All-ceramic layered microcantilevers: Size limitations

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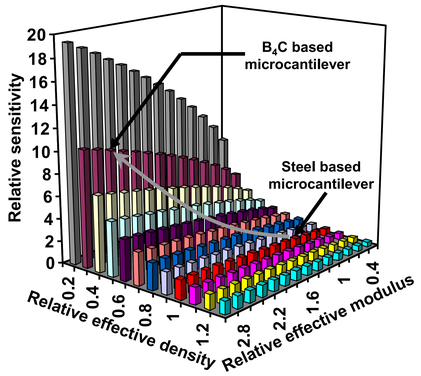
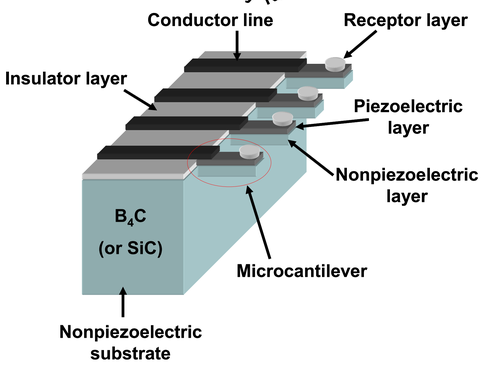
Microcantilever sensors

The goal of this research was to determine size limitations of all-ceramic layered microcantilever sensor. The static model of ultimate state of the microcantilever was developed. Sensors consisted of two layers – piezoelectric and non-piezoelectric. Applied voltage results in strain of the piezoelectric layer i.e. strain mismatch between layers. Critical stresses arise in the clamped end of the microcantilever. These stresses depend on voltage, sensor size and the layer thickness ratio. The model enables the determination of safe intervals for these parameters, allowing for the optimal design of microcantilevers.



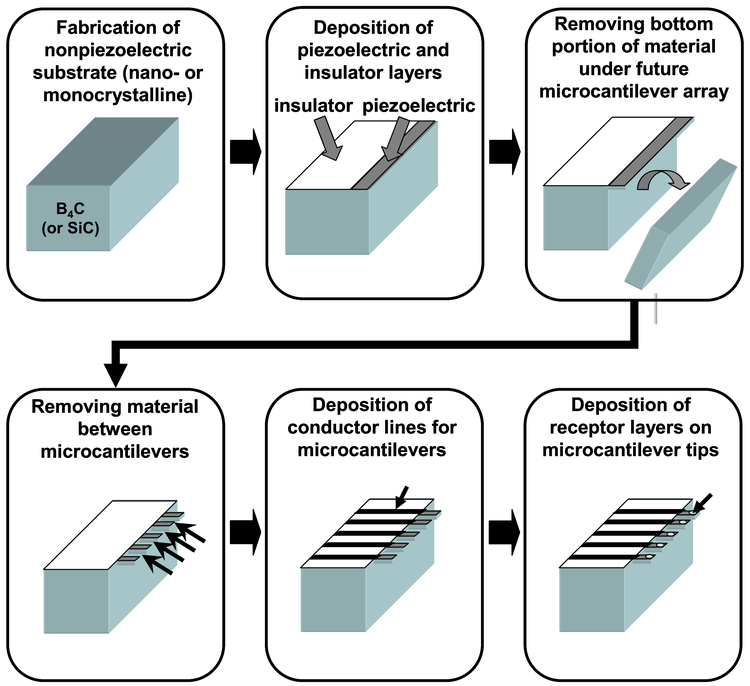
Relative sensitivity of layered microcantilevers with the same shape and dimensions depends on density and elastic moduli of layers

(sensitivity of steel based microcantilever is 1)



Microcantilever array is required to improve signal quality. For larger arrays, piezoresistive cantilevers look promising. Each microcantilever could also detect own agent.

Fabrication process for microcantilever array

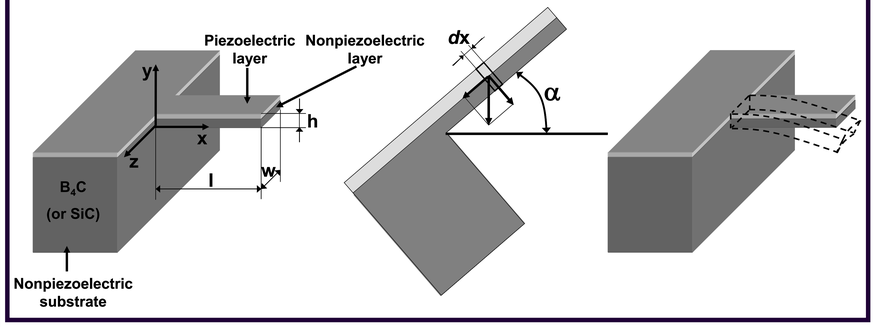


Model

The principal assumptions of the model can be summarized as follows:

1. Only stress distribution in the clamped cross-section of the cantilever is considered as the most critical one.
2. Cantilever is allowed to be expanded and compressed without any constraints along the direction perpendicular to the layers, to result in a stress component in this direction to equal zero.
3. The clamped cross-section of the cantilever is assumed to be plane and rectangular in geometry for all its deformations. It results in stress components are independent on coordinate along direction perpendicular to longitudinal axes of cantilever and parallel to layers.
4. Static problem (cantilever in the largest deflection state) is only analyzed.
5. Upper limit of deflection is evaluated for the free end of cantilever.
6. Direction parallel to layers and perpendicular to longitudinal axis of cantilever remains to be parallel to the horizon plane.
7. The thermal mismatch between the two layers is neglected.
8. Shear stresses in the clamped cross-section of the cantilever are neglected since they are substantially less than normal stresses for the cantilevers analyzed.

Coordinate system of model | **Orientation of cantilever** | **The largest deflection state of cantilever**



Summary

1. The model applicability results from deflection criterion for all considered cantilever sizes.
2. The growth of electric voltage applied to the piezoelectric layer results in stress intensity increase.
3. Dependence of stress intensity on cantilever length has three areas for all electric voltages. The first area is at small lengths where the effect of self weight is negligible. The next area is at large lengths where piezoelectric strain effect is minor compared to self weight. The intermediate area is located between these two areas. Piezoelectric strain and self weight effects are comparable in this area.
4. Stress intensity is approximately reciprocally and directly proportional to the cantilever size in small and large length areas, respectively. Stress intensity has a minimum value in the intermediate area.
5. Cantilever size corresponding to minimum stress intensity depends on electric voltage. The greater the electric voltage, the larger this size.
6. Cantilever serviceability was more critically dependent of von Mises criterion, compared to Mohr's theory of strength for the cantilevers considered.
7. Other conditions being equal, there is a critical minimal cantilever size. Residual strain arises in cantilever with less size at a given electric voltage. This results in a cantilever serviceability violation.
8. Stress distribution in clamped cross-section of the cantilever does not depend on the cantilever width in our model.

Acknowledgments

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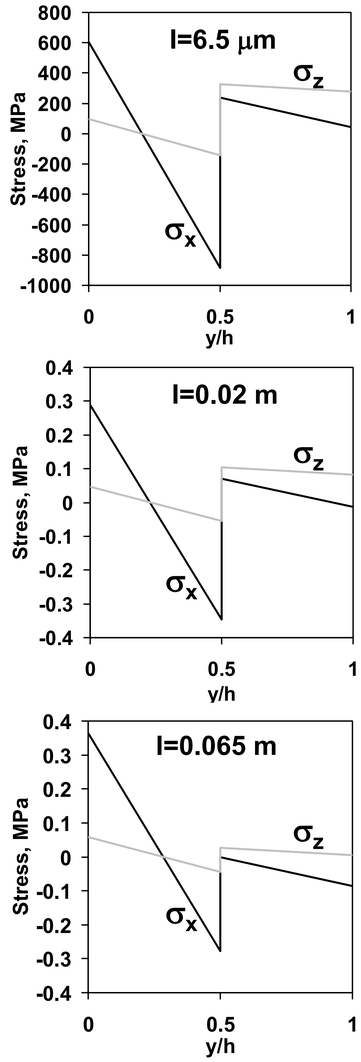
Limitations of microcantilever size

- Model applicability is determined by deflection criterion, namely, the ratio of maximum deflection of the free end of the cantilever to its total thickness should be less than a prescribed value <1 (0.1 in this work).
- Non-piezoelectric layer fracture, which violates the cantilever serviceability, is determined according to Mohr's theory of strength.
- Cantilever serviceability can be terminated by residual strain appearance in the piezoelectric layer too. Residual strain occurs due to ferroelastic behavior of the piezoelectric material. Safe stress state of piezoelectric layer without residual strain can be evaluated from von Mises yield criterion.

Stress distribution in clamped cross-section (electric voltage 15 V)



Stress distribution in clamped cross-sections strongly depends on the cantilever length given the same conditions.

σ_I - stress intensity

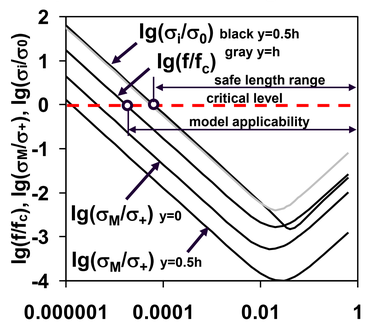
σ_0 - stress of ferroelastic switching onset σ_M

- effective stress from Mohr's theory of strength σ_+

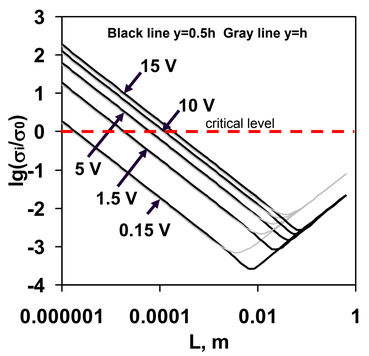
- tensile strength f -

maximum deflection of free end of cantilever f_c - critical deflection

Dependence of cantilever parameters on its length at 5 V



Dependence of stress intensity parameter on cantilever length



Dependence of mass sensitivity of piezoresistive layered cantilever on electric voltage