# E-321: Engineering Design V Lab

# TA Book of Procedures

*2003-2004 Academic Year*

CREATED BY

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# E-321: Engineering Design V Lab

Summary of Module Setup, Instruction, Data Collection, Analysis, Supplies, and Consumable Materials

*2003-2004 Academic Year*

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# 0. General Materials for Design V Lab

## Purpose & Procedure Overview:

(review of APC and outline of procedure & timeline)

## Materials Needed:

(equipment which may need to be replaced or updated)

| | | | |
|---|---|---|---|
| Case of paper towels | 1 (0) | Temco | cs. of 12 rolls lasts whole year |
| Dry erase markers | 12 (0) | Staples | 6 black and 6 blue/red/green |
| Goggles | as needed | Fisher Scientific | replenish supply as needed |
| Gloves (leather) | as needed | MSC | replenish supply as needed |
| Printer paper | | CBME Dept office | |
| Projector lamp bulbs | 4 | Staples | enough for semester |

## Consumables & Preparatory Tasks:

(supplies normally consumed – fall semester of ~ 160 students)

- Review PowerPoint presentation for introduction (confirm file is functional and up-to-date).
- Update contact info and lab procedures on class web site:
  http://www.mat.stevens-tech.edu/faculty/libera/courses/e321_home.html
- Check video of class intro/review.
- Start ordering replacement consumables 1 month before first class.
- Call in broken lights, fixtures, *et cetera* to Physical Plant.
- Make sure to have enough copies (for all sections) of forms and the quizzes before each module begins. Copies of forms may be found in the TA supply room.
- Collect sign in sheets, verify with registrar, & start grade file (post on web with first quiz grade).

## Materials Purchases Necessary: None.

## Typical Module Timeline:

(varies somewhat with TA – no mistakes by students)

| *Stage* | *Duration* | *Total Time* |
|---|---|---|
| Lab roster sheet | 0:10 | 0:10 |
| Presentation | 0:30 | 0:40 |
| Homework assignment (graphing for next week) | 0:05 | 0:45 |

## Module-Specific Safety Concerns:

- Concern 1.
- .

## Module Photographic Highlights:

(supply locations, equipment setups, and key activities)

Many of the module supplies are located in the TA supply room (B-310). The free-standing shelf units, file cabinets, and the built in cabinets and drawers house many of the supplies and visual aids needed. Most material stock is also housed in this room.

Directly below is the TAs' module presentation computer in B-312.

Some modules' supplies are stored in-room. Left is the cabinet in B-311 with some of the tensile testing and Sn-Bi module materials.

Below (both) are the cabinets in B-314 with microscopy, electroplating, polymer processing, and old EDS equipment and materials.

NB: the bottom shelf in the left cabinet in B-314 (pictured below) contains radioactive samples which are stored properly within lead-shielded containers. DO NOT DISTURB these!

The top two photos at the left depict the TAs' microscopy station and the typical 6-station student microscopy setup in B-314. The large monitor at the TAs' station should be swiveled to face the students for demonstrative and guidance purposes.

The two photos below show some of the Sn-Bi casting module materials and equipment. These drawers are located beneath the hardness testers in B-311.

The supplies and some of the equipment for the semi-conductor processing (solar cell) module are located in the cabinets in B-313.

Metallographic mounts for modules 4, 6 and 7 are kept in the drawers beneath the desiccators in B-314.

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# I. Some Basic Properties of Materials

## Purpose & Procedure Overview:

(review of APC and outline of procedure & timeline)

As the first module of the Design V course, this set of exercises aims to bring all students of varying background up to speed. While these efforts will continue through the initial 3-4 modules, the students begin here. Students are introduced to the concept of thermal conductivity versus temperature, conduction of heat by radiation and phonons (lattice vibrations), and how materials properties relate to thermal conductivity, melting temperature and other intrinsic properties. Students also review the concept of density with Archimedes principle, where they measure the density of 10 different objects without doing volume calculations, while becoming familiar with a typical double-beam balance. The module wraps up with discussion and measurement of the hardness of the previously measured samples. Although Mohs relative hardness scale is used, the breadth of available types of testing (and why) is reviewed.

## Materials Needed:

(equipment which may need to be replaced or updated)

| | | | |
|---|---|---|---|
| Balances | 6 (0 extra) | Ohaus | with weigh pans and covers |
| Beaker with water | 6 (1) | Fisher Scientific | |
| Blow torch & striker | 1 (0) | Local hardware store | see professor for training |
| Multi-metal wand | 1 (0) | | for students to compare thermo K |
| Stackable bins | 6 (10) | MSC | to contain all items listed below |
| Mesh-bottom basket | 6 (4) | SIT Machine Shop | be gentle! |
| 10 material cube set | 6 (2) | | |
| Hardness tester kit | 6 (0) | Dad's Rock Shop | magnets go missing very quickly |
| Set of 3 Sn-Bi sinkers | 6 (0) | Prof / TAs | cast with Prof. Libera's sinker mold |
| Set of 3 other matl's | 6 (1) | Various | Rock/museum shops |

## Consumables & Preparatory Tasks:

(supplies normally consumed – fall semester of ~ 160 students)

- Review PowerPoint presentation for this module (confirm file is functional and up-to-date).
- Prepare a sufficient number of copies of the class safety/academic "contract" for each section.
- Extra printouts of the lab procedure for those who forget to bring their own.
- Zero all balances with matching (serial # on bottom) weigh pans.
- Water for beakers (fill to within 1.5" of brim).
- Dry material samples/cubes and weighing basket after each lab group.
- Scribe tips for soft materials need to be re-sharpened once per year (before the fall semester).
- Small propane bottle for torch (very seldom needs replacement).
- Practice lighting torch with striker and holding steady under center of multi-metal wand.
- Beside the minor items and equipment repairs (and replacements) mentioned above, there are no critical consumables for this module.

## Materials Purchases Necessary: None.

Advise students that it is highly preferable to bring their laptops to next week's module.

## Typical Module Timeline:

(varies somewhat with TA – no mistakes by students)

| *Stage* | *Duration* | *Total Time* |
|---|---|---|
| Quiz | 0:10 | 0:10 |
| Presentation | 0:20 | 0:30 |
| Zeroing scales and verifying 1st reading | 0:10 | 0:40 |
| Dry measurements | 0:15 | 0:55 |
| Submerged measurements | 0:15 | 1:10 |
| Example calculation | 0:05 | 1:15 |
| Hardness measurements | 0:10 | 1:25 |
| Thermal K discussion (cubes) | 0:10 | 1:35 |
| Thermal K discussion (rods on hub) | 0:10 | 1:45 |

## Module-Specific Safety Concerns:

- Advise students to be gentle with balances and weighing baskets so-as not to break them.
- .

## Module Photographic Highlights:

(supply locations, equipment setups, and key activities)

Each of six stations should have a balance, hardness testing kit (with 4 double-pointed scribes), beaker of water, custom weighing basket, and box of 16 material samples (fore and background).

Some groups will whip through each weighing stage. While the TA helps other groups, give the fast groups(s) hard credit q's to figure out then and there.

Many students need to be explicitly shown how to use these balances.

# II. Corrosion and Electroplating

## Purpose & Procedure Overview:

(review of APC and outline of procedure & timeline)

Corrosion of materials and protection through coating application are reviewed at the beginning of this module. Students are given an appreciation of the magnitude of annual destruction due to rust (corrosion of Fe) alone. Students are asked to sand rust from tools provided to demonstrate just how difficult it is to remove this thermodynamically stable phase, then dip them in salt water for later observation. The students then set up an electroplating circuit at each of their stations to galvanize (plate with Zn) a steel coupon. Students estimate the thickness of their coating based on an electric/cat ion balance and the area of their coupons. In conclusion, the students observe several pre-rusted coupons, some with scratches, to demonstrate the protective (even from a distance) nature of zinc coatings. At the end of the module, students return to the sanded and wet tools to observe fresh rust formation.

## Materials Needed:

(equipment which may need to be replaced or updated)

| | | | |
|---|---|---|---|
| Stackable bins | 6 (2) | MSC | contain pieces below |
| Power supply | 6 (0) | SIT Inventory | |
| Connecting wires (5) | 30 (15) | | |
| Beaker for $H_20$ rinse | 6 (2) | | |
| Beaker for electrolyte | 6 (2) | | |
| Electrolyte solution | 1 liter | Prof / TAs | prepared 1 wk ahead - good all sem. |
| Steel plate (1 each) | 6 (many) | | 1" * 2" |
| Zn anode (1 each) | 6 (many) | | 1" * 2" |
| Tweezers | 6 (2) | Fisher Scientific | |
| Rusty tools | 6 (4) | | no problem finding these! |
| Cardboard table mat | 4 (0) | SIT Lab | protect table surface from scratching |
| Sand paper | 10 (10) | Home Depot | numerous 1/4 sheets of 120 grit |
| Pre-rusted coupons | 4 (2) | Prof / TAs | with and w/o Zn to show protection |
| Chemicals | various | Sigma-Aldrich | for preparation of Zn plating solution |

## Consumables & Preparatory Tasks:

(supplies normally consumed – fall semester of ~ 160 students)

- Review PowerPoint presentation for this module (confirm file is functional and up-to-date).
- Prepare a sufficient number of copies of the quiz for each section.
- Extra printouts of the lab procedure for those who forget to bring their own.
- After several semesters of use, the alligator clips which hold the coupons begin to rust and prevent good electrical conductivity. They must be sanded or replaced.
- Beside the minor items and equipment repairs (and replacements) mentioned above, the critical consumables for this module are listed below:

**Materials Purchases Necessary:** Sand paper, chemicals for electrolyte solution (make 1liter for the week).

## Typical Module Timeline:

(varies somewhat with TA – no mistakes by students)

| *Stage* | *Duration* | *Total Time* |
|---|---|---|
| Quiz | 0:10 | 0:10 |
| Presentation | 0:20 | 0:30 |
| Sanding of tool and coupon – disc of E expended | 0:10 | 0:40 |
| Rinse and dry steel samples | 0:05 | 0:45 |
| Circuit setup and verifications | 0:05 | 0:50 |
| Galvanization of sample (both sides) | 0:15 | 1:05 |
| Discussion of pre-galvanized / rusted samples | 0:10 | 1:15 |

## Plating Solution Preparation:

Zn plating solution preparation is as follows (must be done in this order):

Start with 1 liter of distilled $H_2O$
and add 180g of $ZnSO_4$ heptahydrate, stirring/agitating in by parts.
When all is dissolved add 14g of $ZnCl_2$, stirring/agitating in one ½ then the 2nd ½.
When all is dissolved add 12g of $H_3BO_3$, stirring/agitating vigorously. The boric acid will take 1-2 hours to full dissolve in at room temperature – agitate several times during this period. To reduce preparation time, raise the temperature to 50degC to aid dissolving and for preparing larger batches. Total time committed is about 1 hour. Recipe makes ~1.2 liters – which is more than the 6 * 150mL needed. Chemicals are currently stored in the blue chemical cabinet in B-308.

## Module-Specific Safety Concerns:

- Electrolyte is an acidic solution. Please do not touch it with bare hands. Rinse all samples after you use them.
- You will be dealing with objects that are sharp and rusty. Be careful – don't cut yourself.
- Acetone is used for rinsing your samples after you sand them. Again, make sure you will not touch it.
- .

## Module Photographic Highlights:

(supply locations, equipment setups, and key activities)

Six stations are prepared as shown in the photo at right. Included are (back row) the power supply, 5 banana plug patch cables, (front row) the coupon holder, 1-ohm resister box, volt meter, tweezers, 150mL electrolyte solution, beaker of water for rinsing.

The rust removal station tables are covered with cardboard to protect the tabletops. 12-15 pre-rusted tools and pieces of sand paper are supplied for the first part of the lesson. Coupons are also cleaned here.

After being sanded clean, coupons are rinsed with acetone to remove all debris (water would rust them). Not much acetone is used, so it just evaporates from the sink. Beakers are stored on the window ledge in the background.

Photo of electroplating setup running.

The electroplating setup for galvanization of the students' coupons runs at 0.5V or 1.0V for 5 minutes. When the zinc coupon turns past dark to black, it will no longer be a suitable source and must be replaced.

Tools and coupons pre-rusted for use by students are in the top set. The bottom set shows galvanized samples which were then exposed to even more harsh conditions, demonstrating the level of protection created by zinc coating.

# III. Tensile Testing and Mechanical Properties

## Purpose & Procedure Overview:

(review of APC and outline of procedure & timeline)

Three exercises are used to give the students an appreciation of materials' tensile properties. Starting in the lobby, students make 3 three measurements of a loaded length of fishing line, observing relaxation in between measurements. After brief calculations and comparison to known values, students proceed to B-311. Using one (high gear) of the two Instron tensile testers, 3 'dog bone' samples are pulled apart—one steel, 1 aluminum alloy, and 1 polymer. Students are guided through the test both in setup and discussion of mechanisms of deformation and property changes of each material during the tests. The last step explores the effect of stress concentrators by comparing the fracture strength of a glass slide with and without a drawn scratch.

## Materials Needed:

(equipment which may need to be replaced or updated)

| | | | |
|---|---|---|---|
| Stackable bins | 6 (2) | MSC | contain pieces below |
| 1 gal. water jugs | 6 (1) | Local supermarket | extra is a metal weight |
| Yard sticks | 6 (0) | Local hardware | measuring extension of loaded line |
| Fishing line | 6 lengths | | over 100' extra of each type |
| (100# test nylon monofilament is preferred) | | | |
| Clamps | 6 (1) | Local hardware | left clamped to ceiling beams |
| Ladder | 1 (0) | SIT Inventory | for hanging and removing lines |
| Carribeaners | 12 (2) | | 2 connected to ends of each line |
| Vernier calipers | 6 (4) | MSC | Measuring line diameter |
| Instron tensile Mns. | 2 (0) | SIT Inventory | B-311: 1 high-rate, 1 low-rate |
| Computers | 2 (1) | SIT Inventory | w/ control & measurement software |
| Set of 4 tensile bars | 16 (100?) | SIT Machine / Other | 1 set per lab section (~30 sets / year) |
| Glass slides 2 per grp. | 12 (20) | Fisher Scientific | stress concentrator exercise |
| Scribe | 6 (2) | | for scribing glass slides |
| | | | |
| Paper towel pieces | 12 (roll) | Temco | protective measure |
| Gloves (pr.- leather) | 10 (0) | MSC | *general protective wear* |
| Goggles | 12 (25) | Fisher Scientific | *general protective wear* |

## Consumables & Preparatory Tasks:

(supplies normally consumed – fall semester of ~ 160 students)

- Review PowerPoint presentation for this module (confirm file is functional and up-to-date).
- Prepare a sufficient number of copies of the quiz for each section.
- Extra printouts of the lab procedure for those who forget to bring their own.
- Suspend the 6 fishing line segments (two 108" lines near the lobby door and the four 114" lines along wall to B-314) from beams in lobby. Note these two floor-to-ceiling measurements for the students' reference.
- Pull table into middle of lobby-load with extra fishing line, water jugs, yard sticks, & calipers.
- Run an extra tensile sample on the machine to confirm both machine functionality and operator familiarity. Practice exporting data set: load and extension.

- Check stock of tensile bars: 1 set per lab section (~30 sets / year). (6061 Al, 1080 plain carbon steel, high density (HDPE) and low density (LDPE) poly(ethylene) )
- Confirm sufficient number of glass slides (2 per group).
- Set 1-2 small, clearly marked, boxes out on table for disposal of broken glass and paper towels.
- Beside the minor items and equipment repairs (and replacements) mentioned above, the critical consumables for this module are listed below:

**Materials Purchases Necessary:** Tensile bars and glass slides. Occasionally, fishing line needs to be scrounged or purchased.

## Typical Module Timeline:

(varies somewhat with TA – no mistakes by students)

| *Stage* | *Duration* | *Total Time* |
|---|---|---|
| Quiz | 0:10 | 0:10 |
| Presentation | 0:20 | 0:30 |
| Explain fishing line E | 0:05 | 0:35 |
| Run fishing line E experiment | 0:15 | 0:50 |
| Describe tensile testing process | 0:05 | 0:55 |
| Tensile test steel, Al, & polymer specimens | 0:40 | 1:35 |
| Stress concentrators exercise (glass slides) | 0:10 | 1:45 |

## Module-Specific Safety Concerns:

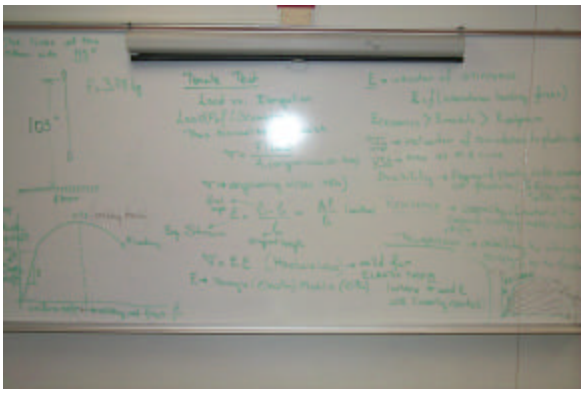
- The water jugs have exposed copper wire on which you might cut yourself – please be careful.
- During the tensile testing phase of this module, samples will be breaking under large loads. Do not touch the equipment during the testing. Keep your face far from the sample.
- When breaking glass slides, wrap the slide in paper towels (to keep the shards from flying) and use gloves provided to protect your hands. Dispose of glass and towels in trash.
- .

## Module Photographic Highlights:

(supply locations, equipment setups, and key activities)

The lecture room is setup with samples and visual aids, safety equipment, and the materials for the stress concentrator exercise part of the module.

Supplies for the first part of the module are readied on the foyer table. Six sets of : 1 gallon water, 1 set of Vernier calipers, and 1 yard stick should be ready for the students.



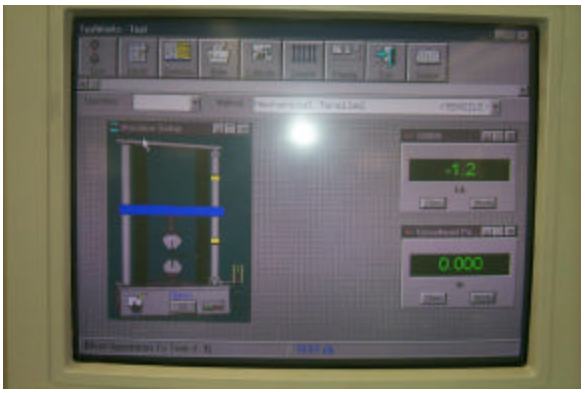
The white board in the lobby is used to cover the basics of stress-strain diagrams and calculations. Lab-specific info, such as the fishing line length and height to the top of the line at each station must also be posted here. Do not go into details during the lab, put the details on the board for students and cover the material succinctly.

Each of the fishing line lengths has a carribeener attached to each end. One end is attached to the ceiling clamp above each station (only three shown here). These distances and lengths should be checked when the module is set up each semester. Every 3 semesters (1year) the fishing line samples should be replaced.

Students are measuring the elongation of fishing line at their respective stations. There are 2-3 types / thickness of line. The known load is 1 gallon of water (~8lbs). Students must be reminded to take readings quickly and provide ample time between readings for relaxation and recovery (1-2 min).

The Instron tensile testing machines in B-311. Although rate is input with the software, there is a gearing difference between the machines. The foreground machine is geared 10:1 (fast). The background machine is geared 100:1 (slow) and is mostly used for the polymer adhesion tests.

Proper mounting of jaws is critical for safe operation!



Picture of screen with correct module/setup loaded for standard tensile testing. Load and extension data is exported at the end to tab or comma delimited text format on a floppy disk. TA must test-graph data before posting for students. If there is a problem, an old set of data may be used.

# IV. Thermo-Mechanical Testing of Aluminum

## Purpose & Procedure Overview:

(review of APC and outline of procedure & timeline)

The cold working of aluminum and an aluminum alloy are explored within. Each team of students is provided with an as-cast specimen and a pre-rolled specimen. Students first measure the HRH hardness of the rolled sample then put it in an oven to anneal for measurement again afterwards. The students then measure the hardness of the as-cast specimens. Each team rolls their sample 5 times (down to ~50% reduction in thickness), measuring the hardness at each thickness. All the data are pooled in the computer at the front of the room, and the students observe the change in hardness due to cold working. Lastly (before removing the annealed samples from their oven), teams are provided with two metallographic mounts—one as cast or lightly rolled/worked and one heavily rolled/worked. This last exercise introduces the students to optical microscopy and gives them an appreciation for physical microstructural changes effected by cold working. The fundamentals of preparing metallographic mounts is also reviewed, including a discussion of etchant and obtaining contrast in optical microscopy.

## Materials Needed:

(equipment which may need to be replaced or updated)

| | | | |
|---|---|---|---|
| Stackable bins | 6 (2) | MSC | contain pieces below |
| High-T furnace | 1 (1) | SIT Inventory | set for 400°C- anneal for 1 hour |
| 3 sets pure Al | 3 (many) | Prof / TAs | 1 as cast ½ bar and 1" sqr rolled 50% |
| 3 sets Al-4wt%Si | 3 (many) | Prof / TAs | 1 as cast ½ bar and 1" sqr rolled 50% |
| 3 hardness testers | 3 (0) | SIT Inventory | Wilson testers with HRH tips |
| 3 hardness tips | 3 (0) | SIT Inventory | HRH tips |
| Cold rolling machine | 1 (0) | SIT Inventory | cold roll bars by 1/3 of wheel turn |
| Optical microscopes | 6 (1) | SIT Inventory | located in B-314 |
| Set of 2 mounts | 5 (0) | Prof / TAs | Al or alloy: as-cast and ~50% rolled |
| | | | |
| Tongs for rolling | 1 (0) | SIT Inventory | sample manipulation |
| Tongs for oven | 1 (1) | SIT Inventory | sample manipulation |
| High T pair of mitts | 1 (1) | Fisher Scientific | *general protective wear* |

## Consumables & Preparatory Tasks:

(supplies normally consumed – fall semester of ~ 160 students)

- Review PowerPoint presentation for this module (confirm file is functional and up-to-date).
- Prepare a sufficient number of copies of the quiz for each section.
- Extra printouts of the lab procedure for those who forget to bring their own.
- ½ hour prior to first lab, turn on oven and verify set point is 400ºC (this will give it ~45 minutes to warm up). If there are numerous lab sections over several days, the oven may be left on.
- Confirm functionality and tip setup of hardness testers in B-311.
- Check rolling machine for functionality and operator familiarity- use a cast bar to set at 0% reduction before each class.
- Check microscopes in B-314 for functionality and lamp operation (extra lamps in cabinet).
- Set up 6 microscopes on tables in B-314 - spread out so 2-3 person groups are not crowded.

- Check metallography samples for finish and clarity-remount or re-polish (& etch) as necessary.
- Place a 2-sample set beside each microscope. It is very important that these specimens are in "very good" condition so the differences in microstructure are obvious to the untrained student eye.
- Beside the minor items and equipment repairs (and replacements) mentioned above, the critical consumables for this module are listed below:

**Materials Purchases Necessary:** As-cast and rolled specimens are prepared during Module 5 by sections from the previous semester. The lab generally operates at a net sample positive, but a check needs to be done ~1 week in advance to give the SIT Machine Shop time to cut up the bars and rolled stock.

## Typical Module Timeline:

(varies somewhat with TA – no mistakes by students)

| *Stage* | *Duration* | *Total Time* |
|---|---|---|
| Quiz | 0:10 | 0:10 |
| Presentation | 0:20 | 0:30 |
| Hardness test of rolled and furnace loading | 0:10 | 0:40 |
| Measure hardness and thickness as cast | 0:10 | 0:50 |
| Roll #1, thickness measurement, hardness test | 0:05 | 0:55 |
| Roll #2, thickness measurement, hardness test | 0:05 | 1:05 |
| Roll #3, thickness measurement, hardness test | 0:05 | 1:10 |
| Roll #4, thickness measurement, hardness test | 0:05 | 1:15 |
| Roll #5, thickness measurement, hardness test | 0:05 | 1:20 |
| Recycle pieces and return to oven | 0:05 | 1:25 |
| Harness test of cooled, annealed specimens | 0:10 | 1:35 |
| Microscopy | 0:10 | 1:45 |

## Module-Specific Safety Concerns:

- The rolling machine next door is old, slow, ugly, powerful, and very good at what it does – flattening objects. Do not fool around with the machine and make sure to secure all loose clothing. Use the tongs to hold samples.
- The hardness testers apply 10-60kg loads…do not test the hardness of you fingers!
- .

## Module Photographic Highlights:

(supply locations, equipment setups, and key activities)

The metallographic samples for this module must be checked for quality of surface. If the features the students need to be able to find are not obvious, the samples should be re-polished and then re-etched. Polishing wheels and supplies are located in B-314.

Each group receives 2 samples, one as-cast and one rolled to 40% original thickness. There are pure Al and Al-4wt%Si specimens. Alternate groups when handing out pairs of each composition.

Al ingot castings from last semester are used for this module, so if there are not enough of any type, more must be prepared beforehand.

This module requires that B-314 be set up with 6 microscopy stations. As they work through their samples, the TA should demonstrate technique and point out features using the TA station and 21" monitor at the front of the room.

Also, the necessity of creating contrast on specimens (typically through etching) for viewing should be discussed while coaching this part of the module.

For the optical microscopy part of this module, the six stations are each given 2 samples from the pool. The students draw representative microstructures and make observations on grain elongation.

Remind students not to touch polished surfaces!


The hardness testers are located in B-311. Proper testing technique must be *demonstrated* to the students so their readings are not invalidated by mistakes. This includes showing them how to locate a suitable testing area on their sample(s). Choose correct tip for test!

Also, proper tip changing procedure and machine error correction must be taught to each TA.

The work-hardened samples are annealed at 300-400degC for 1 hour, then allowed to cool *slowly* on a fire brick, before they are hardness tested again. Ensure students wear goggles and thermal mitts.

The quench bucket is not used in this module.

The rolling mill in B-311 must be treated with respect. The power cut-off is on the wall in the background. Samples should be inserted from the near side using tongs provided, then the student should walk around the machine to retrieve the sample, not reach around it!

No more than a 0.1” reduction should ever be done in one rolling pass.

# V. Casting and Solidification Processing

## Purpose & Procedure Overview:

(review of APC and outline of procedure & timeline)

The operational concept of the thermocouple is introduced today. Students are introduced to both heat capacity and specific heat, through the measurement of cooling curves and phase diagrams, which will be explored in detail next module. Three alloys of the Sn-Bi system are used to cast bars. Students break the bars and observe mechanical, microstructural, and optical variations across the three compositions. Next, and induction furnace is used to cast Al or Al-4wt%Si alloy ingots in an open-face die. These bars are used in the previous module (next semester). This both introduces an industrial casting process as well as gives the students hands-on experience. If the TA splits the class into 2 sets of 3 teams each after the initial explanation of holding the die and pouring the Al, all groups may cast an ingot—with efficient time management. Lastly, using the prepared 'STEVENS' plaque molds, students will use the Sn-Bi eutectic composition to learn the difficulties of both mod design and making defect-free castings. Students are encouraged to make repeated castings in an effort to fabricate a defect-free plaque…which they may keep.

Safety is of the ut-most importance, so 2 TAs are used to run each section of this module.

## Materials Needed:

(equipment which may need to be replaced or updated)

| | | | |
|---|---|---|---|
| Hot pots | 6 (0) | Do-It Molds | 1 Sn, 1 Bi, 4 eutectic Sn-Bi |
| Baking/spill pans | 6 (2) | Local hardware | labeled for hot pots (save spills) |
| Bricks (5 per) | 30 (0) | Home Depot | 4 for spill pan, 1 for under hot pot |
| Utensils (1sp & 1knf) | 6 (2) | Local hardware | for skimming oxides & prying metal |
| Open face bars dies | 6 (0) | SIT Machine Shop | cast 3 Sn-Bi alloy bars for breaking |
| Vice | 6 (2) | MSC | for holding 'STEVENS' plaque mold |
| 'STEVENS' mold | 3 (3) | Do-it Corp. / SIT | SIT shop did machining |
| Sn shot | 10 lbs | Belmont Metals Co | replenish bar casting pots |
| Bi shot | 10 lbs | Belmont Metals Co | replenish bar casting pots |
| Sn-Bi eutectic 'cakes' | 25 lbs | Belmont Metals Co | replenish bar & plaque casting pots |
| Thermocouple (Tc) | 1 (0) | Omega | do not hold in Al above 750°C |
| Tc reader | 1 (0) | Omega | mounted in Tc holder |
| RF generator | 1 (0) | Ecco High Frequency | do not touch Cu terminals! |
| Crucible-pure Al 'P' | 1 (2) | | backup is empty crucible |
| Crucible-Al-4wt%Si 'S' | 1 (2) | | backup is empty crucible |
| Tongs for crucibles | 1 (1) | SIT Inventory | sample manipulation |
| Aluminum shot/bars | 10lbs | Belmont Metals Co | replenish crucible b/w castings |
| Silicon chunks | 5 lbs | | replenish crucible b/w castings |
| | | | |
| Gloves (pr.- leather) | 10 (0) | MSC | *general protective wear* |
| Goggles | 12 (25) | Fisher Scientific | *general protective wear* |
| High T pair of mitts | 1 (1) | Fisher Scientific | for Al pourer |
| Face shield | 1 (0) | Fisher Scientific | additional optional protection |
| Apron | 1 (1) | Fisher Scientific | additional optional protection |

## Consumables & Preparatory Tasks:

(supplies normally consumed – fall semester of ~ 160 students)

- Review PowerPoint presentation for this module (confirm file is functional and up-to-date).
- Prepare a sufficient number of copies of the quiz for each section.
- Extra printouts of the lab procedure for those who forget to bring their own.
- Gather various visual aids: as-cast Al bar, open-face die for bars, large exhaust manifold casting, foam positive for sand casting, 'STEVENS' plaque, injection molded sewing machine body, and others from around B-312 lab.
- Check 'STEVENS' plaque mold handles are securely attached- fix if loose or not affixed.
- Clean all molds and vices prior to use by 4 sections-this minimizes non-removable build-up.
- This module requires 2 TAs. Check with your colleagues to assist each other.
- Beside the minor items and equipment repairs (and replacements) mentioned above, the critical consumables for this module are listed below:

## Materials Purchases Necessary:

Aluminum shot (~15 lbs /yr, purchased in 50 lb bags). Sn-Bi eutectic composition (~50lbs /yr). Pure Sn and Bi (~10 lbs /yr). Occasionally, chunk silicon needs to be purchased.

## Typical Module Timeline:

(varies somewhat with TA – no mistakes by students)

| *Stage ( 2 TAs!)* | *Duration* | *Total Time* |
|---|---|---|
| Turn on hot pots | 0:05 | 0:00 |
| Quiz | 0:10 | 0:10 |
| Presentation | 0:20 | 0:30 |
| Start RF generator / review 3-bar mold procedure | 0:05 | 0:35 |
| 6 groups rotate through pouring 3 pars each | 0:10 | 0:45 |
| Review pouring / handling stations | 0:05 | 0:50 |
| ½ of groups pour Al (cast at least 1. likely 2/group) | | |
| ½ of groups cast plaques (3-4/grp until 2 good) | 0:30 | 1:20 |
| Rotate group locations and switch tasks | 0:30 | 1:50 |
| Break bars, listen, look, think, observe, & record | 0:10 | 2:00 |
| Interactive casting movie from web | 0:12 | 2:15 |

**Revise this module's time schedule.**

## Module-Specific Safety Concerns:

- We will be dealing with liquid metal- 230-700 degC. As such, there will be two TAs for each section during this module. Respect at all times – no fooling around.
- If you are within 6' of any melting/liquid metal, pay attention to it and do not sit down. If there is any accident, you may need to move quickly.
- The RF generator is loud. If you need to step out or a minute, let your TA know.
- The Cu terminals on the sides of the RF generator are LIVE! There is more than sufficient current to kill a person. Please do not go near the terminals for any reason.
- When drying the Al die, make sure it is absolutely dry!
- .

## Module Photographic Highlights:

(supply locations, equipment setups, and key activities)

Alloy bar casting station- one of three types of alloy. Note source / recycling container (tan) on right in background. Remind students to re-supply the hot pot for the next group's pour while they are waiting for the die to cool so they may move to the next station.

Induction furnace setup: left to right, power supply, service switch (green), crucible box (white), and catch pan (red cart with sand).

Some of the visual aids used for the introduction to this module. Note the induction furnace water pump on the floor in the background behind the red cart. Extra crucibles and a coil are also visible on the shelf.

The service disconnect switch for the RF furnace is the green box on the wall. In order to turn the furnace on, the water pump (which supplies cooling water to the leads and coil) must be plugged in (no switch) and the flow valve opened.

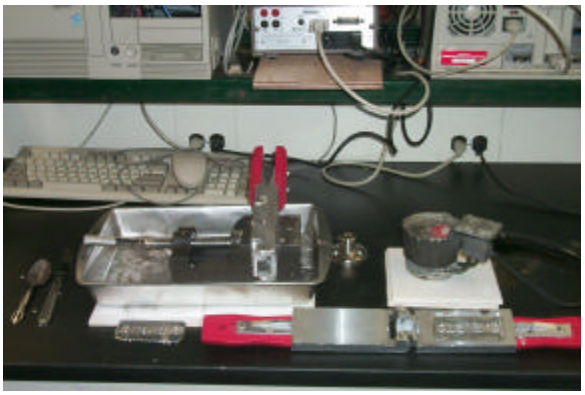
Control panel of the RF furnace generator. Only the power button (out of picture), field and load on/off buttons, and the power level dial maybe adjusted. All other settings must not be changed except by qualified personnel.

Power generator gage settings during a typical heating run. Two TAs are required for this lab to keep safety at it's maximum possible level.

Setup of a bend-bar casting station. Spoon is used to skim liquid metal and remove oxides and other impurities.

Hot puts must only be placed on *two* ceramic tiles to protect table tops from thermal shock.

Always wear gloves and goggles!



Setup of a STEVENS plaque casting station. Note slight tilt of die to facilitate filling die during pouring of metal.

Knife and spoon are used to *gently* extract castings from the die.

Hot puts must only be placed on *two* ceramic tiles to protect table tops from thermal shock.

Always wear gloves and goggles!

Casting of an Al-Si alloy ingot. The die must be *perfectly dry* before pouring!

Each class casts several bars of 1 alloy composition to avoid multiple heat-up times.

Always wear gloves and goggles!

Casting of an Sn-Bi alloy bend bar for alloy effect and property characterization.

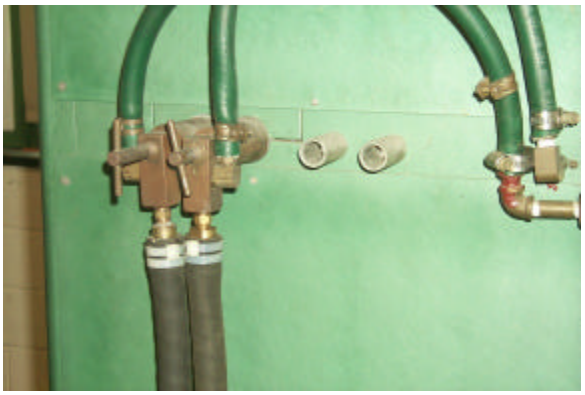
Dies are placed in pans to prevent spillage on to tabletops.

Always wear gloves and goggles!

Pouring of a STEVENS plaque casting station. Note slight tilt of die to facilitate filling die. Once the metal has spilled down die to cover air vent, pour must be stopped and sample removed.

Dies are placed in pans to prevent spillage on to tabletops.

Always wear gloves and goggles!



The copper terminals on the right (at left, above) and left (at left, below) sides of the RF generator power supply are live and dangerous. DO NOT TOUCH, the voltage and current are well beyond lethal! Advise students of the hazard at the beginning of the class.

Ear plugs should be made available to students.

# VI. The Sn-Bi Equilibrium Phase Diagram

## Purpose & Procedure Overview:

(review of APC and outline of procedure & timeline)

This module we continue our exploration of the Sn-Bi binary alloy system. Discussion begins with and overview of phase diagram basics, including level rule, phase composition calculations, and typical microstructure evolution. The effect of phase transformation is observed in an actual cooling curve as it is related to the phase diagram. Students then break down into 5 groups (1 group breaks to form 2 others of 3 members) for cooling curve measurements of five Sn-Bi alloys in B-311. During data acquisition, students migrate to B-314 to observe three different alloy microstructures. The data curves are acquired, then graphed in excel by each group, allowing the students to walk around to all stations and observe the curves and compositions. Data is collected in one file by the TA and put on the web page (or emailed) for students to compare values from the cooling curves to the corresponding points on the phase diagram.

## Materials Needed:

(equipment which may need to be replaced or updated)

| | | | |
|---|---|---|---|
| Computer & cable | 5 (1 extra) | Comp. Serv. Ctr. | connect 9pin RS-232 cable to DMM |
| Digital multimeter | 5 (0) | Keithley | *shared with the solar cell lab* |
| Thermocouple | 5 (1) | Omega | mounted in Tc holder |
| Stands/assemblies | 5 (0) | Cole-Parmer | connect thermocouple to DMM |
| Hot pots | 5 (1) | Do-It Molds | place under each test tube (*Mod. 5*) |
| Baking/spill pans | 6 (2) | Local supermarket | labeled for hot pots (save spills) |
| Ceramic tiles (5 per) | 30 (0) | Home Depot | 4 for spill pan, 1 for under hot pot |
| Utensil (1spoon) | 6 (2) | Local hardware | for skimming oxides |
| 5 test tubes of alloys | 1 (2 as needed) | Prof / TAs | ~10 grams of each of 5 alloys |
| Sheet of directions | 5 (as needed) | Prof / TAs | post at each station for clarity |
| Optical microscopes | 6 (1) | SIT Inventory | located in B-314 |
| Set of 3 Sn-Bi mounts | 5 (0) | Prof / TAs | 90-10, 43-57, 18-82 wt% Sn-Bi |
| | | | |
| Gloves (pr.- leather) | 10 (0) | MSC | *general protective wear* |
| Goggles | 12 (25) | Fisher Scientific | *general protective wear* |

## Consumables & Preparatory Tasks:

(supplies normally consumed – fall semester of ~ 160 students)

- Review PowerPoint presentation for this module (confirm file is functional and up-to-date).
- Prepare a sufficient number of copies of the quiz for each section.
- Extra printouts of the lab procedure for those who forget to bring their own.
- Test "clickme.bat" program in 'E321' folder on each computer's desktop-should run for 12 min. and create a data file called ‘tempf.dat’.
- Confirm all test tubes present and safe (no apparent cracks). Extra tubes are in the cabinet.
- 2 full sets of extra samples/tubes are kept in the B-311 cabinet - if there are missing tubes, prepare replacement tubes of the missing compositions. 3-4 tubes will crack during 16 runs of the module in the fall-- due primarily to fracture by thermal shock.
- Lay out 5 hot pots - one under the test tube of each station - plug in during quiz.

- Check microscopes in B-314 for functionality and lamp operation (extra lamps in cabinet).
- Set up 6 microscopes on tables in B-314 - spread out so 2-3 person groups are not crowded.
- Check metallography samples for finish and clarity-remount or re-polish (& etch) as necessary.
- Place a 3-sample set beside each microscope (this module runs with 5 groups of students).
- Beside the minor items and equipment repairs (and replacements) mentioned above, there are no critical consumables for this module.

**Materials Purchases Necessary:** None. Any Sn or Bi needed is taken from the Module 5 supplies. Occasionally, test tubes need to be purchased (box of 500 = ~$15).

## Typical Module Timeline:

(varies somewhat with TA – no mistakes by students)

| *Stage* | *Duration* | *Total Time* |
|---|---|---|
| Turn on hot pots | 0:05 | 0:00 |
| Quiz | 0:10 | 0:10 |
| Presentation | 0:20 | 0:30 |
| Lower test tubes (only touch tip to melt!) | 0:05 | 0:35 |
| Review data acquisition procedure while heating | 0:05 | 0:40 |
| All 5 stations heated, start data acquisition | 0:05 | 0:45 |
| Microscopy of cast and rolled specimens (2/group) | 0:15 | 1:00 |
| Acquire, store and graph data | 0:10 | 1:10 |
| Review data of other groups | 0:05 | 1:15 |
| Explain lab note expectations | 0:05 | 1:20 |

## Module-Specific Safety Concerns:

- We will be dealing with low melting-point alloys today – please pay attention and do not get careless. Wear your goggles.
- The metallographic specimens take time and care to prepare – take care not to touch or scratch the polished surfaces.
- Remember to unplug your hot pot (when instructed).
- .

## Module Photographic Highlights:

(supply locations, equipment setups, and key activities)

A typical solidification curve measurement station setup. Note that test tube containing samples must be heated as slowly as possible to prevent thermal shock fracture.

Data is collected by TA and put up on web site for all to use in creation of cooling curves graph. Transition temps are compared to phase diagram data.

Always were goggles!

Metallographic samples used by students to examine microstructural changes.

Digital pictures of "ideal" microstructures are on the server and may be put up on the large screen monitor to guide students during the microscopy phase of the lab.

This module requires that B-314 be set up with 6 microscopy stations. As they work through their samples, the TA should demonstrate technique and point out features using the TA station and 21" monitor at the front of the room.

Also, the necessity of creating contrast on specimens (typically through etching) for viewing should be discussed while coaching this part of the module.

# VII. Heat Treatment of Steel

## Purpose & Procedure Overview:

(review of APC and outline of procedure & timeline)

The Fe-C phase diagram / system in explored today through optical microscopy and a heat treatment / annealing exercise. Students start off with a review if the Fe-$Fe_3C$ phase diagram and a Time-Temperature-Transformation diagram. Annealing, quenching, and surface treatments are reviewed in the context of explaining why the sample we anneal is wrapped in stainless steel with a little charcoal (to prevent oxidation during annealing and subsequent spallation of oxides during quenching). While the samples (1 per group) are being annealed, their partners take a second sample, which has been annealed only, and measure HRC hardness. The samples quenched at the end will be measured also, permitting comparison.

Between loading and quenching of samples above, students move to B-314 for optical microscopy of 4 mounts (~7 specimens / mount). Set 'A' contains 8 specimens of varying percent pearlite, set 'B' contains 6 specimens of varying percent pearlite, set 'C' contains 7 specimens of varying percent martensite, and set 'Armco' contains 7 specimens of varying quench time and temperature. Students estimate the % phase present in each specimen of mounts A, B, and C—recording the values in the tables on page 4 of their procedure. For each set, they pick *one* sample (somewhere around ~50% transformed) to draw on their microstructure sheet. For the Armco set of specimens, there are not visual phase content estimations, as each of the seven specimens needs to have its microstructure recorded. In their lab note, students discuss the changes in microstructure and potential properties as they relate to quench temperature, time held at Temp, and cooling rate.

## Materials Needed:

(equipment which may need to be replaced or updated)

| | | | |
|---|---|---|---|
| High-T furnace | 1 (1) | SIT Inventory | set for 900°C- anneal for 1 hour |
| 4340 steel sample | 6 (0) | | quenched for high hardness |
| 4340 steel sample | 6 (0) | | annealed in foil pouch w/ charcoal |
| Stainless steel foil | roll | | wrap samples to min. oxidation |
| Charcoal | barrel | | ½ tsp per package |
| Scissors | 1 (1) | Local hardware | for cutting s.s. foil |
| 5 gallon bucket | 1 (0) | Home Depot | for quenching samples |
| Salt (and water) | 1 lb. | Local supermarket | for quench bath |
| 3 hardness testers | 3 (0) | SIT Inventory | Wilson testers with HRC tips |
| 3 hardness tips | 3 (0) | SIT Inventory | HRC tips |
| Optical microscopes | 6 (1) | SIT Inventory | located in B-314 |
| Mount 'A' | 2 (0) | Prof / TAs | Set A: $\Delta$t lead quench time b4 $H_2O$ |
| Mount 'B' | 2 (0) | Prof / TAs | Set B: $\Delta$t lead quench time no $H_2O$ |
| Mount 'C' (Armco) | 2 (0) | Prof / TAs | Set C: $\Delta$T martensitic transformation |
| Armco samples mnt. | 4 (0) | Prof / TAs | Armco: varied heat treatment history |
| Microstructure sheet | 12 (many) | Prof / TAs | 1 / student – organizes their drawings |
| Tongs for oven | 1 (1) | SIT Inventory | sample manipulation |
| | | | |
| Goggles | 12 (25) | Fisher Scientific | *general protective wear* |
| High T pair of mitts | 1 (1) | Fisher Scientific | *general protective wear* |

## Consumables & Preparatory Tasks:

(supplies normally consumed – fall semester of ~ 160 students)

- Review PowerPoint presentation for this module (confirm file is functional and up-to-date).
- Prepare a sufficient number of copies of the quiz for each section.
- Extra printouts of the lab procedure for those who forget to bring their own.
- Printout and photocopy the microstructure organization sheet for each section – 1 / student.
- Sufficient 4340 steel (similar to tank armor)—quenched pieces can be re-used ~4 times/sections before they require removal of oxides. Pieces are about 1" square by ¼" thick.
- 2 hours prior to first lab, turn on oven and verify set point of 900°C. If there are numerous lab sections over several days, the oven may be left on until last section completes this module.
- Confirm functionality and tip setup of hardness testers in B-311.
- Check microscopes in B-314 for functionality and lamp operation (extra lamps in cabinet).
- Set up 6 microscopes on tables in B-314 - spread out so 2-3 person groups are not crowded.
- Check 'A', 'B', 'C' and 'Armco' metallography samples for finish and clarity-remount or re-polish (& etch) as necessary (not needed very often, usually just clean with –OH).
  Nitinol etchant is 10mL nitric acid in 400mL ethanol
  ARMCO set requires ~25 seconds (more leaves etching pits)
  Sets A through C require ~7 seconds each
- Place a 2-sample set beside each microscope. Draw a sample location diagram on the board.
- Beside the minor items and equipment repairs (and replacements) mentioned above, the critical consumables for this module are listed below:

**Materials Purchases Necessary:** 4340 steel stock as required (~50 pieces / year). Steel foil: ~25 feet long by 6" wide each year. Salt every other year (~1/2 cup for 3 gallons in quench bucket), each batch lasts for the week of labs.

## Typical Module Timeline:

(varies somewhat with TA – no mistakes by students)

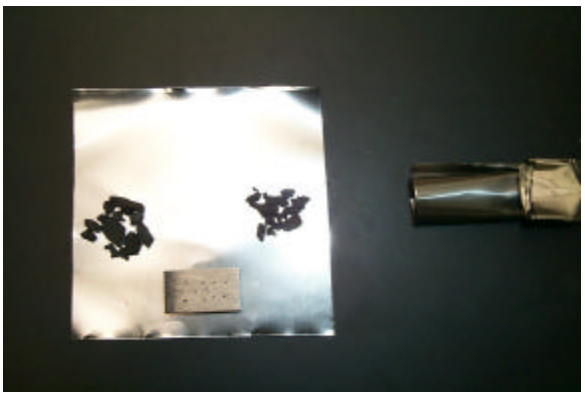
| *Stage* | *Duration* | *Total Time* |
|---|---|---|
| Quiz | 0:10 | 0:10 |
| Presentation | 0:20 | 0:30 |
| Wrap specimens to be quenched | 0:10 | 0:40 |
| Hardness test annealed samples | 0:05 | 0:45 |
| Microscopy of sample sets A, B, C, and ARMCO | 1:00 | 1:45 |
| Remove and quench 4340 samples | 0:10 | 1:55 |
| Hardness test quenched samples | 0:05 | 2:00 |

## Module-Specific Safety Concerns:

- The furnace is literally red hot at 900°C. This is hot enough to give you a sunburn if you get too close! Wear the oven mitts and use the tongs to hold samples!
- The hardness testers apply 10-60kg loads… do not test the hardness of your fingers!
- Please do not tough the polished surface of the mounts– a lot of effort goes into preparing them for each semester.
- Do not drive the mounts into the microscopes' lenses.
- .

## Module Photographic Highlights:

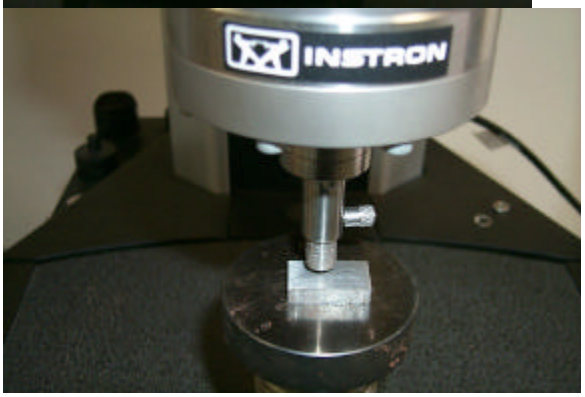
(supply locations, equipment setups, and key activities)



The steel samples to be annealed and quenched as port of the hardness controlling exercise in this module are wrapped like burritos. Inside each stainless steel foil wrapper are placed a few pieces of charcoal to burn off the oxygen in and prevent the steel from oxidizing.

The hardness testers are located in B-311. Proper testing technique must be *demonstrated* to the students so their readings are not invalidated by mistakes. This includes showing them how to locate a suitable testing area on their sample(s). Choose correct tip for test!

Also, proper tip changing procedure and machine error correction must be taught to each TA.




Steel specimen being tested on the HRC scale.

The work-hardened samples are annealed at ~900degC for 1 hour, then quenched, before they are hardness tested again. Ensure students wear goggles and thermal mitts.

When placed in the quench bucket, the sample must be moved about for maximum heat removal.

Typical running parameters for the annealing oven.

Input brief description of oven set point procedure.

Samples are placed in and removed from the oven using tongs provided. Ensure students wear goggles and thermal mitts.

When placed in the quench bucket, the sample must be moved about for maximum heat removal.

This module requires that B-314 be set up with 6 microscopy stations. As they work through their samples, the TA should demonstrate technique and point out features using the TA station and 21" monitor at the front of the room.

Also, the necessity of creating contrast on specimens (typically through etching) for viewing should be discussed while coaching this part of the module.

The top two photos at the left depict the TAs' microscopy station and the typical 6-station student microscopy setup in B-314. The large monitor at the TAs' station should be swiveled to face the students for demonstrative and guidance purposes.

For the optical microscopy ½ of this module, the six stations are each given 2 samples from the pool of sets 'A', 'B', 'C', and 'Armco'. The students draw representative microstructures for 10 samples (specified on MS sheet provided on web page) and make observations on phase presence to fill in tables in their lab manuals. Remind students not to touch polished surfaces!

# VIII. Fabrication of a Solar Cell (A) – Processing

## Purpose & Procedure Overview:

(review of APC and outline of procedure & timeline)

Semiconductors and diffusion/implantation processing are introduced with this pair of modules. Students start off with a discussion of semiconductor processing and the operation of a P-N junction as it relates to a solar cell. With a piece of doped silicon, students use the Seebeck effect to determine the dopant type (p or n). Once the samples have been etched to remove the native $SiO_2$ oxide, they are tested with the four-point probe tester to determine the sheet resistance. The wafers are spin coated with an n-type dopant on one side and a p-type dopant on the other to create a P-N junction at a depth they will calculate. The samples now need to be annealed to drive the dopants into the silicon. As this requires an hour at 1000°C and a slow cool down (~3 hours total), the students received last classes' samples and re-etch to remove the new $SiO_2$ formed during annealing. The samples are masked with electrical tape, then coated with nickel in a heated chemical bath. The samples are set aside for next class.

## Materials Needed:

(equipment which may need to be replaced or updated)

| | | | |
|---|---|---|---|
| Silicon wafers | 6 | SIT Inventory | large supply donated long ago |
| HF acid | 100mL | SIT Chem. Inv. | 200mL lasts a whole week |
| Basket | 1 (3) | SIT Inventory | |
| Tweezers | 6 (0) | MSC | For handling wafers |
| DMMs (2 per) | 6 (4) | Newark | shared with phase diagram module |
| 4-point probe tester | 2 (1) | SIT Inventory | old and expensive ($4^{th}$ is broken?) |
| Voltage source | 3 ( ) | Keithley | for circuit analysis |
| Current source | 3 ( ) | Keithley | for 4pt tester (extra is broken) |
| Spin coater | 1 (0) | SIT Inventory | for dopant coating of specimens |
| P-type dopant soln | 10 mL | *E-321 chemical inv.* | ~15 drops / class |
| N-type dopant soln | 10 mL | *E-321 chemical inv.* | ~15 drops / class |
| Annealing oven | 1 (1) | SIT Inventory | anneal samples for 1 hour at 1000°C |
| Wiring/connecters (7) | 4 sets | Newark | connecting wires and clips |
| Soldering irons | 4 (0) | RS / Local hardware | Seebeck effect |
| Razor blade | 6 (6) | Local hardware | cutting electrical tape for masking |
| Electrical tape | 4 rolls | Home Depot | making sample plating areas |
| BN coating solution | 100 mL | *E-321 chemical inv.* | 100 mL / section (at 95°C) |
| Sodium hydroxide | 12 mL | SIT Chem Inv | 12 mL / section (at 95°C) |
| Thermometer & stand | 1 (0) | SIT Lab Stock | hold plating solution at 95°C |
| Hot plate | 1 (0) | SIT Inventory | hold plating solution at 95°C |
| Pyrex glassware | 1 (1) | SIT Inventory | Plating solution container |
| | | | |
| Calcium carbonate | 2 lbs | SIT Chem. Inv. | HF acid neutralizer |
| Chemical spill kit | 1 (0) | Fisher Scientific | chemical safety equipment |
| Goggles | 12 (25) | Fisher Scientific | *general protective wear* |
| Chem. resist. gloves | 8 pair | Fisher Scientific | *general protective wear* |

## Consumables & Preparatory Tasks:

(supplies normally consumed – fall semester of ~ 160 students)

- Review PowerPoint presentation for this module (confirm file is functional and up-to-date).
- Prepare a sufficient number of copies of the quiz for each section.
- Extra printouts of the lab procedure for those who forget to bring their own.
- Check chemicals on hand for sufficient quantities.
- Setup acid solution for etching $SiO_2$ from samples.
- Check for sufficient baskets and tweezers.
- Ensure spin coater works. (Button sticks. O-ring is problematic)
- Check each station for setup (4 point tester, sufficient wires, V and I sources, etc).
- Check exhaustless hood filters for life/usefulness.
- Beside the minor items and equipment repairs (and replacements) mentioned above, the critical consumables for this module are listed below:

## Materials Purchases Necessary:

HF acid, coating soln 1, and coating soln 2. Every couple of years, new dopant solutions need to be ordered. Plastic gloves and flat tweezers should be restocked as necessary, too.

## Typical Module Timeline:

(varies somewhat with TA – no mistakes by students)

| *Stage* | *Duration* | *Total Time* |
|---|---|---|
| Quiz | 0:10 | 0:10 |
| Presentation | 0:20 | 0:30 |
| Seebeck effect | 0:10 | 0:40 |
| Etch Si pieces | 0:05 | 0:45 |
| Review rinse/clean, 4pt. Probe test & spin coating | 0:10 | 0:55 |
| Students do above and place in annealing furnace | 0:20 | 1:15 |
| Pre-annealed samples need to be (re-)etched | 0:15 (started within above step) | |
| 4-point probe test again to identify P and N sides | 0:05 | 1:30 |
| Mask samples for Ni plating | 0:10 | 1:40 |
| Chemically deposit Ni | 0:05 | 1:45 |
| Discuss calculation(s) and LN expectations | during Ni etch | |
| Remove & rinse samples, remove tape, ID, store | 0:10 | 1:55 |

## Module-Specific Safety Concerns:

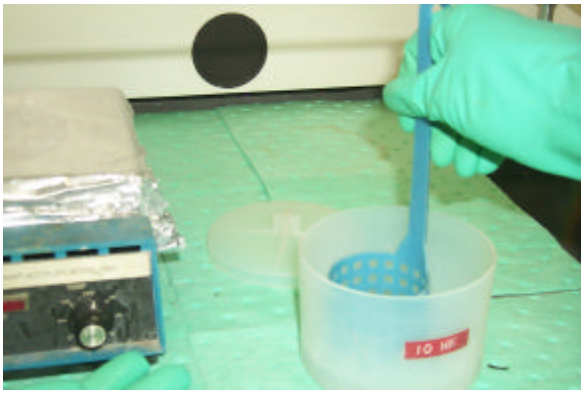
- We will be using HF acid to etch silicon dioxide from our samples. As such, you will observe that plastic containers must be used to contain it. HF is neutralized by Ca+ ions. If you spill any on you, it will slowly migrate to your bone and decalcify it. If you splash any HF you, notify your TA, and we will neutralize the acid with a limestone solution.
- Goggles and gloves must be used when handling HF!
- For you samples to work well, you must keep them scrupulously clean.
- .

## Module Photographic Highlights:

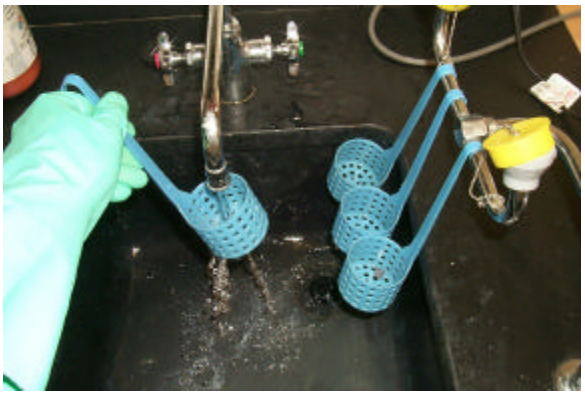
(supply locations, equipment setups, and key activities)

All supplies and materials for the Solar Cell Modules are kept in the cabinet at the front of B-313.

The Seebeck effect shows how heat may be converted to electricity by semiconductor-type materials. Warn students not to press hard on samples, as they will crack.



Samples being etched in a 10% HF solution. Lime (CaCO3) is stored between the hood and the sink in case of a spill or contact with skin. Gloves and goggles must be worn when working in hood at any time, even if not using the HF acid.



Etched samples must be rinsed gently (no splashing) but thoroughly, then sprayed down with acetone and dried with a hot-air blower.

The bottle at the top left edge of the photo is the calcium carbonate used to treat spills and potential burns.

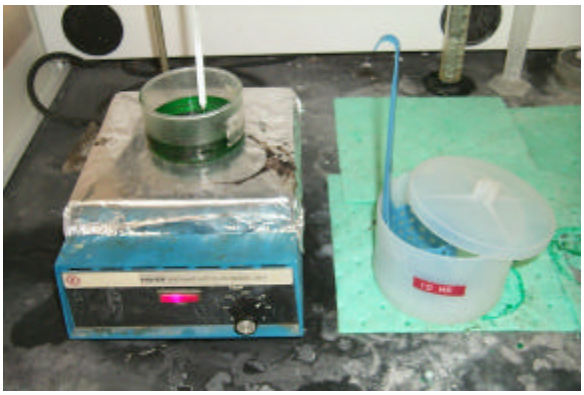
The four-point probe test is used to measure sheet resistivity before doping (but after etching). It is used again after doping/annealing to differentiate between the n- and p-type sides.


Samples are centered on the O-ring and the vacuum applied to hold the sample in place. With the speed dial set to '0' *1000 rpm, the machine is turned on, then over ~5 seconds brought up to 7000 rpm. 3 drops of one dopant are dropped on the center of the sample, and the timer turns the machine off. The sample is removed and the other side coated with the second dopant type.

Dopant solutions and extra supplies of other solutions are kept in the refrigerator beside the spin coater.

Samples are placed in the annealing furnace after spin coating. They will be annealed for 1 hour at 1000degC, then let cool in the oven overnight. The next day, each group who puts a sample in takes one of the pre-annealed samples out and continues the module. ~12 samples must be ready (already etched, coated, and annealed) for the first class of each semester.

Photo of wrapped samples in preparation for nickel plating, creating areas where solder will adhere and allow copper wires to be connected for circuit incorporation.



Plating setup (left half): samples are placed in solution (posted on hood shield) for 5 min at 90degC. Samples should be stirred gently to ensure coating on all exposed surfaces and to prevent sticking.

# IX. Fabrication of a Solar Cell (B) - Characterization

## Purpose & Procedure Overview:

(review of APC and outline of procedure & timeline)

The students pick up from the last module with their newly plated samples. First, the plated areas are scrubbed with a glass fiber brush, then copper leads are carefully soldered to either side of the wafer. The finished samples are then tested with an oscilloscope to check for characteristic functionality. At each station, the students set up their test circuit and apply a varied voltage in the 'dark' (+11 to –11 V) and 'illuminated' (2 to –2 V) states. The graphed data shows them the energy generation by the light in the illuminated state and they calculate the efficiency ('fill factor').

## Materials Needed:

(equipment which may need to be replaced or updated)

| | | | |
|---|---|---|---|
| Silicon wafers | 6 | SIT Inventory | large supply donated long ago |
| Tweezers | 6 (0) | MSC | For handling wafers |
| DMMs (2 per) | 6 (4) | Newark | shared with phase diagram module |
| Voltage source | 3 ( ) | Keithley | for circuit analysis |
| Current source | 3 ( ) | Keithley | for 4pt tester (extra is broken) |
| Wiring/connecters (7) | 4 sets | Newark | connecting wires and clips |
| Soldering irons | 4 (0) | RS / Local hardware | soldering Cu leads |
| Cu wire (2*12") | 12 (roll) | Local hardware | 2 8" leads for each sample |
| Solder | 4 (roll) | RS / Local hardware | in each kit |
| Glass fiber brush | 1 (0) | ?? | for cleaning soldering area |
| Lamps | 3 (1) | Local hardware | to 'illuminate' solar cells for data |

## Consumables & Preparatory Tasks:

(supplies normally consumed – fall semester of ~ 160 students)

- Review PowerPoint presentation for this module (confirm file is functional and up-to-date).
- Prepare a sufficient number of copies of the quiz for each section.
- Extra printouts of the lab procedure for those who forget to bring their own.
- Setup acid solution for etching $SiO_2$ from samples.
- Check for sufficient baskets and tweezers.
- Check each station for setup (4 point tester, sufficient wires, V and I sources, *etc*).
- Beside the minor items and equipment repairs (and replacements) mentioned above, the critical consumables for this module are listed below:

**Materials Purchases Necessary:** Solder (occasionally), and a roll of Cu wire (seldom).

## Typical Module Timeline:

(varies somewhat with TA – no mistakes by students)

| *Stage* | *Duration* | *Total Time* |
|---|---|---|
| Quiz | 0:10 | 0:10 |
| Presentation | 0:20 | 0:30 |
| Identify samples from storage | 0:05 | 0:35 |

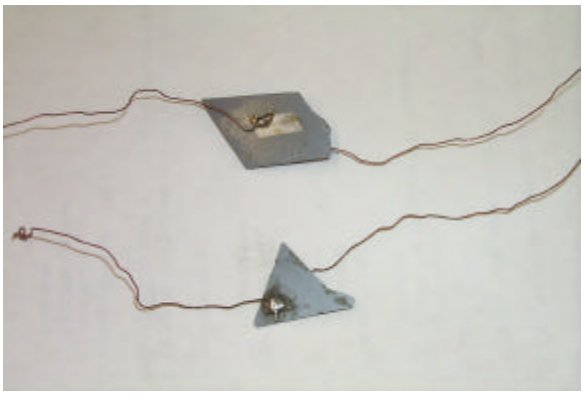
| | | |
|---|---|---|
| Explanation of best soldering technique | 0:05 | 0:40 |
| Soldering of Cu leads to Ni-plated areas | 0:15 | 0:55 |
| Testing of samples with lab oscilloscope | 0:05 | 1:00 |
| Characterization of solar cell in “dark” state | 0:15 | 1:15 |
| Characterization of solar cell in “illuminated” state | 0:10 | 1:25 |
| Explanation of lab note expectations | 0:05 | 1:30 |

## Module-Specific Safety Concerns:

- Soldering electrical leads to your sample requires care and patience- do not burn yourself and please solder only on glass work surfaces.
- For you samples to work well, you must keep them scrupulously clean.
- .

## Module Photographic Highlights:

(supply locations, equipment setups, and key activities)

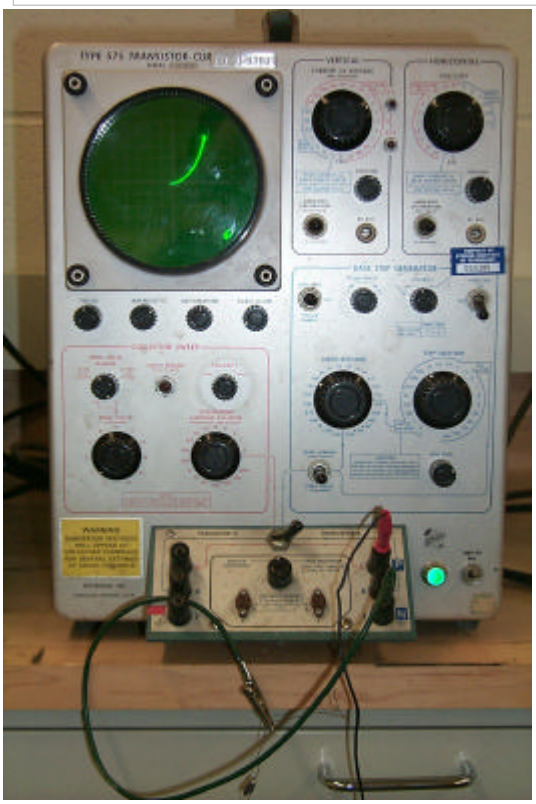


Soldering Cu leads to the P&N sides. The first side is straight forward, just make sure sample is clean and don't use too much solder. The second side is harder, as the longer the soldering iron is applying heat, the more likely the first side will melt off. Generally, more than 2-3 seconds of heat applied to the 2nd side will melt the first side off.

All work must be done on glass.

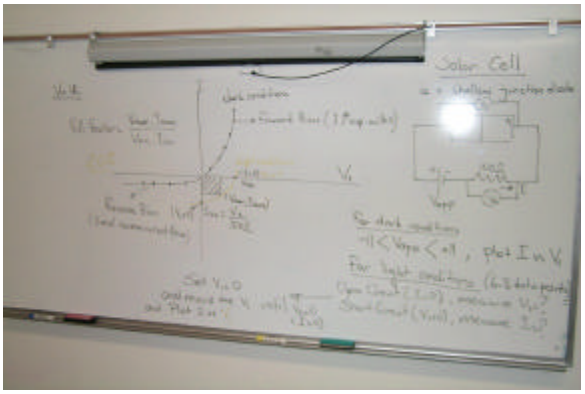
After demonstrating what is expected when "forward" and "reverse" bias currents are applied to a known good sample, each group's sample is then tested. Note settings on Oscilloscope. Only "polarity" and "range" switches should be adjusted.

Group's whose samples do not work (50% failure at this point is typical) are replaced with lab specimens which are known to work. These *must be collected back* at the end of the module.



Characterization and data acquisition of data with photonic energy applied to the n-doped side of the solar cell. Similar data is taken with the light not applied. Fourth-quadrant shift (when data is graphed) is used to determine efficiency (the "Fill Factor").

When taking illuminated measurements, the sample must be close the light and not moved or bumped!




Typical white-board comments which can be written once, then used by each TA for their sections. This is very helpful to increase explanation clarity and maintain consistency in details when explaining a concept initially confusing for many students.

# X. Polymers and Polymer-Matrix Composites

## Purpose & Procedure Overview:

(review of APC and outline of procedure & timeline)

## Materials Needed:

(equipment which may need to be replaced or updated)

| | | | |
|---|---|---|---|
| Adhesion test cyls. | 6 pr. (3 pr.) | SIT Machine Shop | epoxy adhesion test |
| Twin syringe epoxy | 3 (3) | Local hardware | |
| ¼ page scrap paper | 50 (endless) | | for mixing epoxy |
| Tooth picks | 100 | Local supermarket | for mixing epoxy |
| Heated presses | 2 (0) | Carver Presses | compression molding samples |
| Al foil | 3 rolls (3) | Local supermarket | for keeping LDPE of platens |
| Molds | 12 (1) | SIT Machine Shop | dog bone tensile specimens |
| Lecithin mold release | 3 (9) | _____ | keeps LDPE off mold |
| Paper towels | 1 (0) | Temco | smoothing Al foil |
| Balances | 2 (4 extra) | Ohaus | with weigh pans and covers |
| LDPE pellets | 3.5kg (5) | _____ | 100 grams per class |
| LDPE strips | bunch | Prof / TAs | made from prev. class' 2 'pancakes' |
| Instron tensile Mns. | 2 (0) | SIT Inventory | B-311: 1 high-rate, 1 low-rate |
| Computers | 2 (1) | SIT Inventory | w/ control & measurement software |
| Set of 8-12 tens. bars | 8-12 | made by students | 1 set per lab group |
| Set of 4-6 adhesion | 4-6 | made by students | 1 per lab group |
| | | | |
| Gloves (pr.- leather) | 6 (4) | MSC | *general protective wear* |
| Goggles | 12 (25) | Fisher Scientific | *general protective wear* |

## Consumables & Preparatory Tasks:

(supplies normally consumed – fall semester of ~ 160 students)

- Review PowerPoint presentation for this module (confirm file is functional and up-to-date).
- Prepare a sufficient number of copies of the quiz for each section.
- Extra printouts of the lab procedure for those who forget to bring their own.
- Beside the minor items and equipment repairs (and replacements) mentioned above, the critical consumables for this module are listed below:

**Materials Purchases Necessary:** Occasional purchase of LDPE pellets or carbon fiber spools. Both come in very large quantity for our lab, so are purchased only every few years.

## Typical Module Timeline:

(varies somewhat with TA – no mistakes by students)

| *Stage* | *Duration* | *Total Time* |
|---|---|---|
| Quiz | 0:10 | 0:10 |
| Presentation | 0:20 | 0:30 |
| Create and cure epoxy adhesion test specimens | 0:05 | 0:40 |
| Start students on creating 2 'pancakes' for strips | 0:05 | 0:45 |

| | | |
|---|---|---|
| Explain dog bone sample setup | 0:05 | (during above step) |
| Start creating pure LDPE specimens | 0:10 | 0:55 |
| Finish pancake specimens and cut up | 0:10 | (during above step) |
| Press 4-6 pure LDPE tensile specimens | 0:10 | 1:05 |
| Explain and create C fiber composite specimens | 0:10 | (during above step) |
| Extract, cool, and clean pure LDPE specimens | 0:05 | 1:10 |
| Press 4-6 C fiber composite specimens | 0:10 | 1:20 |
| Begin tensile testing of pure LDPE specimens | 0:20 | 1:40 |
| Explain adhesion test to 1 student and let them run | 0:20 | (during above and next step) |
| Extract, cool, and clean pure LDPE specimens | 0:05 | (during above step) |
| Begin tensile testing of pure LDPE specimens | 0:20 | 2:00 |
| Interactive movie on polymer processing from web | 0:10 | 2:10 |

**Revise this module's time schedule.**

## Module-Specific Safety Concerns:

- Epoxy hardens quickly. Do not glue your fingers together. The uncured components are difficult to clean.
- The temperatures of the platens on presses are 275 and 300 F. Wear gloves while handling your sample molds.
- Keep the molds clean all the time and apply the mold release only in the designated area.
- During the tensile testing phase of this module, materials will be breaking under large loads. Do not touch the equipment during the testing. Keep your face far from the sample.
- .

## Module Photographic Highlights:

(supply locations, equipment setups, and key activities)

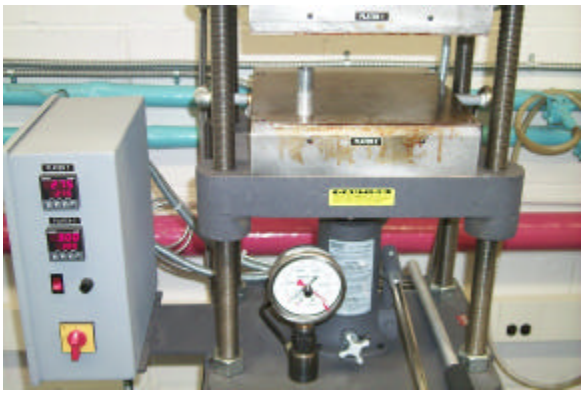
Stations for 6 groups are set up in B-314. In the background (front of the room) are the mold spray areas—these have been replaced with boxed to catch more oil vapor (food service grade, not harmful).

Each station has a "dog bone" mold, epoxy, toothpicks, and scrap paper.

The working/supply area is as shown. Balance, LDPE pellet bin, C-fiber spool, tinfoil rolls, putty "knife", gloves, press platens, adhesion test pieces, paper cutter, and paper towels are available for the students.

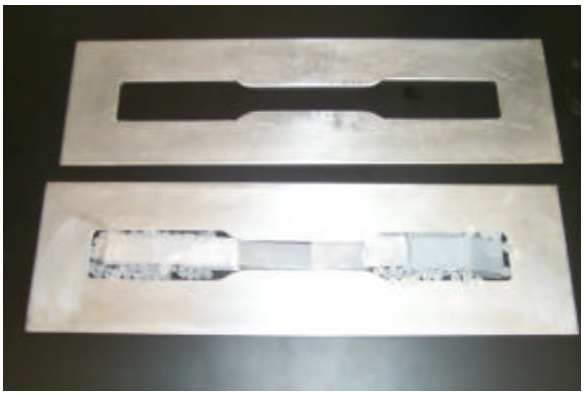
The heated-platen presses in the back of B-314 room.

Do not ever try to lean press over, they are not bolted to the floor. If tipped, a press could become unstable due to high center of gravity created by stand mounting.



Presses are run at 275 degrees (top platen) and 300 degrees (bottom platen) Fahrenheit. Any material which is squeezed from molds must be scraped off platens before next set of samples is pressed.

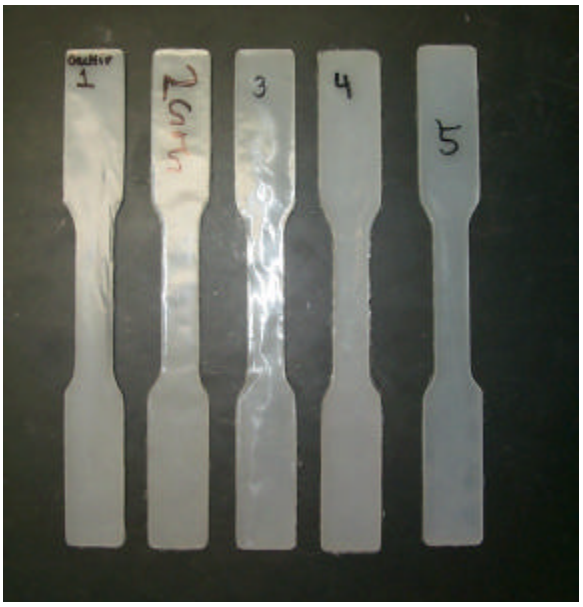
Drying oven used to accelerate epoxy cure time for adhesion test specimens created by students. Specimens are usually heated for 1 hour at 100 degrees C.



The die at the top is empty and cleaned of debris from previous pressings.

In the lower half of the photo, a die has been filled with LDPE strips and pellets in preparation for pressing. When making actual samples, the die must be placed between 2 sheets of aluminum foil to prevent sticking.

In this photo one can see the LDPE “pancakes” from which the strips are formed. Also visible are a test pancake impregnated with fiber tows and the spool of carbon fiber.




One section's pure LDPE "dog bone" specimens (typical).

# XI. Reverse Design of a Hard Disk Drive

## Purpose & Procedure Overview:

(review of APC and outline of procedure & timeline)

This module draws into the course an obvious design element for the students to grasp and work with. The pairs of students are instructed in the basic principles of data storage and operation of a computer hard disk drive. They are then guided through the process of dismantling a set of drives. At each stage, the students are given time to evaluate what they see. During this process, they construct a table of 30-40 components with four columns for function, possible material(s), requisite properties for the part, and possible processing methods. Toward the end of the class, two ten-year-old drives are introduced for inspection. In addition to the table, they are asked to construct a second table with five components which best exemplify the advances in hard drive technology over the past ten years. During this module, the TA needs to budget the time carefully.

## Materials Needed:

(equipment which may need to be replaced or updated)

| | | | |
|---|---|---|---|
| Stackable bins | 6 (2) | MSC | contain pieces below |
| Component boxes | 18 (6) | MSC | 3 per bin/group - hold drive parts |
| Set of 3 hard drives | 6 (2 extra) | Comp. Serv. Ctr. | disassembled at 3 stages & boxed |
| Torx driver handle | 6 (1) | Rt. 22 shop | 1 per bin |
| Torx bit set | 6 (0) | | 1 set of 6 per bin |
| Magnet | 4 (0) | | 1 per bin (some missing) |
| Fine screwdriver set | 6 (0) | RS / local hardware | 1 set of 6 per bin |
| 10 year old drives | 2 (0) | SIT lab stock | for technology comparison |

## Consumables & Preparatory Tasks:

(supplies normally consumed – fall semester of ~ 160 students)

- Review PowerPoint presentation for this module (confirm file is functional and up-to-date).
- Prepare a sufficient number of copies of the quiz for each section.
- Extra printouts of the lab procedure for those who forget to bring their own.
- Check each bin for appropriate contents.
- Check the 3 boxes in each bin for proper components and missing (critical) pieces.
- Make sure that there are 2 fully prepared extra bins. (There are 80+ old hard drives in B-310.)
- Check “old technology” hard drives for operability and cleanliness.
- Beside the minor items and equipment repairs (and replacements) mentioned above, there are no critical consumables for this module.

**Materials Purchases Necessary:** None. Occasionally, more hard drives need to be scrounged and dismantled for kit creation.

## Typical Module Timeline:

(varies somewhat with TA – no mistakes by students)

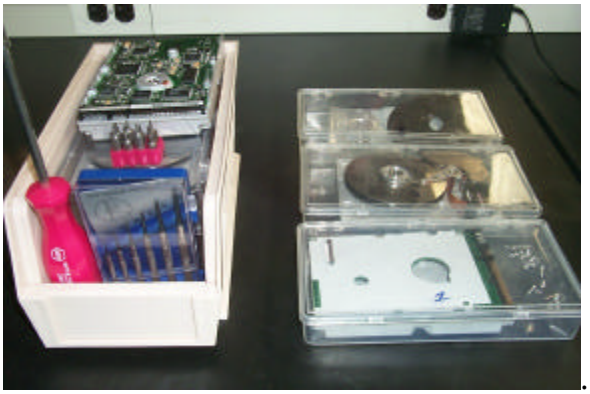
| *Stage* | *Duration* | *Total Time* |
|---|---|---|
| Quiz | 0:10 | 0:10 |
| Presentation | 0:20 | 0:30 |
| Table setup and box explanation | 0:05 | 0:35 |
| Exterior | 0:15 | 0:50 |
| Interior / Box 1 | 0:10 | 1:00 |
| Box 2 | 0:20 | 1:20 |
| Box 3 | 0:20 | 1:40 |
| Compare old and new hard drives / technologies | 0:15 | 1:55 |

## Module-Specific Safety Concerns:

- Please be gentle with the hard drive and components. Only use force when instructed.
- Avoid contaminating platter surfaces with finger prints-handle by edges.
- .

## Module Photographic Highlights:

(supply locations, equipment setups, and key activities)



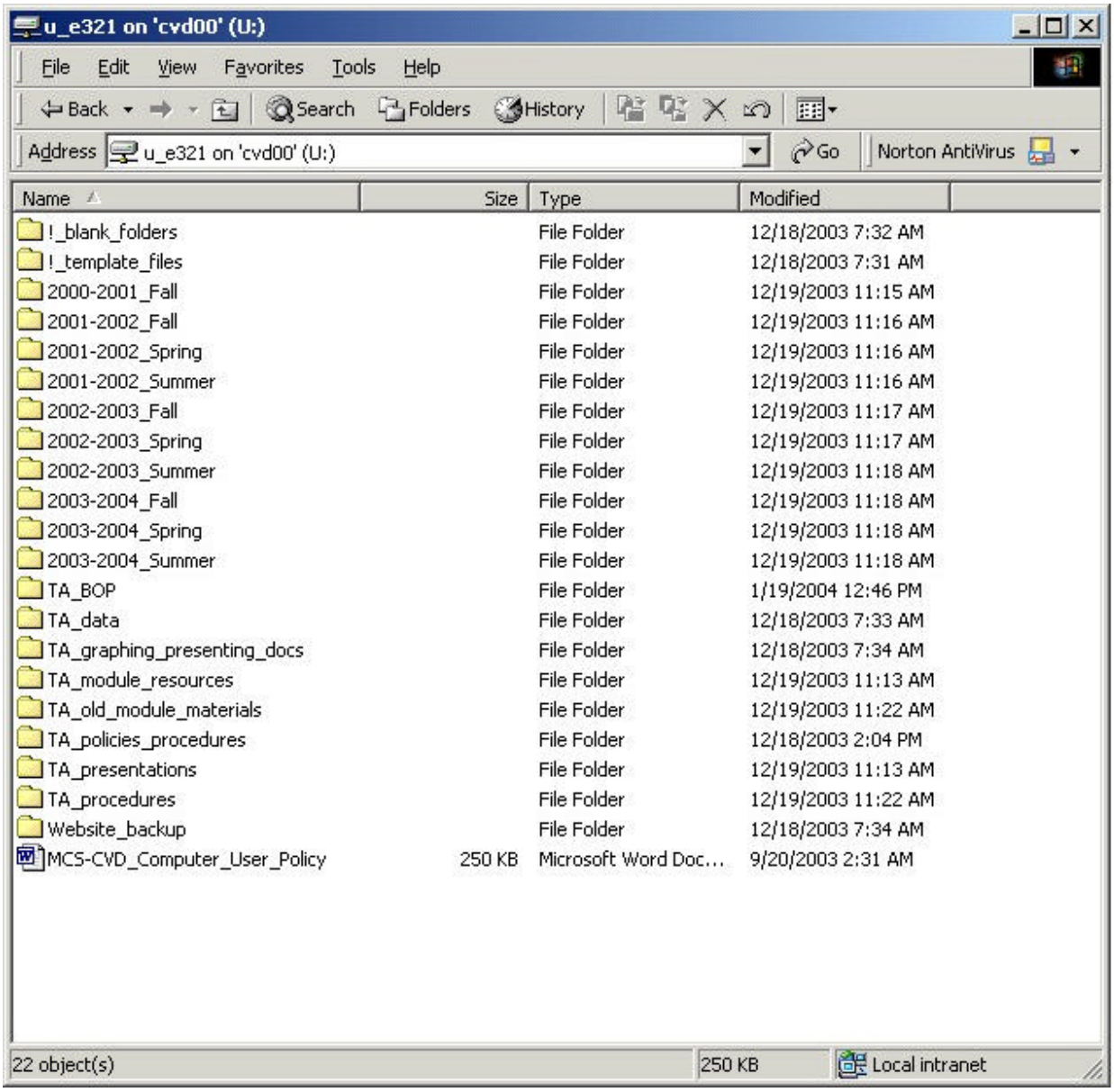
Layout of B-312 setup for reverse design of hard drive module- six stations. Students are guided through the disassembly and evaluation process, referencing all the knowledge they have accrued through the semester.

Kits must be checked before students arrive and before they depart: all tools and parts present and in correct boxes.

# XII. Administrative information for the TAs.

The TA materials and support information and files are located on the MCD-CVD server "CVD00" in the u_e321 directory. New TAs should contact the CVD Lab computer manager for an account and access information.

The contents of the u_e321 directory are depicted below.

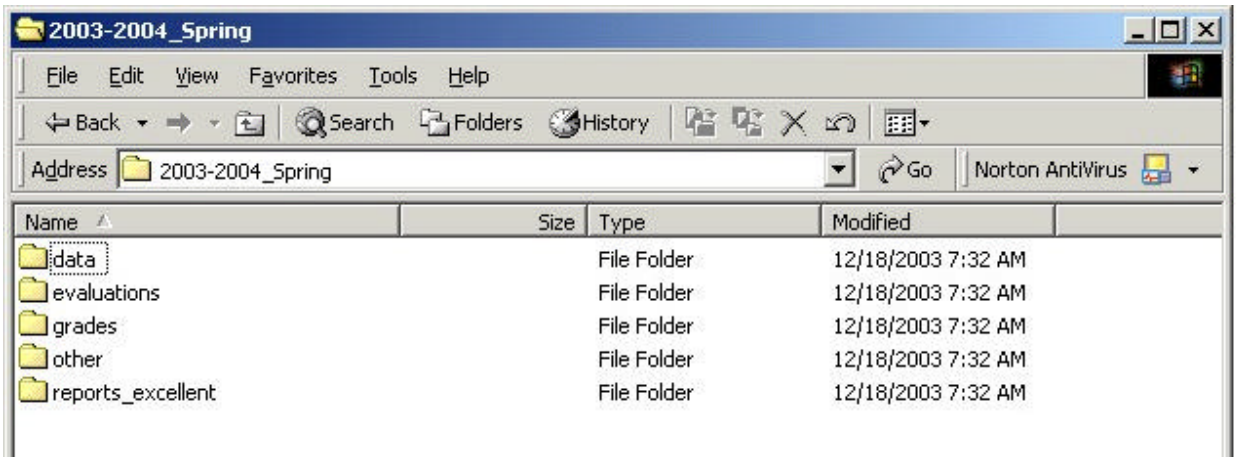



Each semester has its own directory for files which pertain to the specific classes of students: grades, lab data, example reports, detailed TA/course evaluations and summaries, *et cetera*. An example of one semester's directory contents is visible below. The other directories are used for

reference materials and files which change little or are supportive to the TAs and their efforts. Do not delete information from any of the older semester directories, as they are for reference by the course Professor. The contents of the TA_-type folders should only be removed if absolutely necessary, as the older materials may be reused (for example) if an old module is brought back. These older and supporting materials will give TAs and Professors a place to start and information on equipment and supplies already in stock.

The TA_BOP folder houses the E-321 TA Book Of Procedures. This should only be edited by the senior TA or professor. All pictures are *linked* to the BOP documents, not embedded, so the "pictures" directory must be copied along with the latest BOP file when making a copy.

When TAs run a lab to validate setups or evaluated new modules, the data may be stored in (or compared to data already in) the "TA_data" directory. This folder houses "ideal" data already taken by previous TAs or really good groups of students.




Grading guidelines may be observed in the "Lab Notes Format" document on the course website. All TAs should discuss the details of this system and come to an agreement on the "point system" at the beginning of each semester. If a new TA comes in mid-semester, they need to be brought up to speed by the other TAs!

Grades are recorded in the most recent semester's folder on the data server, CVD00. The file name follows a standard format (and should be easy to find), the most recent version of which was titled "E321_Grades_2003_fall.xls".

When starting a new semester, either a blank spreadsheet may be copied from the "!_template_files" directory, or copied from the previous semester's folder. If there are any residual student records, they should be deleted, do not clear the contents of the cells, as the built-in formulas might also be deleted. The first worksheet in the file is completely automated, except for the title. The last worksheet is used as a summary of the course's grades at the end of the semester to see how each section averaged out (the process is easy and should be obvious).

The middle four worksheets are dedicated to each of the course's four TAs. Within each worksheet, the TA's name and section letter should be filled in, then each of the students'

information. As the semester progresses, Quiz and Lab Note grades may be added and the file saved to update it. The last 4 columns (averages and final grade) are calculated automatically, and these values, plus some student information are related to the first worksheet to create the end-of-semester report for the Professor. In these calculations, the lowest grade for quizzes and lab notes is automatically dropped. Blank cells do not count against this, so if a quiz of lab is missed without makeup, a zero must be entered. When first getting acquainted with this procedure, make sure to work with an experienced TA.

Grade posting maybe done by one or more TAs. See the senior TA for instruction and privileges for this. The procedure for posting grades to the web site may be described here in more detail in the future.

**In this document, the following "standards" are adhered to:**

- Normal text is Times New Roman, 12 point font
- All "tables" consist of tabbed text
- Section titles are "Heading 1"
- Photos are stored in the "pictures" directory and are formatted as .jpg or .jpeg.
- Photos are inserted only as *links*, not as embedded files, and in-line with text
- Photos are formatted to 3.0 inches wide (landscape) or 2.75 inches (portrait)
- Captions to each photograph are done in text boxes which are anchored over/in-front of the text, not inline.

# XIII. Typical Supply Quantities & Prices (ordered Fall 2002)

| *Company* | *Mods.* | *Qty.* | *Description* | *Unit $* | *Total $* |
|---|---|---|---|---|---|
| Dad's Rock Shop | 1 | 3 | Deluxe hardness test pick set | $ 57.95 | $ 173.85 |
| Do-It Corporation | 6 | 10 | 1155 blank specialty mold | $ 30.95 | $ 309.50 |
| Do-It Corporation | 5,6 | 4 | 1892 hot pot-2 melter, 120V | $ 45.95 | $ 183.80 |
| Belmont Alloys | 5,6 | 50 | Pure Sn shot, 8-20 mesh (lbs) | $ 4.72 | $ 236.00 |
| Belmont Alloys | 5,6 | 50 | Pure Bi shot, < 1/8" (lbs) | $ 6.60 | $ 330.00 |
| Belmont Alloys | 5,6 | 150 | Belmont Alloy 2581A, Bi-Sn eutectic (lbs) | $ 6.75 | $ 1,012.50 |
| MSC Industrial Sup. Co. | all | 2 | 00143263 cs of 12 stackable bins | $ 32.84 | $ 65.68 |
| MSC Industrial Sup. Co. | 8,9 | 10 | 02674976 precision utility tweezers | $ 4.51 | $ 45.10 |
| MSC Industrial Sup. Co. | 3 | 10 | 06498752 carbide scribe | $ 2.11 | $ 21.10 |
| Epsco Inc. | 9 | 2 | Model D-612T power supply | $ 282.50 | $ 565.00 |
| Wilson Instruments | 3,4,7 | 3 | HRC indentor tips, # 9100-401 | $ 171.00 | $ 513.00 |
| Newark Electronics | 8,9 | 10 | 91F6071 Fluke #16 multimeter | $ 129.00 | $ 1,290.00 |
| Keithley Instruments | 6 | 1 | Model 2000 61/2 digit DMM | $ 995.00 | $ 995.00 |
| Home Depot | 5,6 | 1 | Box of 50 brt. Wht. 6" ceramic tiles | $ 19.99 | $ 19.99 |
| | | | | Grand Total: | **$ 5,760.52** |

## Future Items to be Acquired / Purchased:

ID tags / labels or inventory tags
Dry erase markers
HF and $H_2SO_4$ for solar cell
6’ of wire-hiding tread (for projector cables on floor)
Pyrex test tubes (2 dozen+), which won’t thermally fracture
Done- Cheap gloves
Glass slides
Glasses / goggles

# XIV. Supply Sources

**Belmont Metals**
330 Belmont Ave
Brooklyn, NY 11207
718-342-4900
www.belmontmetals.com
"Fernando"

**Cole-Parmer Instr. Co.**
625 E. Bunker Court
Vernon Hills, IL 60061-1844
847-549-7600
www.coleparmer.com

**Computer Service Center**
Basement, Stevens Library
Patrizia Cioce
201-216-5108
www.stevens-tech.edu

**Dad's Rock Shop**
PO Box 10649
Ft. Mohave, AZ 86427
928-788-2513
www.dadsrockshop.com

**Do-It Corporation**
501 North State Street
Denver, Iowa 50622
319-984-6055
www.doit-molds.com

**Epsco Inc.**
1115 Hilltop Drive
Itasca, IL 60143
630-250-0410
www.epscoinc.com

**Fisher Scientific**
Some street
Some state
Phone number
www.fisherscientific.com
Acct# 801686003

**Home Depot**
Secaucus, NJ
www.homedepot.com
Off Rt. 3w across from Sony 6 Theaters (by UPS)

**Keithley Instr., Inc.**
28775 Aurora Road
Cleveland, OH 44139
440-248-0400
www.keithley.com

**Local hardware stores:**
Ace Hardware
George's Paint & Hard.
Home Depot (Secaucus)

**MSC Ind. Supply Co.**
100 MSC Drive
Jonestown, PA 17038
800-645-7270
www.mscdirect.com
Acct# 83

**Metals USA**
Street
Town, State zip
800-700-3032
www.metalsusa.com

**Newark Electronics**
800-463-9275
www.newark.com

**Ohaus Corporation**
29 Hanover Road
Florham Park, NJ 07932-0900
973-377-9000

**Omega Engineering**
P.O. Box 4047
Stamford, CT 06907
800-826-6342
www.omega.com

**Radio Shack**
218 Washington St.
Hoboken, NJ 07030
201-459-0490
www.radioshack.com
Reimbursed by voucher

**Sigma-Aldrich**

**SIT Chemical Inventory**
McLean 214
Fax: 201-216-8971
Weekdays: 1-2pm

**SIT Inventory**
Lab equipment purchased for Eng. Design V Lab

**SIT Lab Stock**
Assembled from old hardware already on hand in CBME Dept. labs

**SIT Machine Shop**
Burchard Basement
George Wholrab
Joe _____
X _____

**Staples**
Newport, NJ (by Modell's)
Order through CBME dept
www.staples.com

**Temco**
Janitorial Services
Pedro _____
x _____

# XV. Future Suggestions

Module 0: photos of supply locations?

Module 3: add Photo of glass slide / stress concentrator exercise?

Module 5: where are replacement crucibles purchased? None known to have been since 1997.

Contacts:

Gaetano Liberatore x5208