Micro Automation Programmable Dicing Saw, Model 1006

Purpose:
Operational and procedural instructions used to separate individual die on a silicon wafer or glass substrate.

Initial Precautions

(1) Edges of the metallic bonded diamond-and-epoxy resin blades are very sharp and can very easily cut through the skin during regular handling.

(2) There is high risk of damage to the delicate blades during handling.
Handle the blades with extreme care, as they break very easily. Never touch the cutting edge of a blade, as even the slightest touch can bend, deform, and/or break a blade. Do not flex or bend these thin blades!

(3) The spindle should never be turned on without the clear plastic guard tightly in place.

(4) You are encouraged to wear hearing protection, as the spindle is loud when it is running. There is a beaker full of earplugs on the conduit to the left of the saw, please dispose of them when you’re done.

(5) Due to the age and unpredictability of this machine, do not leave it running unattended. For example, it is not uncommon for the spindle to slow down, jam, or halt suddenly, causing one or more internal fuses to blow inside the machine, disabling the saw. If the spindle is damaged or destroyed, it may cost at least $20,000 to replace! If you are nearby watching or listening for these problems while operating the dicing saw, you should immediately push
the STANDBY key to stop the spindle, if it seems to be slowing down, jamming, or operating unstably (which you can easily detect by a dramatic change in pitch of the noise it emits when running).

(6) The red pushbutton switch, is used to turn the saw's main power on and off. To turn the saw on, push the button in, to turn it off, push the button again. Although this button may be used to immediately stop the saw in a crisis situation, do not turn off the main power when the spindle is running (instead, press the STANDBY key to stop the spindle).

(7) The operating controls are clustered into two groups of pressure/touch-sensitive switches on either side of the spindle. Operate them by pressing on the switch area with your finger. You will hear a beep when you press these buttons. Due to the age of this machine, you may experience problems in "double-pressing" these switches when you touch them. If this occurs, simply touch the button again, so that it is pressed only once (and then press the enter key, if applicable). You can damage these switches by pushing them with metal tools.

(8) IMPORTANT NOTE: If you are dicing silicon wafers or other samples with delicate or suspended microstructures, you are strongly encouraged to spin on photoresist to protect your sample from saw blade and vibration damage before you begin cutting your sample.

**Procedure:** Please read this entire document before training. Schedule a training session before operating alone.

**I. PRELIMINARIES**

1. Obtain a copy of and fill out the "SAW PROGRAM " sheet (see section II., below)
2. Check the water level in the Vacuum Water Trap. This trap is located on top of the saw table to the right of the saw.
   a. If the water level is above the tape on the side of the flask, empty the flask. To empty it, carefully remove the stopper (leave the two tubes in the stopper), leave the flask in the wooden base, and remove both. Hold the neck of the flask and tilt the base into a sink. Slowly pour water out into the sink.
3. Check the Log Book for previous entries. If the previous user had trouble with the machine, please report it to lab staff. Also, record your entry and how your run went. If you notice anything strange, please record it in here.
4. Check the two drain holes at the left and right of the brown catch tray around the chuck for visible obstructions. **Once operating the dicing saw, if you find that water is spilling over the top water basin area, you may need to unclog one or more of the drain tubes** (flow rates around 50 - 55 GPH for the vacuum-chuck-and-diamond-cutting-blade cooling water will not cause water to spill over the top basin, if both drain holes are unclogged!).

5. Check to insure that all of the water drain tubes are properly situated/mounted to drain into the water drain. There should be two large (one-half-inch diameter) tubes for draining chuck and cutting blade cooling water out of the top water basin that lead to one big drain tube and one smaller tube to drain spindle water.

6. Decide how you will mount the sample to be cut or diced (e.g. with or without tape or film under the sample). Discuss mounting your sample with Joe Fleck or other staff members. Your sample to be diced or cut with any mount underneath will be hereafter referred to as the **SPECIMEN**. There is ultraviolet sensitive adhesive in a black bag to be used for backing material, this is the recommended method. You will need to mount your sample on something or other, a bare wafer is unacceptable.

7. Check to see if there is a **blade sheet** present on top of or near the saw. This document describes the blade which is currently mounted on the saw (**grit, cutting depth, and thickness**).

   a. Visually inspect the blade to make sure it is not damaged or broken.

   b. If you need to change the blade, please alert staff of any broken/damaged blades, we will change them as soon as possible.

8. If the dicing saw itself is not already plugged in, plug it in. If you do not see any LED's on the front panels lit, click in the red button to turn on the saw. If the saw is still not on, check to make sure the top-cover interlock switch in the back of the unit is pushed down and latched (it can be unlatched, even if the top cover is on the saw).
II. PROGRAM

1. These are the left-panel program and data-entry keys you will use.
   a. 
   b. These are the right-panel program and chuck movement keys.

2. a. You must first store a program before you can initialize and use the saw.

   First, press the PROGRAM key:

   b. General Program Rules and Notes

   i. Once you have begun to program the saw, you must finish (a value must be entered for each cutting parameter).

   ii. A non-zero number must be entered for each parameter (except CUT COUNT).

   iii. When the red LED next to the PROGRAM key is lit, the saw is in program mode. The saw cannot be operated unless the PROGRAM LED is not lit (i.e. all sufficient program parameters have been entered).
iv. If the saw is started up from the *standby* condition, the program stored and used in the last operation will be used.

v. If during programming, you hear a *beep* and receive a flashing error code, refer to the error code list in Section V (below). Typically these can be cleared by pressing *CLEAR*, re-entering the number or parameter, then pressing *ENTER*. Because the program-entry keys are very sensitive to touch, a key may register multiple touches or presses, generating an error. Carefully re-entering the number or parameter usually corrects this problem.

vi. The numbers entered and displayed (on the red 7-segment LED display) are either in mils (0.001 in.) or mm, depending on the state of the *ENG/METRIC* switch.

vii. If you accidently enter a wrong number, press *CLEAR*, change the number, then press *ENTER*.

3. a. Press the *MODE* key: , enter a mode number (see below) on the numeric keypad, and press *ENTER*. 

<table>
<thead>
<tr>
<th>Mode Number</th>
<th>Description</th>
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<tbody>
<tr>
<td>10</td>
<td>For round specimens, with alignment required for each pass.</td>
</tr>
<tr>
<td>11</td>
<td>For round specimens with no alignment required for the second pass. (Blank wafers)</td>
</tr>
<tr>
<td>20</td>
<td>For round specimens, hexagonal die, where alignment is required for each pass (Triple alignment option).</td>
</tr>
<tr>
<td>21</td>
<td>For round specimens, hexagonal die, with no alignment required for the last two passes. (Blank wafers)</td>
</tr>
<tr>
<td>22</td>
<td>For round specimens, hexagonal die, with no alignment required for the second pass. The third pass alignment is made to an intersection of cuts made during the first and second passes. (Blank wafers)</td>
</tr>
<tr>
<td>30</td>
<td>For rectangular specimens, with alignment required for each pass.</td>
</tr>
<tr>
<td>31</td>
<td>For rectangular specimens, where no alignment is required for the second pass. (Blank wafers)</td>
</tr>
<tr>
<td>60</td>
<td>Progressive depth cuts for round specimens, with alignment required for each pass.</td>
</tr>
<tr>
<td>61</td>
<td>Progressive depth cuts for round specimens, with no alignment required for the second pass. (Blank wafers)</td>
</tr>
<tr>
<td>70</td>
<td>Progressive depth cuts for rectangular specimens, with alignment required for</td>
</tr>
</tbody>
</table>
Progressive depth cuts for rectangular specimens, where no alignment is required for the second pass. (Blank wafers)

4. Select which base units system you will use when entering cut parameters. Press the **ENG/METRIC** key to toggle between mils (0.001 inch) and millimeters (mm). The LED indicator to the left of this key will indicate which base units the saw is currently configured to use.

5. Press the **SCR/DICE** button (if needed) to toggle the red LED to the **DICE** mode.

6. Press the **1ST INDEX** key, enter the street-to-street distance for the first cut pass, then press **ENTER**.

   *The range of possible street widths is 0.125 mils - 4,000 mils, or 0.0032 mm - 101.6 mm.*

   **VALUE (1ST INDEX):** _____________________________

7. Press the **THICKNESS** key, enter your specimen's total (maximum) thickness, then press **ENTER**.

   *Thickness is programmable from 0.25 mils - 511 mils, or 0.0064 mm - 13 mm.*

   **WARNING:** Make sure you know, accurately, your specimen's maximum thickness (measure it with a **micrometer**) to avoid cutting into the vacuum chuck.

   The Micrometer is located here:

   ![Micrometer Diagram]

   **VALUE (THICKNESS):** _____________________________

8. Press the **HEIGHT** key, enter the amount of the specimen you want left after the cut, then press **ENTER**. The depth of the cut equals the **THICKNESS** of the specimen minus this programmed **HEIGHT** parameter.
The height range is 0.25 mils - 511 mils, or 0.0064 mm - 13 mm.
VALUE (HEIGHT): _______________________________

9. Press the ANGLE key, enter the theta-axis angle the vacuum chuck will rotate between cut passes, then press ENTER. The normal range is 1° to 121° (except in 'Hex' cutting mode where the largest angle is 60.1°).
VALUE (ANGLE): _______________________________

10. Next, you will enter parameters to specify whether your specimen is round or rectangular.
   a. For round specimens, press the DIA key, enter the specimen diameter, then press ENTER. The range of possible values is 0.25 mils - 6000 mils (6 inches), or 0.0064 mm - 152 mm.
      VALUE (ROUND): _______________________________
   b. For rectangular specimens, press the DIA key, enter the specimen's width dimension, then press ENTER.
      VALUE (RECT): _______________________________

      Then press the * key, enter the specimen's length dimension, then press ENTER.
      VALUE (RECT): _______________________________

      The range is 0.25 mils - 6000 mils (6 inches), or 0.0064 mm - 152 mm.

11. Press the 2ND INDEX key, enter the street-to-street dimension for the second cut pass (which is the pass that occurs after your programmed theta-axis ANGLE rotation of the vacuum chuck), then press ENTER. The range of possible street width values is 0.125 mils - 4,000 mils, or 0.0032 mm - 101.6 mm.
      VALUE (2ND INDEX): _______________________________

12. Press the SPEED key, enter the speed of X-axis travel (i.e. the wafer cutting speed), then press ENTER. The best cutting SPEED is largely determined by the specimen material's hardness. Speed is programmable from 50 mils/sec - 19,999 mils/sec, or 1.27 mm/sec - 508 mm/sec. NOTE: A recommended starting speed through silicon samples is 50 mils/sec.
      VALUE (SPEED): _______________________________

13. If you want to use progressive-depth cuts, press the 0 (zero) key, enter the desired incremental depth cut distance, then press ENTER. This is only used if you have already programmed MODE number 60, 61, 70, or 71.
      The incremental-depth cut range is 1 mil - 15 mil, or 0.025 mm - 0.381 mm.
      VALUE (PROGRESSIVE DEPTH CUT DISTANCE): _______________________________
a. Progressive depth cuts are used the thickness of your specimen is too thick to be effectively, cleanly cut all at once. In this cutting mode, the saw will make a series of progressively deeper cuts on the same street before moving to the next street.

b. An example of using progressive depth cuts, is to cut through a thick glass specimen to reduce blade wear.

14. Press the **PROGRAM** key to indicate that you have entered all cut parameters for your specimen.

15. Press the **RESET** key.

### III. **OPERATION**

1. Turn ON the TV monitor, that is located beside the saw, by rotating the right-most knob (below the monitor screen) clockwise.

2. Turn on Facilities. From back to front, Air, Nitrogen, Vacuum, DI Water, Industrial cooling water. Be careful with Air/Nitrogen valves, they may turn the compression fittings and cause a leak.

6. Press the **SPINDLE** key, on the right-panel keypad.
a. After pressing the **SPINDLE** key, carefully watch the blade assembly through the clear plastic cover and verify that the spindle begins to rotate.

**WARNING:** If the spindle fails to start rotating within a few seconds, immediately press the **STANDBY** key to abort start-up. Failure to do this may damage the expensive spindle motor assembly.

**NOTE:** If the lab air or cooling water is not already turned on, the spindle may not start-up.

b. Cooling water should begin flowing to the spindle once it is started. Verify that the right GPH flow meter (for spindle cooling water) is reading approx. 26 GPH. The flow meter has a black mark on it to indicate where the flow rate should be.

7. Next you need to "zero" the saw blade with respect to the vacuum chuck.
   a. First, locate the round metal **gauge disk**, which should be stored near the saw on top of the saw table. This metal disk is about 4 inches in diameter and 1/8th of an inch thick.

   b. Make sure that the **gauge disk** and vacuum chuck assembly are dry.

   **NOTE:** **Make sure the gauge disk and vacuum chuck assembly are dry. Also make sure the water spray tube (which protrudes out over the vacuum chuck assembly) is not dripping water onto the chuck.** During chuck zero calibration (step 7.g., below), the vacuum chuck and gauge disk are slowly elevated until the gauge disk is brought into brief contact with the saw blade, closing an electrical circuit. Thus, if the gauge disk is wet, erroneous chuck zero calibration will result, because the water will conduct current causing the saw to calibrate for a chuck that is thicker than it really is.

   c. Center the **gauge disk** and gently slide it onto the chuck
d. Press the **LOCK** button, if you need to reposition it press the **UNLOCK** button, the lock it again before zeroing. Make sure the Vacuum hose is not kinked.

f. Press **LOCK** to activate the chuck vacuum (if the lock/unlock solenoid is not working properly, you cannot proceed to the next step until this is done). The Vacuum gauge on the right hand side should read 20-25 if the chuck is locked. Normally, it should read 0-5.

g. Press the **CHUCK ZERO** key to "zero" the vacuum chuck assembly. The chuck should slowly raise the **gauge disk** up under the rotating saw blade until it actually comes into brief contact with the blade, and then the chuck should lower and reset.

**NOTE:** If you receive error codes when trying to "zero" the chuck, refer to **Section V**, below to identify and clear them. A common error often occurs when the saw does not register that the **gauge disk** has been locked onto the vacuum chuck assembly. Try repeatedly pressing the **LOCK, UNLOCK, LOCK**, then **CHUCK ZERO** keys.

h. After the vacuum chuck assembly has finished zeroing, press the **UNLOCK** key, remove the **gauge disk**, and re-store it next to the saw. Also, it may be necessary to unplug the vacuum hose from the vacuum chuck to release the vacuum (leave the hose disconnected until you have placed your specimen onto the chuck).

8. a. There is a line of screws in the vacuum grooves of the top surface of the vacuum chuck which can be removed as desired to enlarge the diameter of vacuum suction for the specimen. Depending upon the size of your specimen, you may need to remove additional screws.
b. If you remove any screws, they should be stored along the side edge of the vacuum chuck in threaded holes specially designed for that purpose.

Set screw storage locations

c. Now, center and gently place your specimen onto the vacuum chuck. Try to align it by eye at first; it will save you a lot of headache when aligning by camera later.

9. Press the **LOCK** key.

10. Next you need to optically align the saw blade with respect to the specimen on the vacuum chuck.

   a. Press the **ALIGN** key to allow you to align the saw's first cut on your specimen.

b. The TV monitor shows a split-field image of your specimen. You can put your finger under the camera to see which one is which. Try not to touch the camera head and mess up the alignment.

c. You should see two white, horizontal reticle lines on the black and white TV monitor. They are set to where the blade actually cuts whenever a new blade is installed. Use these lines to figure out what part of your wafer is going to be sawed away. Ideally, these lines should be equidistant from the edges of your devices on your SPECIMIN.

d. Align the streets to the plane of the cutting blade. Press-and-hold the **LEFT, RIGHT, BACK, FWD, CW** (clockwise), or **CCW** (counter-clockwise) keys on the right panel keypad to align your specimen. The **LEFT** and **RIGHT** keys move the specimen rapidly along the horizontal X-axis, while the **BACK** and **FWD** keys move the specimen along the vertical Y-axis. The **CW** (clockwise) and **CCW** (counter-clockwise) keys rotate the specimen.

   NOTE: By default, pressing-and-holding the **BACK, FWD, CW, or CCW** key moves the specimen very slowly for **fine** alignments. For faster, **coarse** alignment, first press the **FAST**
key, followed by pressing-and-holding the BACK, FWD, CW, or CCW key (the FAST key only works for the next key pressed). You should attempt to align horizontal features (such as streets) on your specimen to the horizontal reticle lines. This is done by horizontally moving across your specimen to see if your horizontal features or streets are parallel to the reticle lines. If not, rotate the wafer (by pressing-and-holding the CW or CCW key) and continue moving across the wafer until X-axis features or streets are parallel to the reticle lines.

e. You can move to every street on your specimen by first pressing the INDEX key followed by the FWD or BACK key. You should see your specimen step to the next (or previous) cutting street (through a distance specified by the 1ST INDEX program parameter). By first pressing the INDEX key followed by the CW or CCW key, the saw will rotate the vacuum chuck assembly an angular distance specified by the ANGLE program parameter to prepare your specimen for the 2nd cutting pass. Thereafter, pressing the INDEX key followed by the FWD or BACK key should move your specimen to the next (or previous) cutting street, through a distance specified by the 2ND INDEX program parameter.

NOTE: If you press the FAST key before pressing the INDEX key, the Y-axis will continue to step the programmed vertical distance as long as the INDEX button is held down, or until the end of the wafer is reached.

11. Next, decide how you will dice your specimen.

a. To execute only a single pass and cut through only the current street visible on the monitor (in either INDEX or ALIGN modes), press the SINGLE CUT key.

Water should immediately begin to flow onto the vacuum chuck assembly. Make sure the blade-and-chuck cooling water is draining properly into the sink drain basin. Make sure the beige water guards are positioned on the right hand side of the spindle to prevent splashing.

b. To cut through all streets in the X-axis (horizontal) dimension (and possibly the Y-axis streets on the second pass, depending on the programmed MODE number) of your specimen, press the AUTO CUT key. If the saw is in ALIGN mode when AUTO CUT is pressed, it will begin cutting in the first street. If the saw is in INDEX mode when AUTO CUT is pressed, it will begin cutting in the next street.

Water should immediately begin to flow onto the vacuum chuck assembly once AUTO CUT is pressed. Make sure the blade and chuck cooling water is draining properly into the green drain behind the table.

i. If the saw has been programmed in MODE 10, 30, 60, or 70, you have aligned the streets to the blade along only the X-axis (for the first pass), and you have pressed AUTO CUT, the saw will make all cuts for the first pass, rotate the specimen through
the programmed ANGLE, return the specimen to the align position, and beep to tell you that you can re-align your specimen prior to the 2nd cutting pass. You can then align for the 2nd pass, then press AUTO CUT again to cut all of the specimen's streets in the 2nd pass.

ii. If the saw has been programmed in MODE 10, 30, 60, or 70, you have aligned your specimen for the first pass, then rotated the specimen, aligned the streets for the 2nd cutting pass, and you have pressed AUTO CUT, the saw will make all cuts for the first pass, rotate the specimen through the programmed ANGLE, and make all cuts for the second pass without operator intervention. A beep will sound when the saw has finished all dicing.

iii. If the saw has been programmed in MODE 11, 31, 61, or 71, the specimen and chuck will rotate through the programmed ANGLE after cutting through the first pass and then make the second pass without pausing for operator alignment. There is no provision for alignment on the second pass (the center of the chuck is used for an alignment reference)

c. After pressing SINGLE CUT or AUTO CUT, verify that the left GPH flow meter (for vacuum chuck and diamond cutting blade cooling water) is reading approximately 58-60 GPH and the right GPH flow meter (for spindle cooling water) is reading 26 GPH. The meters each have a black mark on them to indicate where the flow rate should be. Adjust the flow rates by turning the black knobs at the bottom of each meter as needed. NOTE: If you find that water is spilling over the top basin when the dicing saw is running, you may need to unclog one or more of the drain tube holes at the edge of the basin.

IV. SHUTDOWN

1. After your specimen has been diced, press the STANDBY key to stop the rotating spindle and saw blade and to return the chuck to its original position. The saw will go through a homing sequence to return to standby status. The chuck zero will be lost, but your working file program will remain stored. Please remove your wafer and dry it with the hand-spray when done

NOTE: Other methods of stopping the saw or for stopping the saw to make alignments during a cut are described in the table below.
a. Alternate Procedures for Stopping the Dicing Saw During Cuts

i. PANIC STOP Press the red EMERGENCY OFF pushbutton switch located below the left-side programming panel to immediately shut down everything.

ii. RESET Press the RESET key to enter a mode similar to STANDBY, except that the spindle will continue to run, the blade will remain spinning, and chuck zero will not be lost.

iii. INDEX Press the INDEX key, and the saw will finish the current cut it is making, then return to the Index position. When AUTO CUT is pressed, cutting will start at the next street. Chuck zero is retained.

iv. ALIGN Press the ALIGN key, and the saw will finish the current cut and then stop in the Align position. However, when AUTO CUT is pressed, sawing will begin at the front of the wafer. Chuck zero is retained.

v. CLEAR In SINGLE CUT mode, when the saw is within the second pass ("PASS 2" is displayed on the LED display), pressing CLEAR at any time will reverse the vacuum chuck and specimen by the programmed ANGLE to return to the first pass orientation and halt.

2. Turn the water (DI and IC) and vacuum OFF [rotate the handles CLOCKWISE so they are perpendicular to flow].

3. Turn the Nitrogen and Compressed air OFF by rotating the knob CLOCKWISE until the handle is perpendicular to flow.

4. Spray off the chuck with the nitrogen gun, spray across the DI cooling rod to get water out of it as well. Let it drip, then spray it dry.

5. If the saw will be unattended and unused for a prolonged period, turn the EPO off. Turn the Monitor and Video modulator console off.

V. LIST OF COMMON ERROR CODES

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<tr>
<th>Error Code</th>
<th>Definition</th>
<th>Cause or Corrective Action</th>
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</tbody>
</table>
E001  Saw is currently in **STANDBY** mode. The **RESET** button must be pressed before attempting to turn the spindle on or otherwise operate the saw.

E002  The operator tried to *operate* the machine while in **PROGRAM** or **READ** modes. See if the **PROG** or **READ** LED's are lit. Press the appropriate switch to extinguish the LED's.

E003  A number parameter entered is *out of the valid range.* An attempt was made to enter a numerical parameter which is outside the design capability of the saw. Press **CLEAR** and program an acceptable number.

E004  The dimension entered for *height* is greater than the dimension entered for wafer/specimen thickness. This results in no dicing of the wafer/specimen. Press **CLEAR** and enter the correct dimensions.

E005  The dimension entered for **INDEX** is greater than the dimension entered for the wafer/specimen size. This implies that the dies are larger than the wafer/specimen. Press **CLEAR** and enter the correct dimensions.

E006  The saw has detected the lower chuck limit. This is likely caused by an excessive **THICKNESS** number. Press **CLEAR** and enter the correct **THICKNESS**.

E101  More than one switch was pressed simultaneously. Press **CLEAR**. The panel program buttons are very sensitive to touch. If this error code is displayed there may be a shortsed switch or connector.

E102  An attempt has been made to operate the saw without the chuck **LOCKed**. Press chuck **LOCK** (and, then perhaps chuck **UNLOCK**, and **LOCK** again).

E103  An attempt has been made to operate the saw with one or more program parameters missing. Make sure all parameters have been programmed into the saw (check this by pressing a program parameter key, such as **HEIGHT**, to display the stored parameter, then press **ENTER**, and so on). Check the asterisk (*) entry key if in rectangular **MODE** 30 or 31. Check the decimal (.) entry key if in progressive depth cut **MODE** 60, 61, 70, or 71.

E104  **Chuck zero** is required. Place the **gauge disk** on the vacuum chuck and perform a chuck zeroization (III., 7.g., above). Chuck zeroization is required when exiting **STANDBY** or **RESET** modes.

E105  **Chuck zero** was attempted before the Wait until the spindle reaches its operating
spindle was up to operating speed. speed (you should hear a *beep* when this occurs).

**E106** A switch was pressed while the spindle was ramping up to its operating speed. Wait until the spindle reaches its operating speed (you should hear a *beep* when this occurs).

**E108** Program storage is full. This error code indicates that all memory spaces are full. If you still want to store a program, you must erase or write over an existing program to make room for a new one.

**E109** An attempt was made to retrieve a program that does not exist from storage. Check the program ID number requested.

**E110** There is already a program stored in the memory location you requested, and if you continue, an existing stored program will be altered. This error code is a warning that an existing program is about to be altered.

**E111** An attempt was made to turn on the spindle while the machine was in a service mode. The spindle will not run while in a service mode. Select the proper mode.

**E113** The chuck was not unlocked after a *chuck zero* operation. Press the **UNLOCK** key to remove this block.

1 *Note: Details on how to store and retrieve programs and a complete list of error and fault codes are provided in the "1006 Dicing Saw Operation Manual" stored in the main office manual book shelves.*

Information and some images credited to:

**Louisville Microlab:**

http://www.mems.louisville.edu/sops/sop53.html