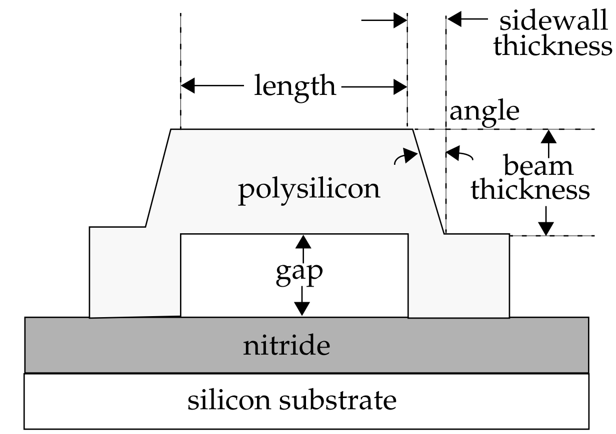

Property	Nominal	Std Dev
Elastic modulus	170 GPa	3 GPa
Residual stress	10 MPa (C)	5 MPa
Beam thickness	2 µm	0.02 µm
Nitride thickness	0.6 µm	0.02 µm
Gap	2 µm	0.05 µm
Sidewall angle	0^o	5^o
Sidewall thickness	2 µm	0.05 µm
Length	300 µm	0.5 µm
Width	30 µm	0.5 µm

Fig. 1: Beam geometry and parameters

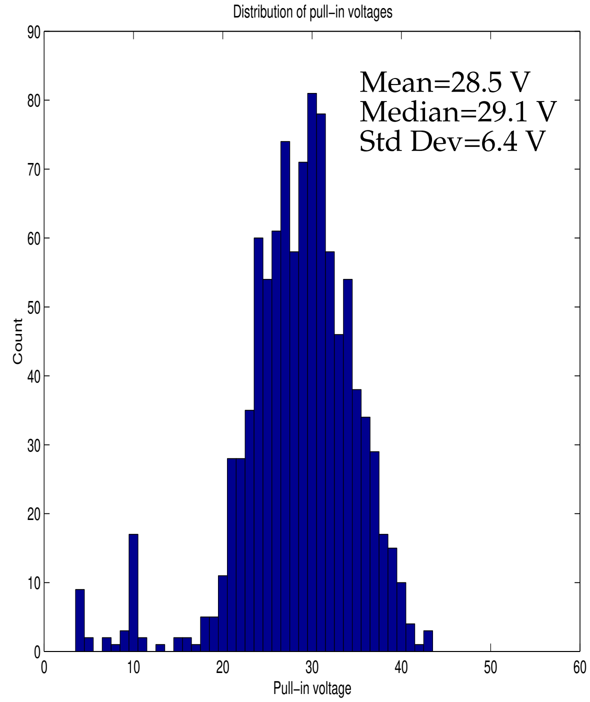

Fig. 2: Distribution of pull-in voltages given distribution of parameters in Fig. 1.

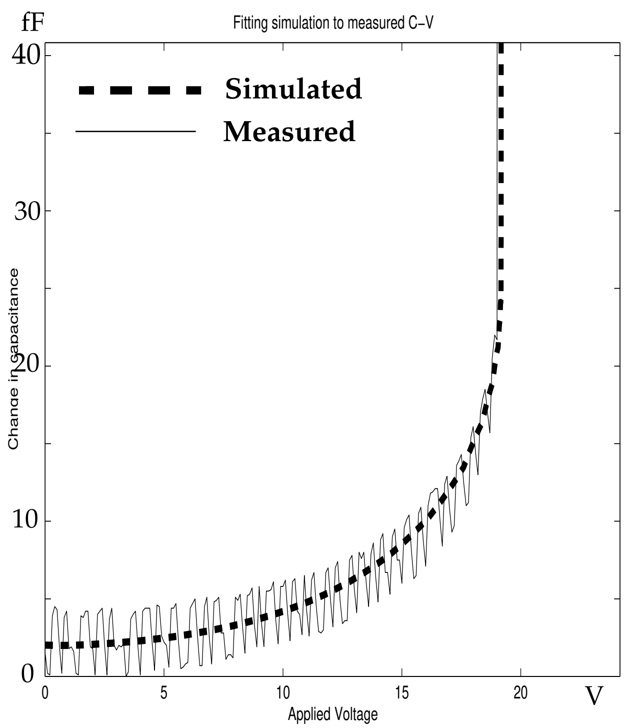

Fig. 3: Fitting simulated C-V characteristic to measured C-V characteristic

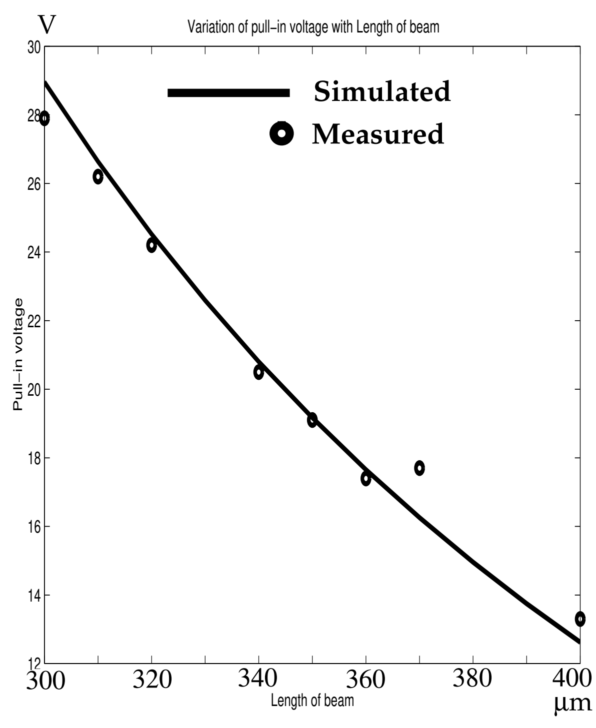

Fig. 4: Variation of pull-in voltages with beam length

Characterization of Electrostatically Actuated Beams Through Capacitance-Voltage Measurements and Simulations

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The effects of detailed geometric and material parameters used in simulations of electrostatically actuated beams, including properties of step-ups, are investigated and quantified. The statistical distribution of device performance is determined from the distribution of processing-induced variations. Beams of various dimensions are characterized in detail from capacitance-voltage (C-V) measurements. Accurate characterizations, including the effects of step-up supports, allow accurate scaling studies without requiring arbitrary parametric adjustments.

I. Introduction

The detailed geometry and material properties of simulation models are often insufficiently accurate. Usually, when simulation results are compared to experimental measurements, these inaccuracies are lumped into either geometric or material property "parametric adjustments". Often, these approximations need to be tailored to each specific device when modeling similar devices of different dimensions. In order to perform accurate scaling studies, the minimal set of parameters required to characterize a wide range of devices must be determined. We examine in detail the dependence of the capacitance-voltage (C-V) characteristics of electrostatically actuated beams on beam dimensions and material properties.

II. Statistical Distribution of Device Performance

Fig. 1 shows a fixed-fixed beam fabricated in the MUMPs process, along with properties of the process [1]. Assuming normal distributions of these properties, we perform Monte Carlo simulations to obtain the distribution, shown in Fig. 2, of pull-in voltages of the beam. The standard deviation of pull-in voltages is 6.4 V, about 20% of the mean value. The performance of beams in this process is highly dependent on residual stress. The standard deviation reduces to only 1.5 V if residual-stress is held invariant. Further investigations are critical for understanding the yield of devices with complex geometries, and statistically-dependent parameters.

III. Characterization of Device to Capacitance-Voltage Measurements

Fig. 3 shows measured and simulated capacitances of a 300μm by 30μm device as functions of applied voltage. We calibrate our simulation model parameters (listed in Fig. 1) to the detailed C-V curve, not only to a single characteristic such as pull-in voltage. This enables us to characterize material and geometric properties based on measurements of just one or two devices, rather than on measurements over multiple devices which tend to mask some effects of geometric scaling. The exact shape of the C-V curve reveals the dominant mechanisms involved in beam actuation.

IV. Scaling Studies

Once the parameters required to simulate one beam structure are determined, we can compare the simulated behavior of scaled structures to experimental measurements. We find that a calibration of simulation parameters to a single measurement is adequate to predict the trends of geometric scaling as shown in Fig. 4.

V. Conclusions

Processing-induced variations can cause large variations in device performance. Simple capacitance-voltage measurements can be used to calibrate simulation models for scaling studies.

References

[1] "MUMPs Introduction and Design Rules", D.A. Koester

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