Advanced CAD for iMEMS (αχαδεμια)

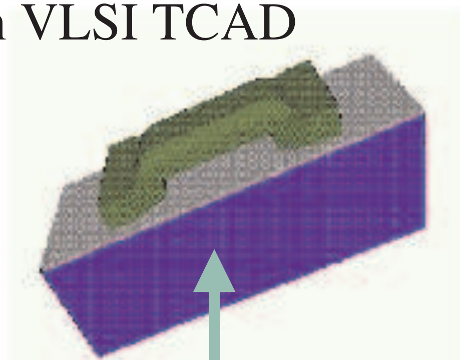
Robert W. Dutton, Stanford University

- Project Overview (+ Quad Chart)
- Major Accomplishments
- Milestones and Schedule
- Highlights from Tasks (including Edward Chan presentation)
- Design PROBLEM! (challenge to be solved...)
- Interoperability
- Issues and Challenges

αχαδεμια---Advanced CAD for MEMS

Goals:

Ability to prototype MEMS devices with advanced CAD that exploits progress in VLSI TCAD

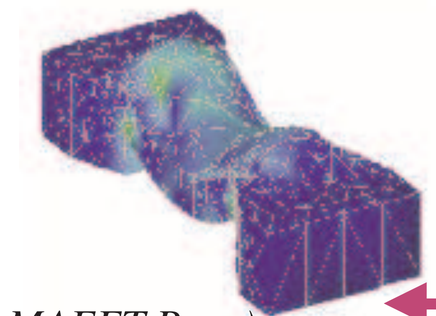


- HLL + APIs
- Grid + FEM
- Test Devices
- Materials

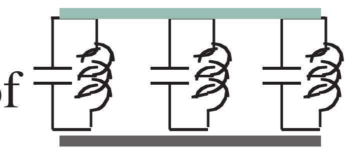
RF Switch as Demo

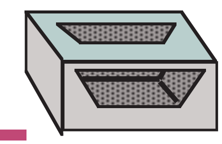
Approach:

Hierarchical extraction of essential behavior from detailed FEM models



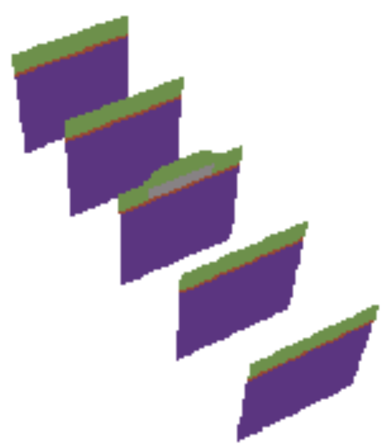
1D Compact Model





(i.e.. MAFET Pgm.)

Status: Level-set geometry creation (simulation-based)



Schedule:

Year	2	Q2	3
•3D Geo Proto. based on TTX+CIF(in) -> VRML(out)			(Adv. Geo & Grid) (Integration & GUI)
•Integrated CAD Demo			(FEM Solvers)
•Test Chips -- Materials Char. & Fatigue Struct.			(Test Structures) (Materials Eval.)
•RF Switch Demo (new materials)			(Demonstrations)

Δ NOW

Tasks & Objectives

Task 1. **Software Development** (Dutton)

Demo of fully-integrated, FEM-based solver capabilities for modeling *structural/process-dependent behavior* of MEMS.

Develop hierarchical extraction methodology (and lumped models) in support of physical modeling, design optimization and test of CAD

Task 2. **Materials Characterization** (Bravman)

Define materials issues for reliability in MEMS devices.

Develop extraction schemes of materials properties including in-situ test MEMS structures

Task 3. **MEMS Device Design & Testing** (Kovacs)

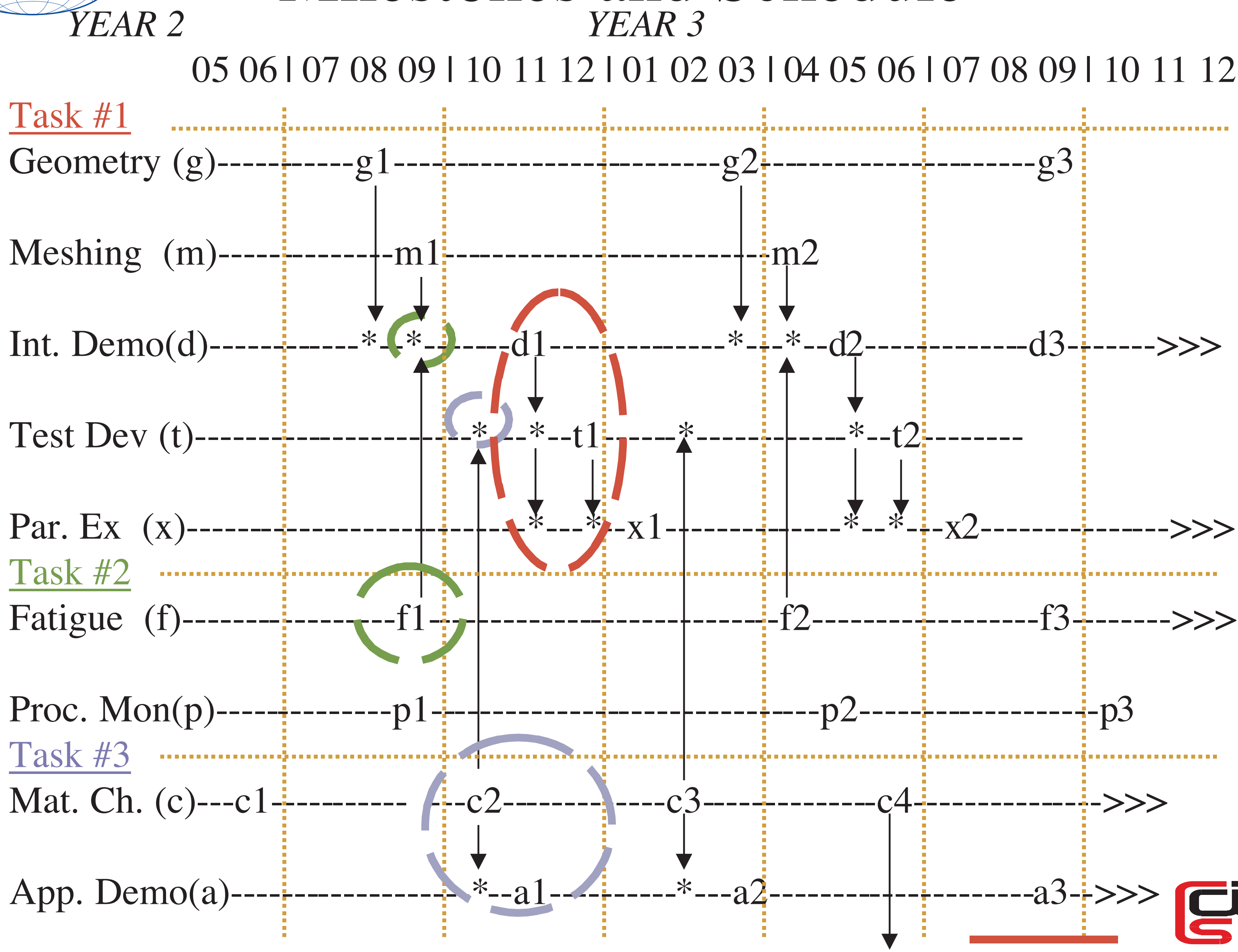
Design and implementation of MEMS structures for parameter extraction that facilitate *critical evaluation of models & CAD*.

Support for both application-pull and parametric (CAD) design, based on *limits due to (new) materials and processing*.

Major Accomplishments

- Internet-based virtual prototyping:
  (CIF & TTX) ->(VRML geometry)
- Geometry and Meshing Servers that support FEM-based simulations of RF (MEMS) switch
- Extraction Methodology for doubly-clamped beams (RF switch) including interface effects (for MUMPS process)
- Test structures for fatigue analysis (uniaxial stress) that show microstructure features during failure
- Demonstration of Test Structure Array (Testarosa) that enables application-driven characterization of new materials

Milestones and Schedule



Overview of Tasks & Deliverables

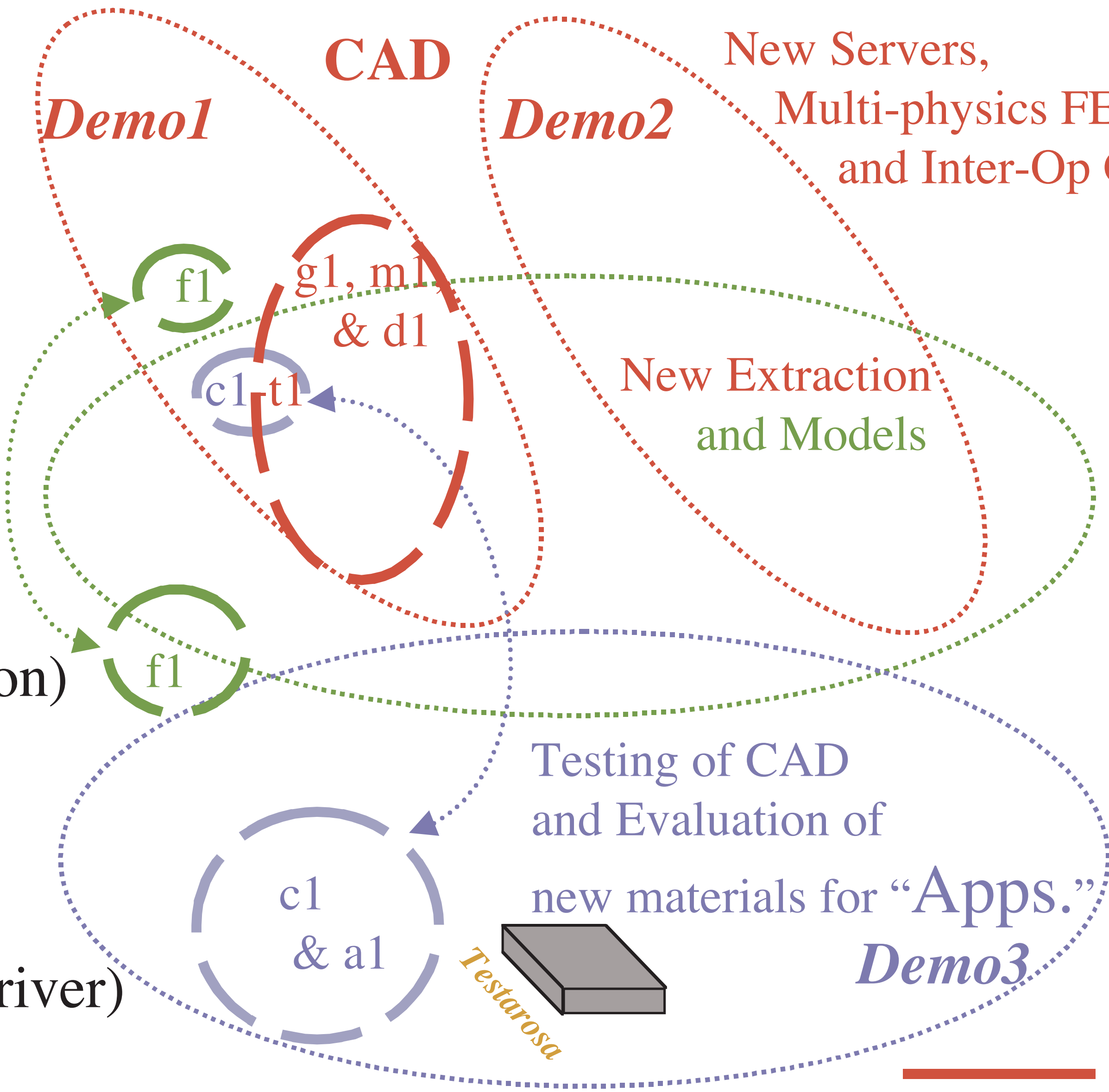
YEAR 2 *YEAR 3*

05 06 | 07 08 09 | 10 11 12 | 01 02 03 | 04 05 06 | 07 08 09 | 10 11 12

Task #1
(software & modeling)

Task #2
(materials characterization)

Task #3
(test chips & application driver)



Task 1. Accomplishments & Plans

NOW

- Developed geometry server (3D and quasi-3D) based on level set
- Portable geometry representation define and demonstrated---VRML-based in support of prototyping across the internet
- Parameter (C-V) extraction for doubly-clamped beams (MUMPs process) that quantifies accuracy of method and parameters based on measurements and simulation

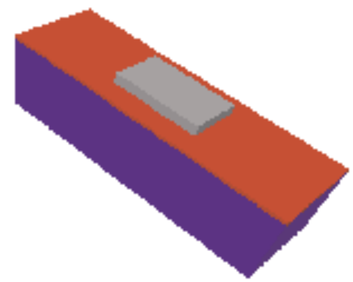
NEXT

- Integrated Demo (d1) that uses: quasi-3D geometry(g1), meshing (m1) and FEM-based multi-physics simulations
- Canonical (RF) test structure characterization --simulation and experimentation (MUMPs) and moving towards other metals (t1)
- Feasibility for FEM modeling of: 1) fatigue (f1) and 2) alternate materials--metals (c2)
- Interferometric measurements integrated into data flow for: a) extraction from C-V, b) parameterized geometry/stress

Pseudo 3D Process Simulation

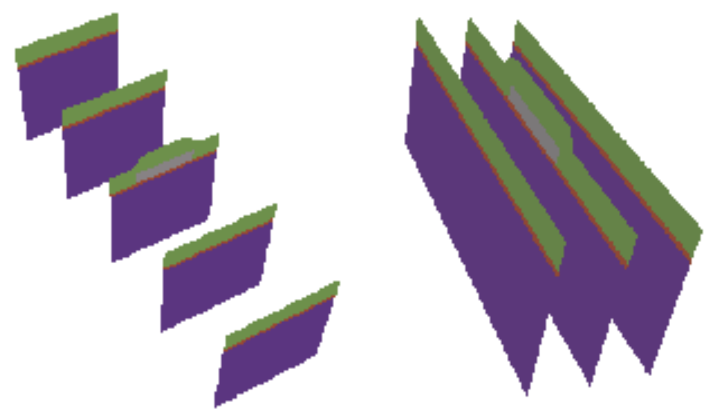
The technique used to create 3-D physical geometry consists of five major steps:

1) Create an initial geometry.



2) Cut the geometry into "slices" in the x and y planes.

3) Perform 2-D physical simulation on the "slices".



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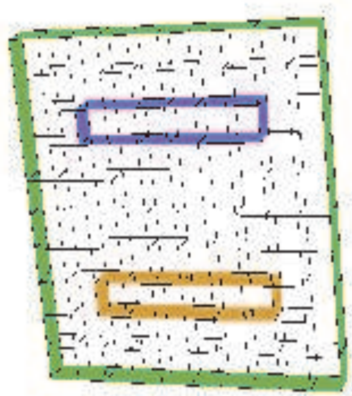
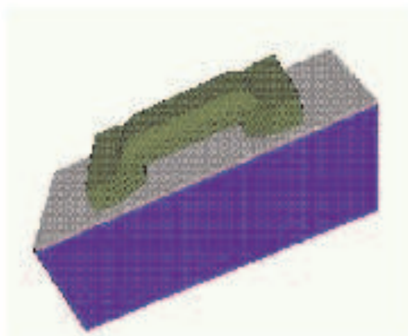
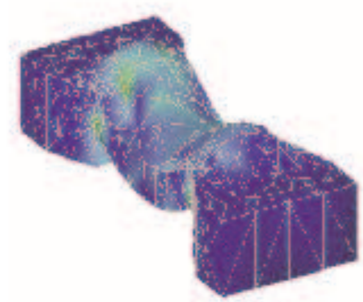
Simulation Results

clamped-clamped beam



RF switch





Task 2. Accomplishments & Plans

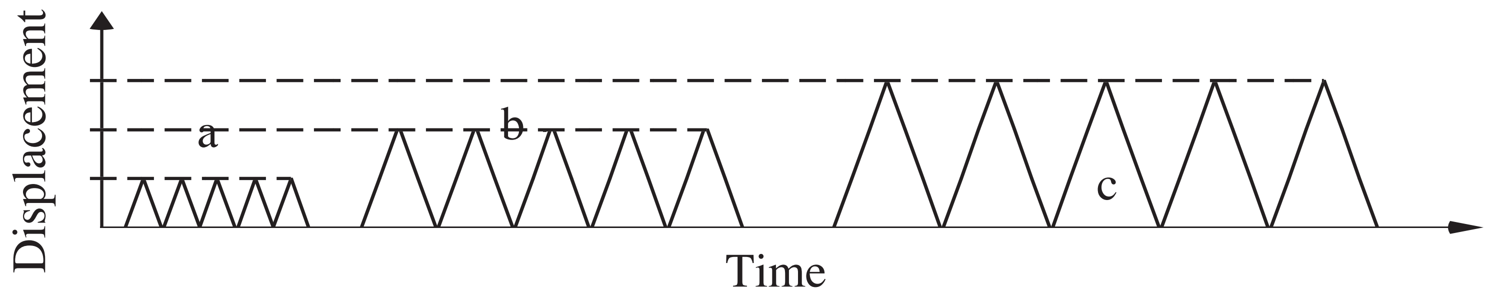
NOW

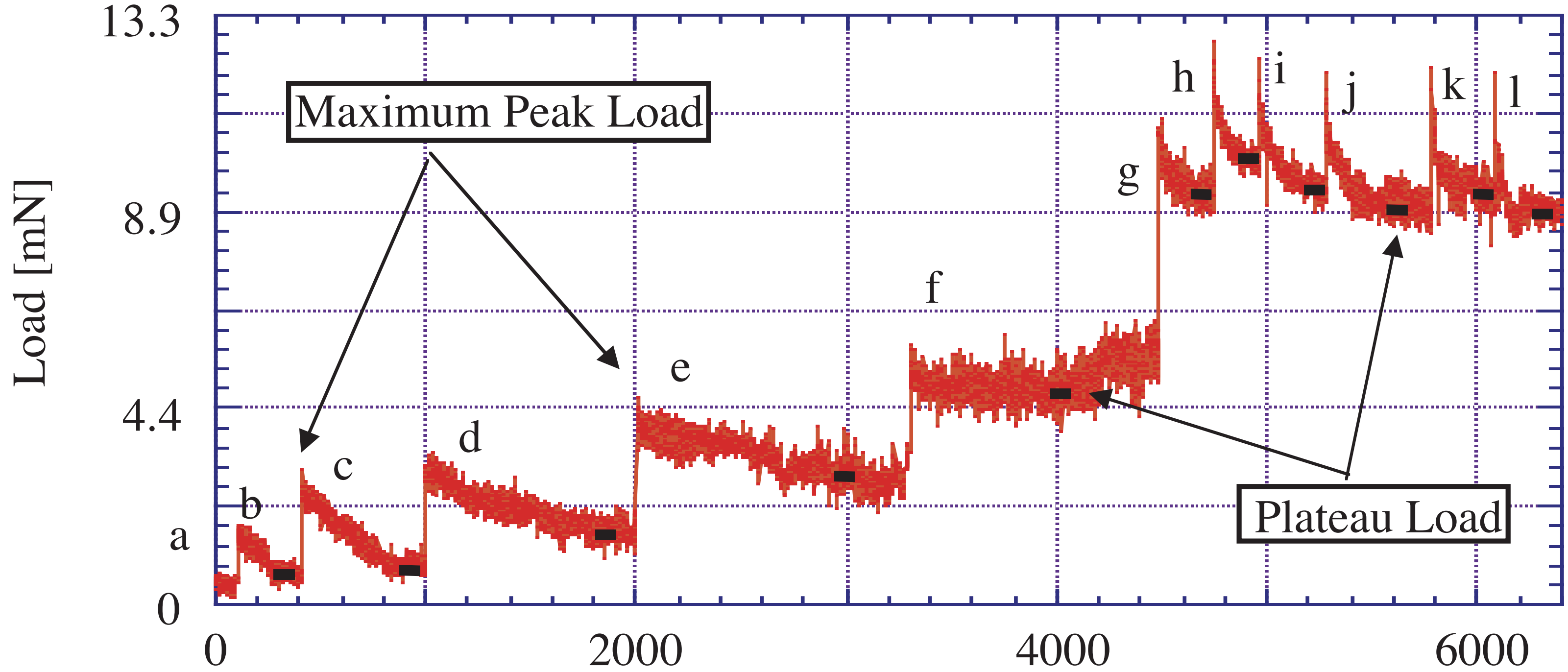
- Fatigue test structures characterized, showing feasibility of method and important materials-dependent details of failure
- Calculations quantify resolution of in-situ stress measurement; circuitry and overall implementation design in progress (p1)

NEXT

- Prototype in-situ structure defined based on existing tunneling tip device; environmental issues for circuitry being addressed
- Improve hard-/soft-ware for fatigue measurements to increase data acquisition rates, greater cycles and testing frequency
- Collect and analyze more fatigue data for Aluminum layers
- Develop fatigue model in collaboration with Task #1 (f1)
- Investigate on-chip fatigue testing for increased frequency range

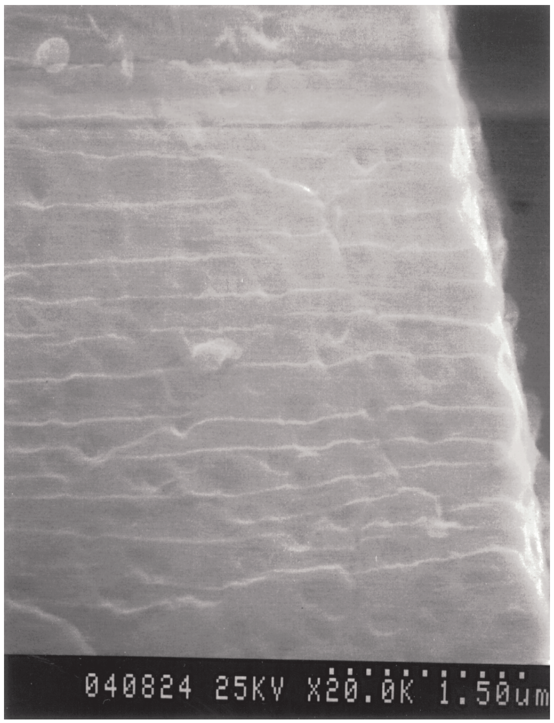
Load drop observed in microtensile sample for cyclic loading at constant displacement





- Peak Load vs. Cycle Number for 12 Blocks of Displacement

SEM Image Comparison: Cyclic Loading vs. Monotonic Loading



6400 Cycles

Monotonic

- Slip markings only evident in cyclically loaded sample

Task 3. Accomplishments & Plans

NOW

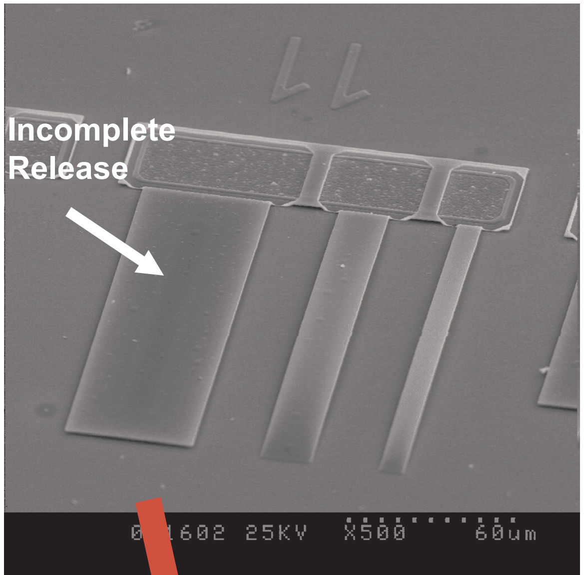
- Test Array Actuated Structures (*TestAroSA*) results show: 1) viability for new materials characterization, 2) sensitivity to overall thermal cycling (+/-)
- Interferometer (Zygo) installed results demonstrate sub-nm (z-) resolution as well as lateral "stitching" across mm's
- Zygo measurements on C-V structures used to determine critical dimensions, supporting improved accuracy of materials extraction

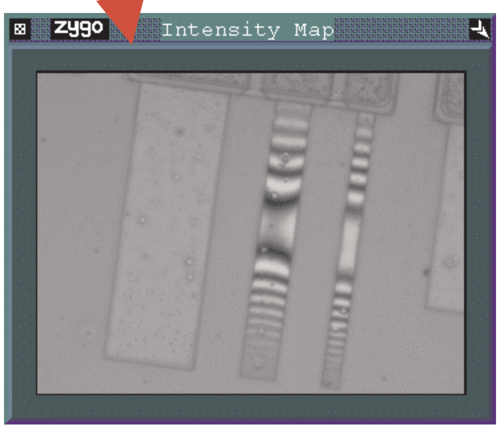
NEXT

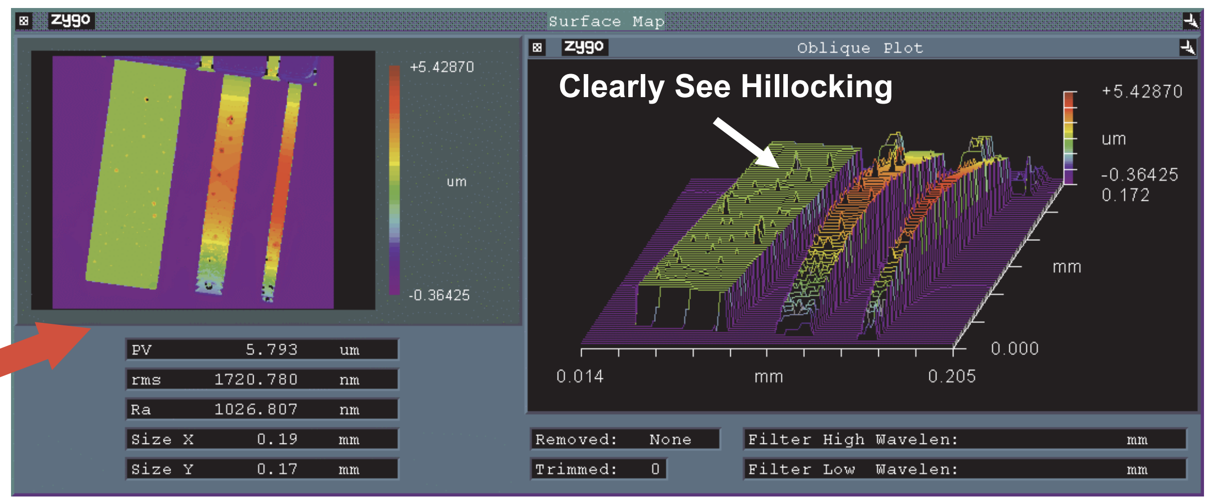
- Improve process flow and thermal cycles to optimize fabrication, including the use of new metal layers (c2)->link to Task #1
- Complete diagnosis on Test Array to quantify accuracy limits and to formalize testing procedures
- Identify application(s) that leverages Test Array for specific (RF) end-user target performance requirements (a1)

Fabrication and Measurement (Testarosa)

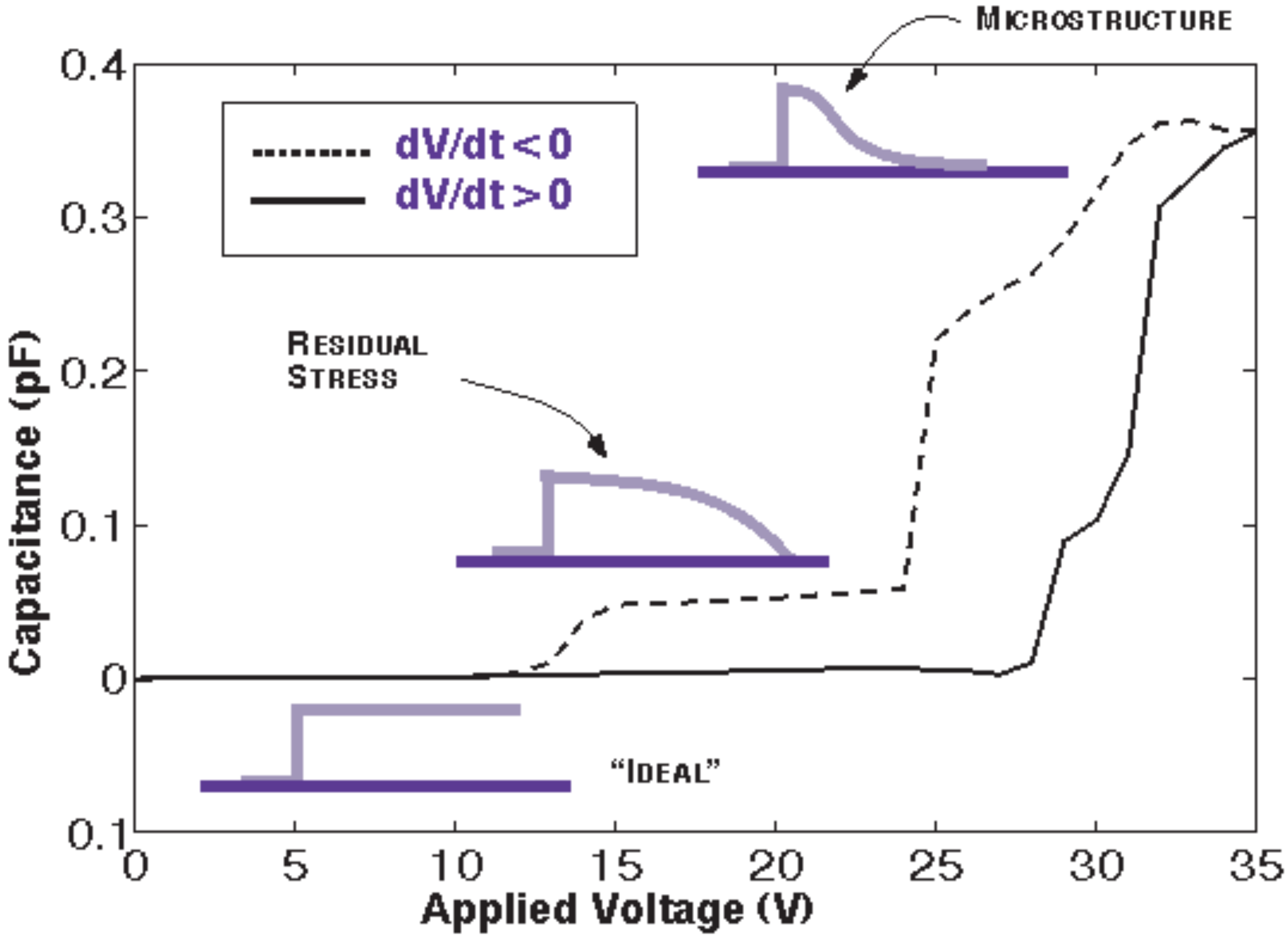
- Interferometry Enables Accurate Measurement of Device Deformation
- Data Used to Extract Mechanical Properties and Quantitatively Verify Modeling Efforts





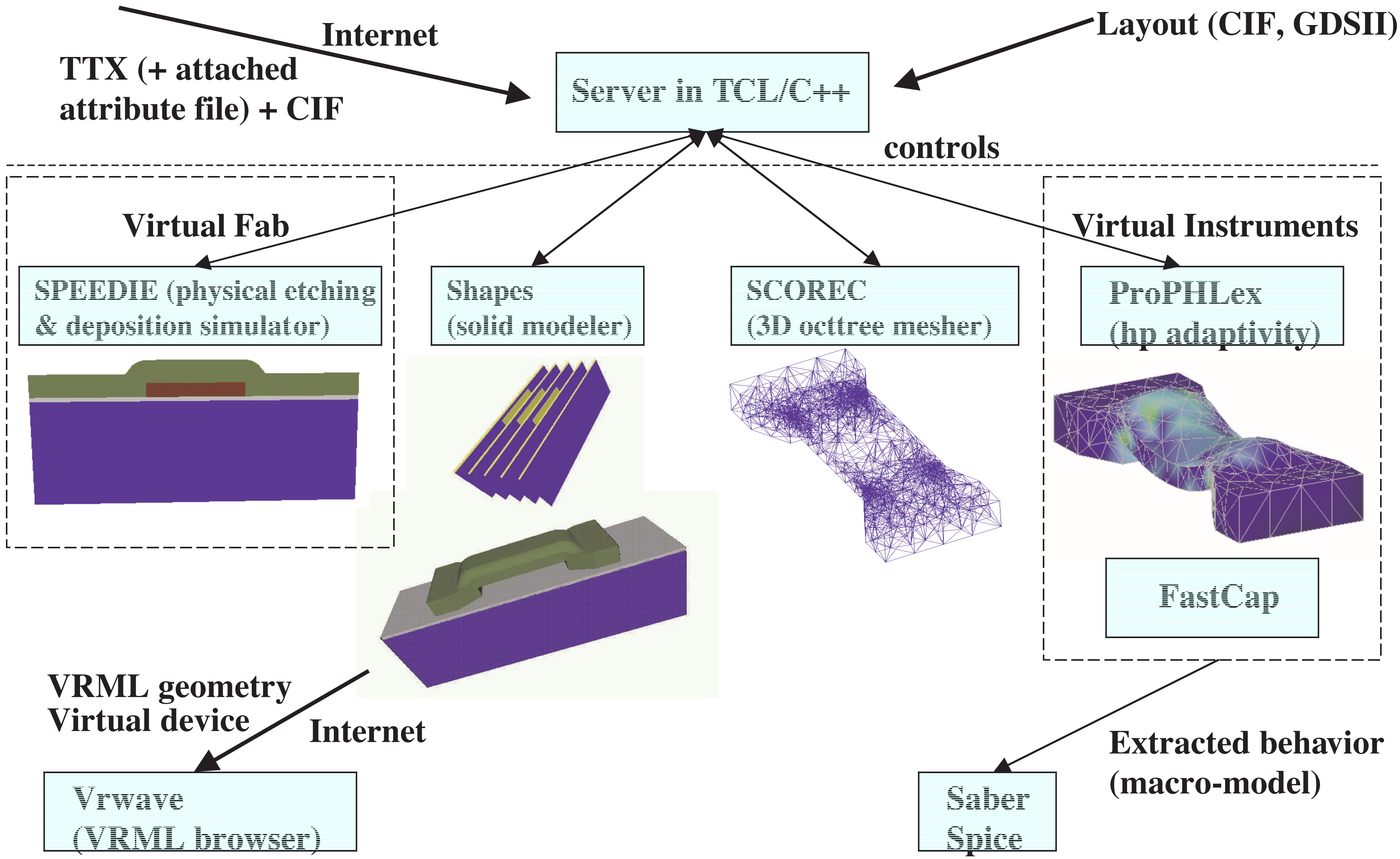


Design PROBLEM...



Progress towards Inter-Operability

Internet-based Computational Prototyping



Research Issues/Challenges

- **Demonstration of alternative material(s) for RF MEMS (c2):**

  There is a very exciting set of candidates with application-pull from other DoD contracts at Stanford. Testarosa (test array) is being used to evaluate. Promise of this task really offers "breakthrough" potential *(and proof-of-concept for "Round Robin")*

- **Development of fatigue model in support of MEMS analysis (f1):**

  The demonstration of microstructure features of Aluminum during cyclic failure opens exciting new avenues to link into the FEM-based multi-physics simulations. Challenges are two-fold: 1) creating the model, 2) moving beyond Al as metal

- **Software integration for Demo (d1)--wrappers (interface definition) that supports interoperability:**

  Details in the choices (and trade-offs) for passing pure geometry versus gridded structures (that implicitly contain geometry) is the key point that needs to be evaluated

Papers Published

Journal

- Z. K. Hsiau, E. C. Kan, J. P. McVittie, and R. W. Dutton "Robust, Stable, and Accurate Boundary Movement for Physical Etching and Deposition Simulation," IEEE Trans. Electron Devices, vol. 44, p. 1375, 1997
- G. Cornella, S-H Lee, W.D. Nix, and J.C. Bravman, "An analysis technique for extraction of thin film stresses from x-ray data", Appl. Phys. Lett., 71 (20), 1997.

Conference

- E. K. Chan, E. C. Kan, P. M. Pinsky and R. W. Dutton, "Nonlinear Dynamic Modeling of Micromachined Microwave Switches," MTT Conference, June 1997.
- E. C. Kan, Z. K. Hsiau, V. Rao, and R. W. Dutton "Gridding Techniques for the Level Set Method in Semiconductor Process and Device Simulation," 1997 Int'l Conf. on Simulation of Semiconductor Processes and Devices (SISPAD'97) Tech. Dig., p. 327, Sept. 1997.
- R.W. Dutton, E. Chan, Z-K. Hsiau, S. Shen, “Challenges in Process Modeling for MEMS,” International Conference on Modeling and Simulation of Microsystems, Semiconductors, Sensors and Actuators (MSM 98), Santa Clara, CA., April 6-8, 1998.

•E.K. Chan, Z.K. Hsiau, K. Garikipati, R.W. Dutton, “Characterization of Electrically Actuated Beams through Capacitance-Voltage Measurements and Simulation,” MSM 98, Santa Clara, CA., April 6-8, 1998

•G. Cornella, R. P. Vinci, J. Bravman, “Observations of Fatigue in Al Microbeams for MEMS Applications,” presented at MRS Spring Symposium, San Francisco, April 1998.

•T. Chen, D.W. Yergeau, R.W. Dutton “A Common Mesh Implementation for Both Static and Moving Boundary Process Simulations”(accepted), International Conference on Simulation of Semiconductor Processes and Devices (SISPAD 98), Leuven, Belgium, Sept. 2-4, 1998.

•N.M. Wilson, Z.K. Hsiau, R.W. Dutton, P.M. Pinsky, “A Heterogenous Environment for Computational Prototyping and Simulation Based Design of MEMS Devices”(accepted), SISPAD 98, Leuven, Belgium, Sept. 2-4, 1998.

•X. Qi, S. Shen, Z.K. Hsiau, Z. Yu, R.W. Dutton, “Layout-based Solid Modeling of IC Structures and Interconnects including Electrical Parameter Extraction” (accepted), SISPAD 98, Leuven, Belgium, Sept. 2-4, 1998.