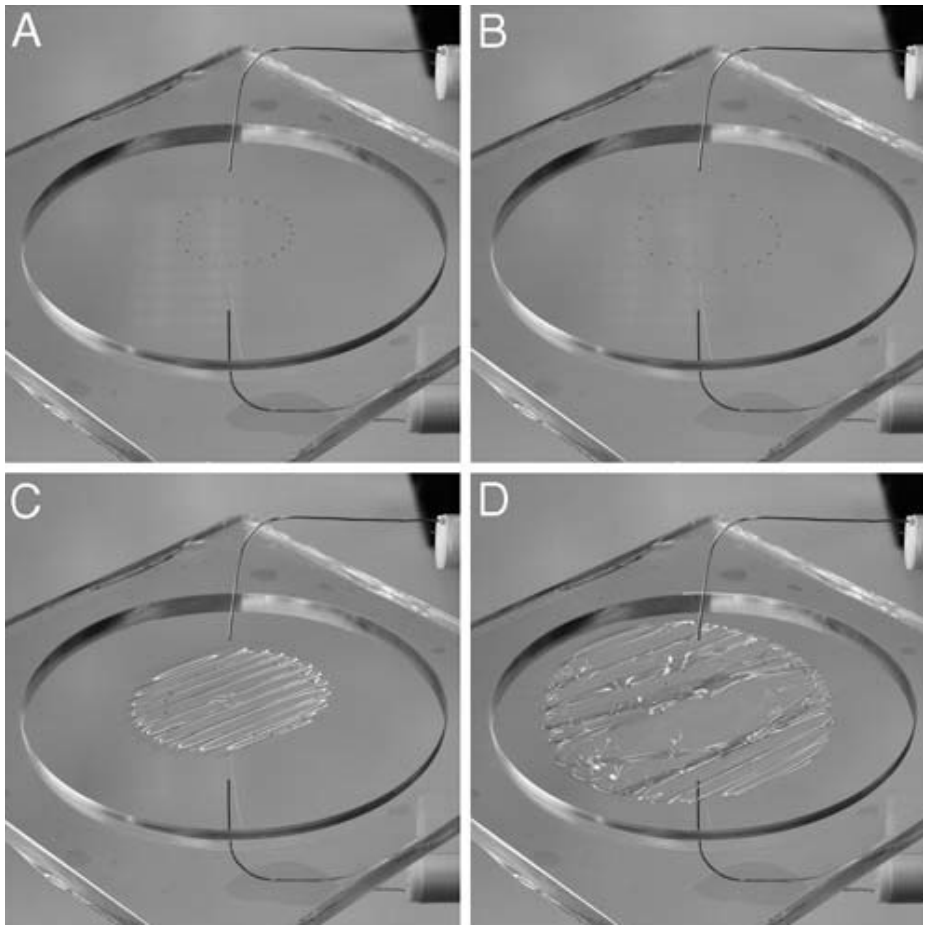
Results


50
40
30
20
10
0
$\overline{Q}$
0
1
2
3
4
5
λ
thin-plate
Wrinkling
region
thick-plate

Future Work

Other deformations or boundary conditions [5]





Future Work

Charge-controlled actuation is difficult to implement in a practical device.

Some possible solutions may be:

- Local charge-controlled actuation
- Using both charges and electrodes (i.e. charge and voltage-controlled)

References

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