Microsystems Technology Labs:

a MEMS (and other devices) Fabrication Facility



Dr. Vicky Diadiuk MTL Associate Director, Operations Massachusetts Institute of Technology



MTL Mission

- Support EDUCATION (graduate & undergraduate) through research in semiconductor devices and processes
- Support RESEARCH in microsystems technologies and foster new microstructure initiatives
- Provide FACILITIES and infrastructure for research in microsystems and associated technologies



MTL – Fabrication Infrastructure

- Integrated Circuits Laboratory (ICL)
 - Class 10 2800 sq.ft. (6")
 - 0.5 micron CMOS baseline process
- Technology Research Laboratory (TRL)
 - Class 100 2200 sq.ft. (6")
 - Flexible Process Environment
 - Silicon, Compound Semiconductors
 - Ceramics, Plastics, ...
- Exploratory Materials Laboratory (EML)
 - Class 10,000 2000 sq.ft.
 - Thin Film Processing Facility







MTL - People

- Faculty
 - 14 'Core' Faculty
 - 73 'Affiliate' Faculty
- Staff
 - 21 Semiconductor Process Staff
 - 4 Computer Support Staff
 - 7 Administrative Staff
- Students
 - ~350-400 Associated Students



Revenues: ~\$3.3 M 40% Industrial support 60% Lab Fees

Expenses: ~\$3.3 M 55% Materials & services 45% Personnel

MTL Research Volume: ~\$8M Enabled Research Volume: ~\$40M



2

MTL Industrial Support (MIG)

- AMD
- Analog Devices
- HP
- Intel
- IBM

- Motorola
- Novellus
- TI
- Applied Materials
- TSMC
- u-chips (MAP)



MTL Industrial Support (MIG) Member Companies



CORAL

(Common Object Representation for Advanced Laboratories)

Developed jointly with Stanford, for use in University fabs

- Reservation Actions
 - Make, view, delete reservations
 - Review user daily schedule, or multi-machine view
- Equipment Actions
 - Turn on, turn off
 - Enter, review run data
 - Report problem, shutdown
 - Maintenance history/lab status
- Reporting functions
 - Usage by Machine or User
 - History Reports by Lot, User or Machine
 - Qualification logs (by Users or Machine)
 - Buddy Finder (for specific time range)
 - Accounting



MTL Descrivations for This, DCC 5 © MTL Descrivations for This, DCC 5 © Matheman Descrivations for This, DCC 5 <th>RESErvations for this, DCC 5 C Multiple Days Per Machine View * Multiple Idactines Per DayView Day Schwidzle for (construction for 18:3405-54) Feetimerov Listing * (construction for 19:340 * 100 * 100 * (construction for 19:340 * 100 * 100 * (construction for 19:30 * 100 * 100 * (construction for 10:30 * 100 * 100 * (con</th> <th>100 C C C C C C C C C C C C C C C C C C</th> <th></th> <th>LE SACE P</th> <th>The second second</th> <th>San Chaile.</th> <th>e Equipminent</th> <th>Status Zauninada</th> <th></th>	RESErvations for this, DCC 5 C Multiple Days Per Machine View * Multiple Idactines Per DayView Day Schwidzle for (construction for 18:3405-54) Feetimerov Listing * (construction for 19:340 * 100 * 100 * (construction for 19:340 * 100 * 100 * (construction for 19:30 * 100 * 100 * (construction for 10:30 * 100 * 100 * (con	100 C C C C C C C C C C C C C C C C C C		LE SACE P	The second second	San Chaile.	e Equipminent	Status Zauninada	
Vil. Display between b	Image: Second control of the second control	TALL	Reservation	n Yor 'Anu, B	1005				
P Initiations Disp Schwidzlic from (paraditional 1) (30, Cheros)s (bateOx Feedimmon (Lisking) Gel ANNE-0L1* (Concluse and 1) (30, Cheros)s (bateOx 22:0 (30, Cheros)s (bateOx 30,0 (30, Cheros)s (bateOx 10,0 (30, Cheros)s (bateOx 11,0 (30, Cheros)s (bateOx 11,0 (31,0) 11,0 (31,0) <t< td=""><td>Desp St.med/Net In: (year advocal 1) Example Advocal 1) ide.adv2x-st. ide.adv2x-st. ide.adv2x-st. ide.adv2x-st.</td><td>¢ KL</td><td>C Multiple D</td><td>says Per Ma</td><td>Chine View 🔅</td><td>Multiple Mach</td><td>nev Per DayA</td><td>ficin</td><td></td></t<>	Desp St.med/Net In: (year advocal 1) Example Advocal 1) ide.adv2x-st. ide.adv2x-st.	¢ KL	C Multiple D	says Per Ma	Chine View 🔅	Multiple Mach	nev Per DayA	fi cin	
Max CM093 BateOX 200 413110 918 Geb ANMEAL* (conducent) 2:0 12:00 12:00 12:00 Geb ANMEAL* (conducent) 3:00 12:00 12:00 12:00 Geb ANMEAL* (conducent) 3:00 14:00 12:00 12:00 Geb ANMEAL* (conducent) 3:00 14:00 12:00 12:00 Geb ANMEAL* (conducent) 3:00 14:00 12:00 12:00 Geb Com/IS HeadOte 2:00 14:00 14:00 14:00 Geb Com/IS HeadOte 2:00 14:00 14:00 14:00 Geb Com/IS HeadOte 7:00 FS X/MINEO 16:00 16:00 Geb Com/IS HeadOte 7:00 FS X/MINEO 17:00 16:00 HAMP 2:00 2:000 2:000 16:00	image: state in the server of the s	O telligon	Disp Skihwik	the Don for an a	deviii 11	Gigninenvill	isting)		
Get CheV/S GataG/s 2:00 2:00 1:00 Get ARMERL* (Conducarit) 3:00 1:00 1:00 Get ARMERL* (Conducarit) 3:00 1:00 1:00 Get ArmerAL* (Conducarit) 3:00 1:00 1:00 Get ArmerAL* (Conducarit) 3:00 1:00 1:00 Get Chevics ArmerAC* 4:00 1:00 1:00 Get ArmerAC* 4:00 1:00 1:00 1:00 Get ArmerAC* 4:00 1:00 1:00 1:00 Get ArmerA* 4:00 1:00 1:00 1:00 Get ArmerA* 4:00 1:00 1:00 1:00 <t< td=""><td>ata 0% 200 1200 1200 '(conducant) 0.00 1200 1200 '0.00 10.00 10.00 10.00 adm. '4.00 14.00 14.00 '4.00 14.00 14.00 14.00 adm. '4.00 14.00 14.00 adm. '5.00 16.00 16.00 if:00 16.00 17.00 17.00 if:00 17.00 17.00 17.00</td><td>Contraction and a second</td><td>-</td><td>THEAD - 2</td><td>4</td><td>and the second s</td><td>404.10</td><td>MIK.</td><td></td></t<>	ata 0% 200 1200 1200 '(conducant) 0.00 1200 1200 '0.00 10.00 10.00 10.00 adm. '4.00 14.00 14.00 '4.00 14.00 14.00 14.00 adm. '4.00 14.00 14.00 adm. '5.00 16.00 16.00 if:00 16.00 17.00 17.00 if:00 17.00 17.00 17.00	Contraction and a second	-	THEAD - 2	4	and the second s	404.10	MIK.	
Get ANNELAL* (conducant) 2:00 12:00 90: Thick Oxchi 3:00 11:00 90: Chairs Headdles 2:50 14:00 90: Chairs Headdles 2:50 16:00 90: Chairs Headdles 2:50 16:00 90: Chairs Headdles 2:50 17:00 90: Chairs Headdles 17:00 17:00 90: Chairs He	* (Conducant) * 2:0 12:00 10:00 * 3:00 * 3:00 10:00 10:00 * 4:00 * 4:00 14:00 14:00 * 4:00 * 4:00 14:00 14:00 * 4:00 * 4:00 14:00 14:00 * 4:00 * 4:00 14:00 14:00 * 4:00 * 4:00 14:00 14:00 * 4:00 * 4:00 14:00 14:00 * 4:00 * 4:00 14:00 14:00 * 4:00 * 4:00 14:00 14:00 * 4:00 * 4:00 14:00 14:00 * 4:00 * 4:00 14:00 14:00 * 4:00 * 4:00 14:00 14:00 * 4:00 * 4:00 14:00 14:00 * 4:00 * 4:00 14:00 14:00	👹 WA CINUS SateOx	2:00		1	12:00			
360 Attribut, "Cooldmast is a spectrum of the product of the prod	3.60 15.30 3.60 14111 4101 14111 4101 1431 4101 1431 4101 1431 1431 1431 1431 1431 1431 1431 1431 1431 1431 1431 1431 1431 1431 1431 14331 14331 14330 14331 14330 14331 14330 14331 14330 14331 14330 14330 1530 1600 1600 1600 1730 1730 1730 1730 1410 1811 1811 1811 1811 1811	The set with all a description with	+ 2:00			12:00			
66 Hindk Orada 13.50 14.10 60 Charles HaldChe: 4.50 14.10 66 Access Sciences 4.50 14.10 66 Access Sciences 7.50 14.10 66 Access Sciences 7.50 16.00 66 Access Sciences 7.50 16.00 66 Access Sciences 7.50 16.00 66 Access Sciences 7.50 17.00 67.00 7.50 17.00 7.50 17.00 17.00 7.50 17.00 17.00 7.50 17.00 18.00 180 Access Sciences 6.50 18.30 180 Access Sciences 20.00 20.00 18.30 20.00 20.00 18.31 20.00 20.00 18.32 20.00 20.00 18.00 21.00 21.00	3.30 15.30 $4100ec$ 2.50 2.50 14111 2.50 14111 14.01 14.01 14.01 14.01 14.01 14.01 14.01 16.00 15.30 16.00 16.00 16.00 17.00 17.00 7.50 $1-0.0000$ 7.50 $1-0.0000$ 18.01 18.01 18.01 18.01		20.00			10.00			
GRI CINE IS: HealdCite: 2 111 14 111 GRI CINE IS: HealdCite: 2 511 14 111 GRI CINE IS: Printy 750 14 111 GRI CINE IS: Printy 750 16 00 GRI CINE IS: Printy 5 00 16 00 GRI CINE IS: Printy 5 00 16 00 GRI CINE IS: Printy 5 00 17 00 GRI CINE IS: Printy 7 00 17 00 GRI CINE IS: Printy 20 00 20 00 20 00 GRI CINE IS: Printy 20 00 20 00 20 00 GRI CINE IS: Printy 21 00 21 0	(441) (443)	🌆 60 Hinsk Oxeda	13,90			19.30			
600 CMM PS HeathODE 24/31 640 CMM PS HeathODE 25/31 640 CMM PS HeathODE 25/30 640 CMM PS HeathODE 21/30	4331 1431 4510 1431 1431 1431 1431 1633 14331 1603 1600 1600 1700 1700 1700 1700 1730 1730 1730 1730 1700 1730 1730 1730 1730 1730 1730 1730 1730 1730 1730 1730 1730 1730		4111			11111			
isk Chartis Prity 7:50 10:30 10:30 isk thopad Weby 5:00 10:30 10:00 isk thopad Weby 5:00 17:00 17:00 isk thopad Weby 7:00 F+ 2/3000/01 17:00 17:00 isk thopad Weby 7:00 F+ 2/3000/01 17:00 17:00 isk thopad Weby 7:00 F+ 2/3000/01 17:00 17:00 isk threate* 6:00 15:00 17:00 17:00 isk threate* 6:00 15:00 17:00 17:00 isk threate* 6:00 15:00 16:00 16:00 isk threate* 6:00 15:00 17:00 17:00 isk threate* 6:00 15:00 16:00 16:00 isk threat* 6:00 15:00 16:00 16:00 isk threat* 6:00 16:00 16:00 16:00 isk threat* 6:00 16:00 16:00 16:00 isk threat* 6:00 20:00 20:00 20:00 isk threat* 51:00 21:00 21:00 2	$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	GAD COMMUNE HABITCHE	~ 4-544 72-440		_	1431			
100 Childres Unity 100 300 500 700 100 700 100 700 100 17.00 100 Childres 17.00 77.90 17.00 17.00 17.00 17.00 100 Childres 18.00 18.30 18.00 18.30 100 Childres 18.00 20.00 18.30 20.00 100 Childres 20.00 20.00 20.00 20.00 100 Childres 21.00 21.00	13:00 16:00 13:00 16:00 15:00 16:00 17:00 17:00 17:00 17:30 13:00 18:01		+ 7/50			1025			
Image: Set the paid Weby 3.10 Image: Set the paid Weby 17.00 Image: Set the paid Weby Image: Set the paid Weby 17.00 Image: Set the paid Weby 17.00 Image: Set the paid Weby Image: Set the paid Weby 17.00 Image: Set the paid Weby 17.00 Image: Set the paid Weby Image: Set the paid Weby 17.00 Image: Set the paid Weby 17.00 Image: Set the paid Weby Image: Set the paid Weby 17.00 Image: Set the paid Weby 17.00 Image: Set the paid Weby Image: Set the paid Weby 17.00 Image: Set the paid Weby 17.00 Image: Set the paid Weby Image: Set the paid Weby 17.00 Image: Set the paid Weby 17.00 Image: Set the paid Weby Image: Set the paid Weby 17.00 Image: Set the paid Weby 17.00 Image: Set the paid Weby Image: Set the paid Weby 17.00 Image: Set the paid Weby 17.00 Image: Set the paid Weby Image: Set the paid Weby 17.00 Image: Set the paid Weby 17.00 Image: Set the paid Weby Image: Set the paid Weby 17.00 Image: Set the paid Weby 17.00 Image: Set the paid Weby Image: Set the paid Weby<	nty	Re fax charies priny	5.00			16:00			
7.00 F - //MNH-91 17.00 7.50 F - //MNH-91 17.30 180 MILHERH** 7.50 F - //MNH-91 180 MILHERH** 7.50 F - //MILHERH** 180 MILHERH** 7.50 F - //MILHERH*** 180 MILHERH*** 7.50 F - //MILHERH*** 180 MILHERH*** 7.50 F - //MILHERH*** 180 MILHERH**** 7.50 F - //MILHERH**** 180 MILHERH***********************************	77.00 F - ANN-01 17.00 77.50 F - ANN-01 17.30 1410 1810 1810 4500 1800 1800	🜆 😹 tionad Pate	13:00			16:00			
#2.110** 17.50 1-7.30 #0.011606** 18.00 #0.00** 18.00 #10.00** 18.00 <tr< td=""><td>17.50 17.30 1410 18.00 4300 18.00 18.00 18.00 18.00 18.00 18.00 18.00</td><td></td><td>7.00</td><td>5 X3MH-2</td><td>9</td><td>17.02</td><td></td><td></td><td></td></tr<>	17.50 17.30 1410 18.00 4300 18.00 18.00 18.00 18.00 18.00 18.00 18.00		7.00	5 X3MH-2	9	17.02			
isto militame* *810 *810 # MVD* *800 1800 # MVD* *9:00 18:30 # MVD* *9:00 20:00 20:00 20:00 20:00 20:00 20:00 20:00 20:00 20:00 20:00 20:00 20:00 20:00 20:00 20:00 20:00 20:00 20:00 20:00 20:00 20:00 20:00		(#C1.1D*)	7.50	(ī	17.30			
Image: Constraint of the second se	2400 1831 2400	Careful Contracts	1810	10000000	1.	38411			
Image: Second	2401	180 MILENIE.	43030			15-21			
18:30 20:00 20:00 20:00 20:00 20:00 20:00 20:00 20:00 20:00 21:00 21:00 21:00 21:00		THE MERCEN	240.0		12	16.01			
Image: Solution of the	30:0		· 9(80		8	18:30			
21.00 21.00 21.00 21.00 21.00 21.00 21.00	200	A MINE .	200			2000			
	21.00	in the second	53.50 51.00		1	20.00			
		🚝 roat	51.50			21.21			
P: Divin	22 00	Pr. Dividu	22.00			22.00			
22.91	991	1/2/// AMAN	9290			2231			
P Fluit 2 (10 1))))))))))))))))))))))))))))))))))	2 200	P Flui	2300			.27914			



Yearly Machine Units (Monthly Average)







Major Fab Tools

- Diffusion: atmospheric & LPCVD furnaces
- Photolithography: mask-aligners, stepper
- Dry Etch: various chemistries, depth, wall angle
- Deposition: PECVD, e-beam, sputtering
- Wet Processes: clean, etch, release
- Metrology: thickness, index, morphology
- Packaging: CMP, die-saw, wire-bond



MEMS-centric Machines

- EVG Wafer aligner-bonder
- STS Deep Reactive Ion Etching (DRIE)





Issues related to sharing a VLSI fab

- Must control contamination and particles
- Au vs non-Au machines (color-coded)
- Handling of perforated wafers





Emerging Microsensor Applications

Industrial Plants and Power Line Monitoring (courtesy ABB)





Operating Room of the Future (courtesy John Guttag)



Target Tracking & Detection (Courtesy of ARL)

Location Awareness (Courtesy of Mark Smith, HP)

NASA/JPL sensorwebs









Integrated MEMS





Accelerometer







Si Field Emission Device

(1-µm gate aperture)



T. Akinwande



Smart Silicon MOSFET / Field Emission Devices (Akinwande)



Applications

- Field emission displays
- RF electron sources/amplifier
- Multi e- beam lithography

MOSFET control of electron emission results in

- low voltage control
- spatial uniformity
- temporal stability/ lower noise

Sponsored by DARPA HDS Program



Integration of Function: Crosstalk Isolation for SoC Applications

New *Faraday cage* substrate crosstalk isolation.sconcept:





This project leverages MTL's MEMS technology onto Si RF world



World record crosstalk suppression at 1 GHz and 5 GHz (distance=100 µm) J. delAlamo



Silicon Substrate-Via Technology



- Low-impedance ground for RF circuits
- Backside routing for power and ground in digital ICs
- Backside electrical connection for MEMS

J. Wu and J. A. del Alamo



Silicon Substrate-Via Technology





Microchemical Systems - Motivation

K.F. Jensen



O Potential advantages:

- Safer operation in small dimensions
- Improved chemical performance
- Distributed manufacturing on demand production of toxic intermediates
- Fast scale-up to production by replication
- High throughput reaction/catalyst screening combinatorial chemistry

 Can scale-up by replication of microfabricated reactors as opposed to

a few large units revolutionize chemical production?





Integration into Arrays: Microchemical **Systems**

- Scale-up of microreactor systems is by replication of the reactor unit
- Increased flexibility and faster laboratory-to-market transfer

K.F. Jensen

Chip

Fluid Circuit Board

Mini Chemical System



Experiments

Elastomer Microchip



Separation Channel



Drug Delivery







www.mchip.com

* Figure reprinted by permission from*Nature* 397, 335-338 (1999) Macmillan Magazines Ltd.

Silicon field-effect sensor for molecular biology





μDAC = microfabricated <u>Dynamic Array Cytometer</u> Monitors dynamics of many individual cells







Courtesy: J.Voldman-MIT



Final structure







Manipulating cells



Calcein-labeled HL-60 cells

J.Voldman-MIT



Electric Power: Current Technology





MIT Micro Gas Turbine Generator



	Micro Turbo	LiSO2 Battery		
	Generator	(BA5590)		
Power Output	50 W	50 W		
Weight	50 grams	1000 grams		
Specific Energy	3500 W-hr/kg	175 W-hr/kg		

 A portable power source with ten times the power density of state-of-art batteries



Demo Engines







Batteries vs. Fuel

- Batteries
 - ~500 Watt-hours per kilogram for Primary Systems
 - ~120 W-h/kg for Secondary (Rechargeable) Systems
- Fuel Combustion
 - ~39,000 W-h/kg for Hydrogen
 - ~14,000 W-h/kg for Propane or Butane (C₃H₈ / C₄H₁₀)
 - ~12,000 W-h/kg for Gasoline
 - ~6,000 W-h/kg for Methanol

Fuel Contains 10-300x the Specific Energy of Batteries

Courtesy: S.Schaevitz



Advantages of Fuel Burning



Courtesy of S. Schaevitz



Energy Scavenging



Jose Mur Miranda

Scott Meninger

Rajeevan Amirtharajah

A. Chandrakasan, J. Lang

Energy can be scavenged from mechanical vibrations to power micropower sensor systems



Heel-Strike Energy Harvesting





Microrocket Engine







The rocket's first firing....



What does it take?

- An Incubator, that:
 - Enables people to cross disciplinary boundaries
 - Encourages free flow of information across projects at the 'core technology' level
- The MTL (Technology Infrastructure System Focus)
 - ~350 researchers (3% of MIT student population)
 - Shared experimental facilities
 - Cleanrooms, Testing, CAD, IC Design
 - Participants from 29 Departments/Labs/Centers
- The Output:
 - Ideas
 - Students

