Engineering Model
CDE Manufacturing Status

October 2002

J. Eric Grove

Naval Research Laboratory

Manufacturing Status

- **Engineering Model CDEs**
  - 55 completed (i.e. bonded and wrapped), in storage at Swales
  - 6 spares completed, in test at NRL
  - All 108 CDEs will be completed by mid November
- **Components of CDEs**
  - CsI(Tl) crystals
    - 94 xtals have been received at NRL
      - 74 xtals have been sent to Swales for bonding
      - 2 xtals have been rejected
        - » One for cracks in bonding face, one for 2 mm "banana" distortion
      - 18 are undergoing visual, optical, and mechanical inspections at NRL
    - 24 xtals are in transit from Kalmar to NRL
  - Photodiode assemblies
    - 300 Hamamatsu S8576 diodes have been visually and electrically inspected at NRL
    - 243 diodes have been sent to Swales for soldering and staking (PDA manuf)
    - ~190 PDAs have been completed (i.e. wires soldered and staked)
    - Minimum 218 diodes are needed for EM build
  - VM2000 wrappers
    - ~120 wrappers have been cut to size at Swales
    - ~90 wrappers have been heat-formed at Swales

CDE Performance

- CDEs have two fundamental requirements:

1. They must fit into the mechanical structure
   - EM spare CDEs now at NRL do fit into EM Mechanical Structure
   - True test insertions will occur week of 28 October with Oscar Ferreira
     - Test insertions so far have not used elastic cords at cell corners
2. They must meet optical performance specs
   - Requirements
     - Light yield: >5000 e/MeV in large photodiode, >800 e/MeV in small
     - Light taper: Far / near = 0.70 $\pm$ 0.10
     - Light ratio: Small / Large = 1/5 to 1/7
     - Energy resolution: <8% (1 sigma) for muons
   - We will review these specs based on actual performance of EM CDEs
     - Specs may change

Receipt Testing at NRL

- Components of CDEs are subject to receiving inspections at NRL
- Photodiodes
  - Visual inspection
    - Inspection form/checklist exists and is in use
    - Look for flaws, especially in resin window and solder posts
  - Electrical inspection
    - Leakage current and capacitance of both diodes
    - Test procedure and standard output form exist and are in use
- Crystals
  - Visual inspection
    - Inspection form/checklist exists and is in use
    - Look for flaws and distinguishing marks
  - Dimensional inspection
    - Go / no-go gauge for height, width, and length
  - Optical inspection
    - Light yield and taper with PMTs in Crystal Optical Testing Station (XOTS)
    - Test procedure and standard output format exist and are in use

Scope of Bonding Studies

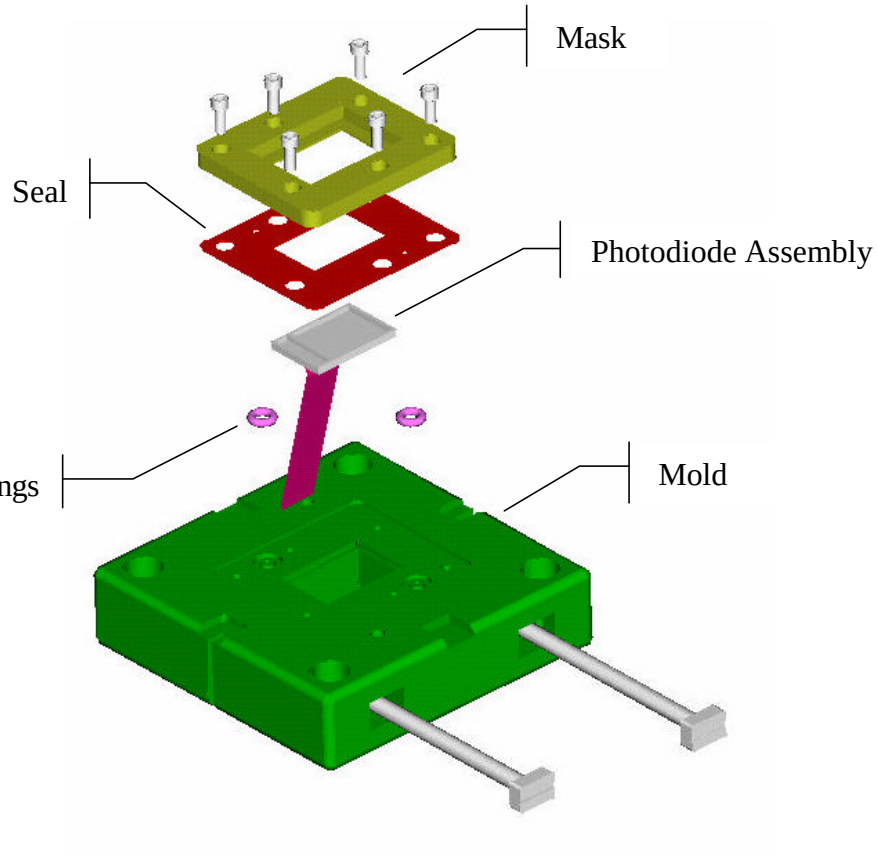
- **Assumptions**
  - Bond material is DC93-500 silicone encapsulant, with DC92-023 primer.
  - The bond thickness shall be 0.7 ± 0.1 mm.
  - The bond material shall not extend past the edges of the diode.
  - The crystal surface shall be roughened to improve adhesion.
- **Parameters studied**
  - Method of bond lay-up
    - Conclusion: one-stage mold with mask to define bond geometry
      - Encapsulant is injected into bounded volume, allowed to flush bubbles out.
  - Mix ratio of DC93-500 encapsulant
    - Conclusion: vendor-recommended 10:1 is soft enough after cure
  - Amount and method of DC92-023 primer to be applied
    - Conclusion: measured volume of primer is spread with spatula
  - Surface treatment of diode and xtal (factory polish or roughened)
    - Conclusion: diode to remain polished, xtal to be roughened
    - EM study: is milled xtal surface rough enough?

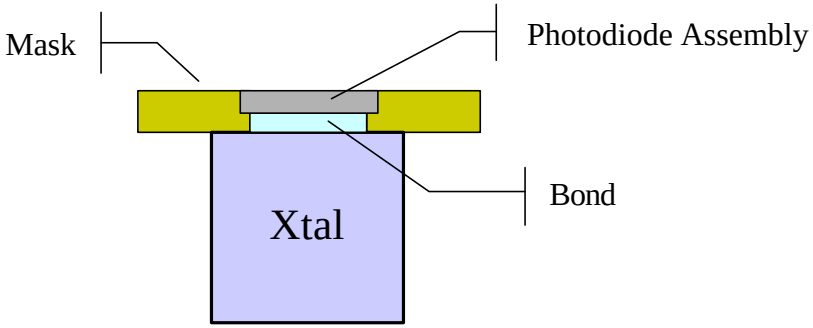
Bonding Method Selected

- **One-stage mold**
  - **Principles of method**
    - **Bond is formed within break-apart Teflon mold holding diode and xtal**
    - **Mold precisely defines bond thickness, area, and location on face of xtal**
    - **Mold is sealed against xtal face to prevent leakage of silicone encapsulant**
    - **Encapsulant is injected into bond cavity and allowed to flow until any trapped bubbles are removed**
  - **Bonding procedure is written and configured**
    - **“Process Specification for the Bonding of the PIN Photodiode Subassembly to the CsI Crystals", LAT-PS-00385**

Bonding Fixtures

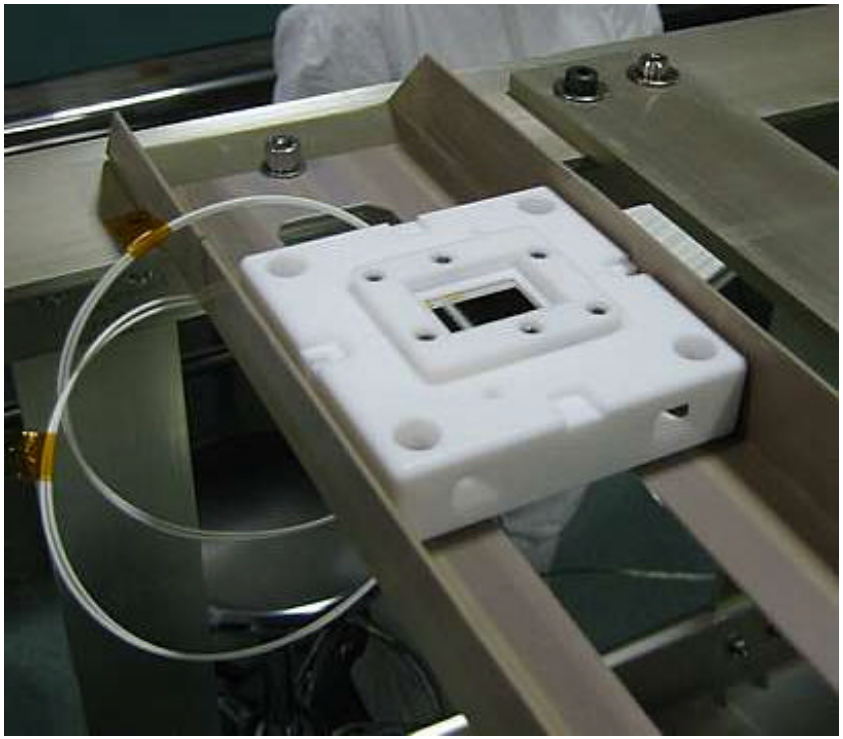
- **Exploded view of PDA and Mold subassembly**
  - **Mold: defines location of bond on xtal (referenced to xtal corner)**
  - **Mask: defines bond thickness (0.7 mm) and area (covers epoxy resin)**
  - **Seal and O-rings: prevent spread of encapsulant outside bond area**





Bonding Fixtures

- **PDA in bonding Mold**
  - **Mold: defines location of bond on xtal (referenced to xtal corner)**
  - **Mask: defines bond thickness (0.7 mm) and area (covers epoxy resin)**

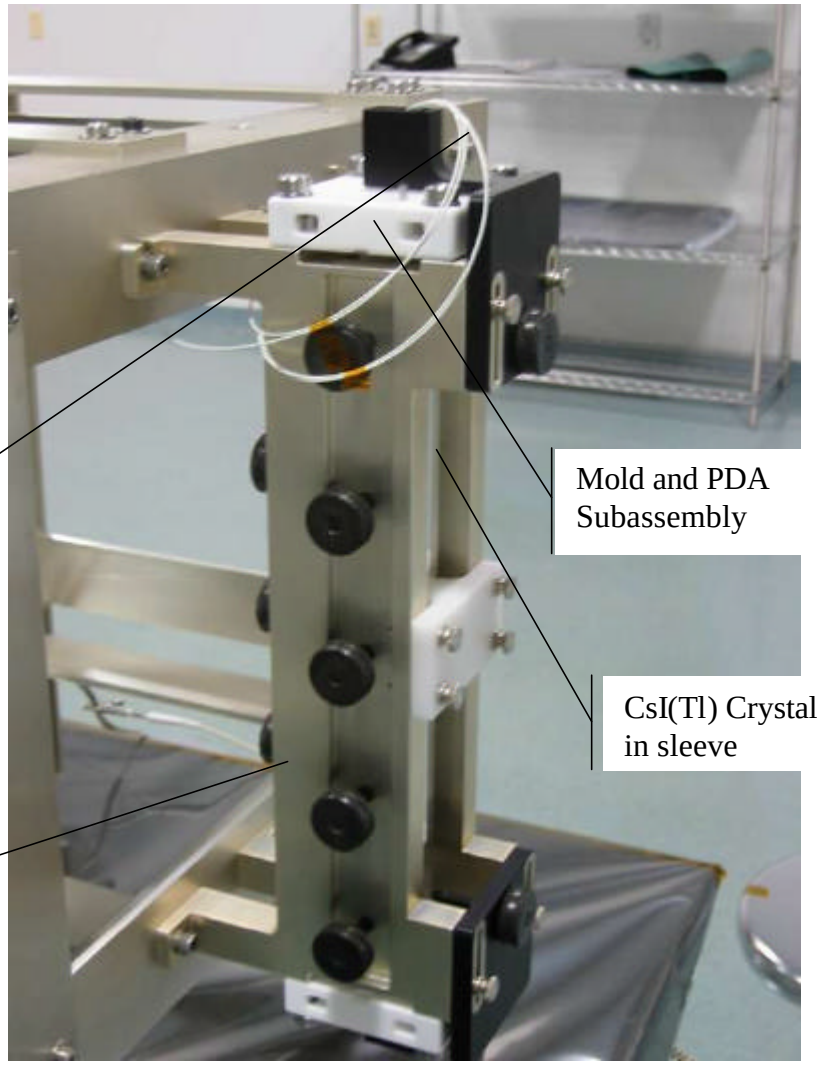


Bonding Fixtures

- **Back of PDA in Mold**
  - **Window in mold**
    - **Allows wire bundle to dress freely**
    - **Allows mold to load diode ceramic rather than staking and wire bundle**
  - **Injection and outflow ports are visible**

Bonding Fixtures

- **Fixture and molds for single crystal**
  - **Independent bonding molds are created for each crystal end**
  - **Support sleeve prevents distortion of crystal and registers mold to corner of crystal**



Bonding Fixtures

- **Bonding work station**
  - **12 bonding stations: six on one side, five on the other, one in France.**
  - **Encapsulant is injected with CDE in vertical position**
  - **Only one face of each xtal is bonded each day.**

  - **Practice session with Swales team**
    - **Mai-Anh Byron (Cog. Eng.)**
    - **Doug Ng, Jim Weinrich (Techs)**
    - **Nick Virmani, with finger in his eye**

Bond Process

- **Process at Swales Aerospace**

1. **Prepare Surfaces**
   - Clean factory-polished diode bond surface
   - Clean roughened crystal surface
   - Allow cleaned surfaces to air dry
2. **Position Crystal into Fixture and Prime**
   - Position xtal into fixture
   - Adjust pads to align xtal into proper position
   - Prime xtal surface with DC92-023
3. **Position Photodiode into Mold and Prime**
   - Assemble diode into mold cavity
   - Create desired bond area by assembling mask to mold assembly
   - Prime diode surface with DC92-023

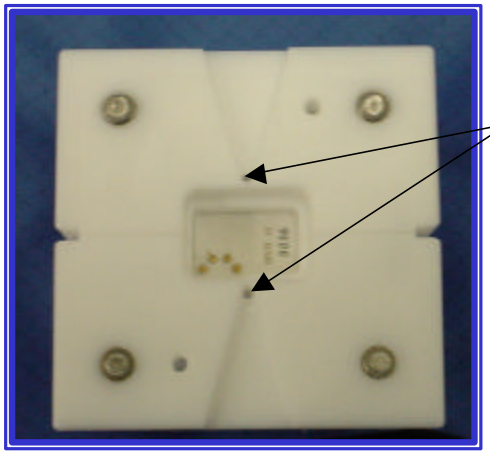


Figure 1: Diode in Mold, Top Side of Mold

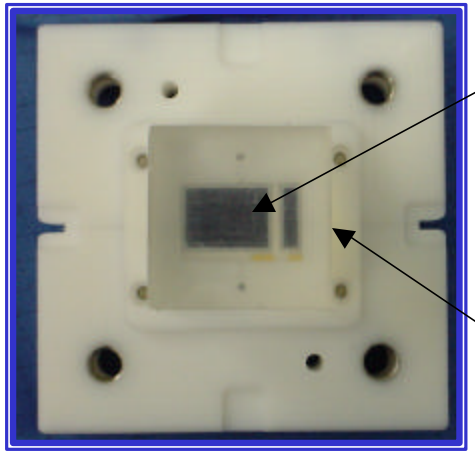


Figure 2: Diode & Mask in Mold, Back Side of Mold

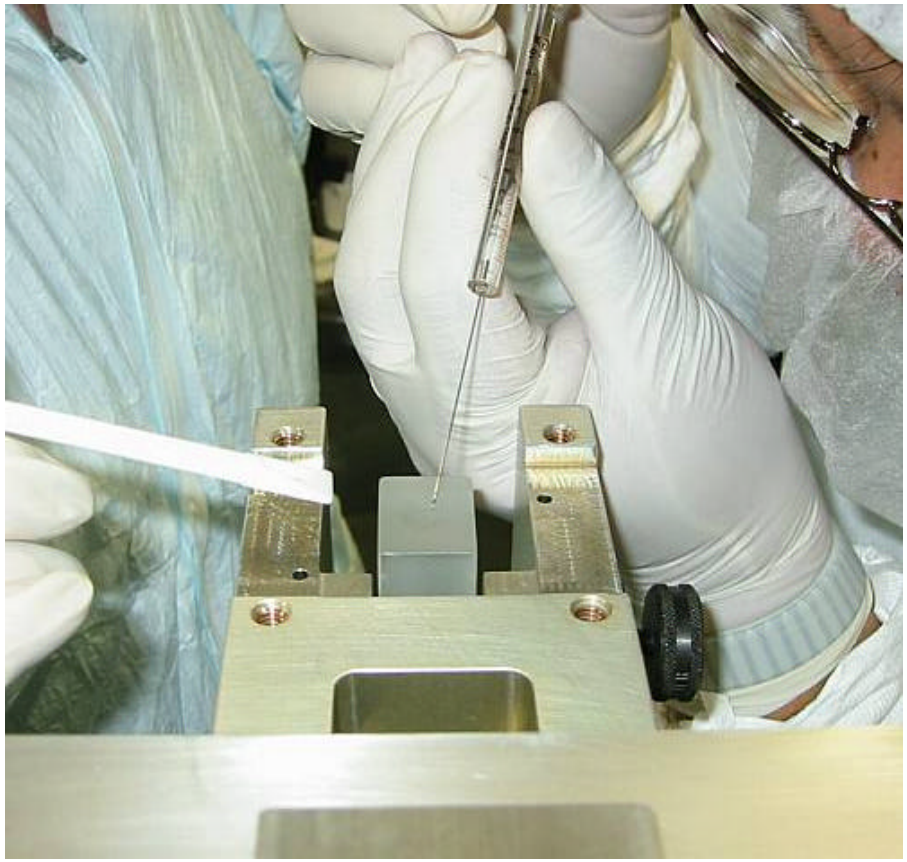
Bond Process (cont.)

4. **Join Mold and Xtal fixture**
   - Assemble fixture (which now contains crystal) to mold assembly
   - Preload crystal to mask/diode surface to create a tight seal

5. **Apply Adhesive**
   - Prepare adhesive mixture and de-gas
   - Slowly pour mixed/degassed adhesive into syringe
   - Inject adhesive into mold inlet hole until the bond cavity is filled
     - NOTE: process does not require fixed, known volume of bond cavity. Non-flat diode surface is acceptable.

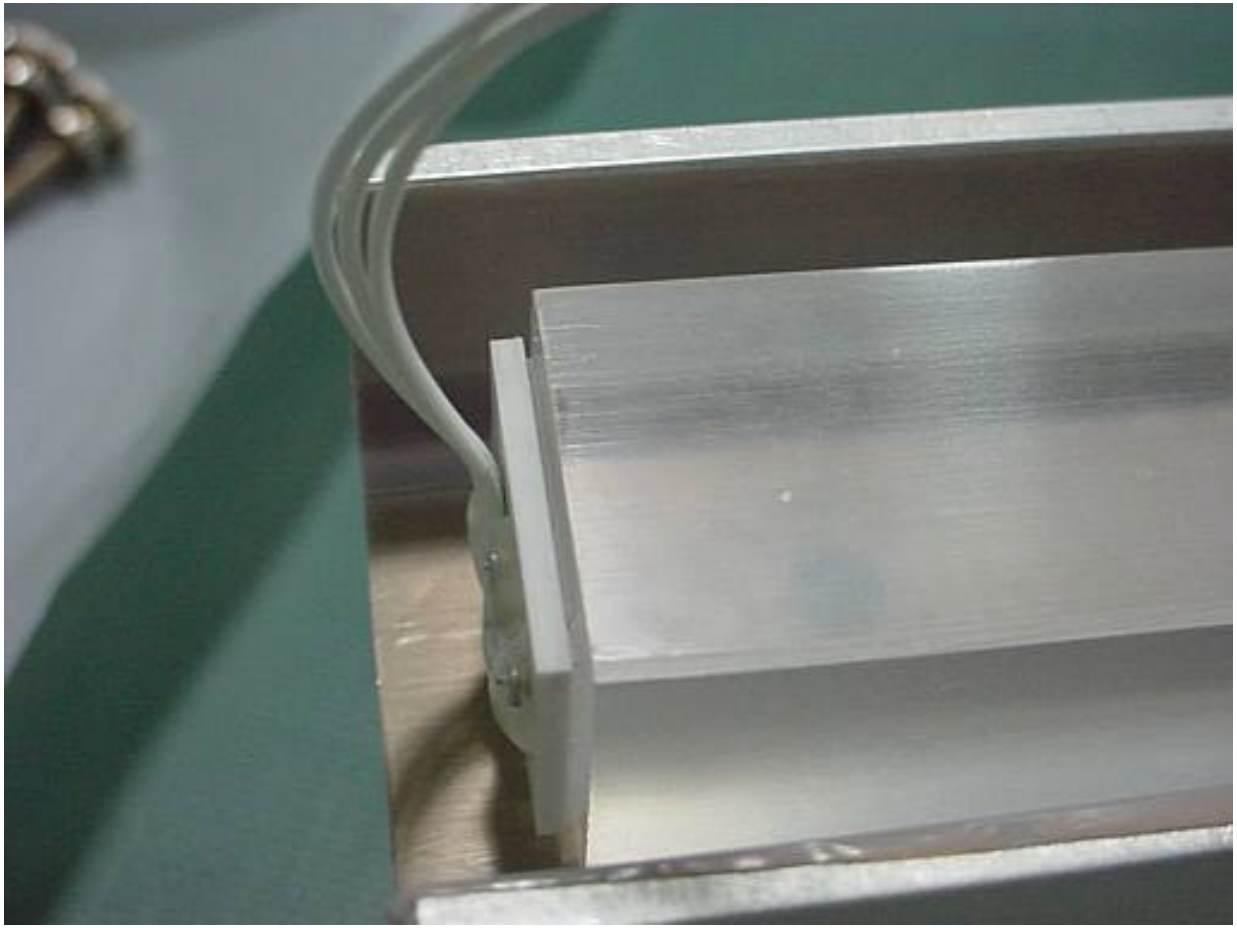
6. **After Injection**
   - Wipe clean adhesive from areas around inlet and outlet hole
   - Cure for 24 hours until tack free
   - Remove bonded crystal & diode from mold after 24 hours
   - Allow bond to finish 7-day cure

Hanging and Priming the Xtal



Injecting into the Mold

Completed Bond



Thermal Cycling

- **Bonds need to be mechanically strong and maintain optical properties**
  - **To survive handling loads**
  - **To survive thermal cycling in test, shipping, and storage**

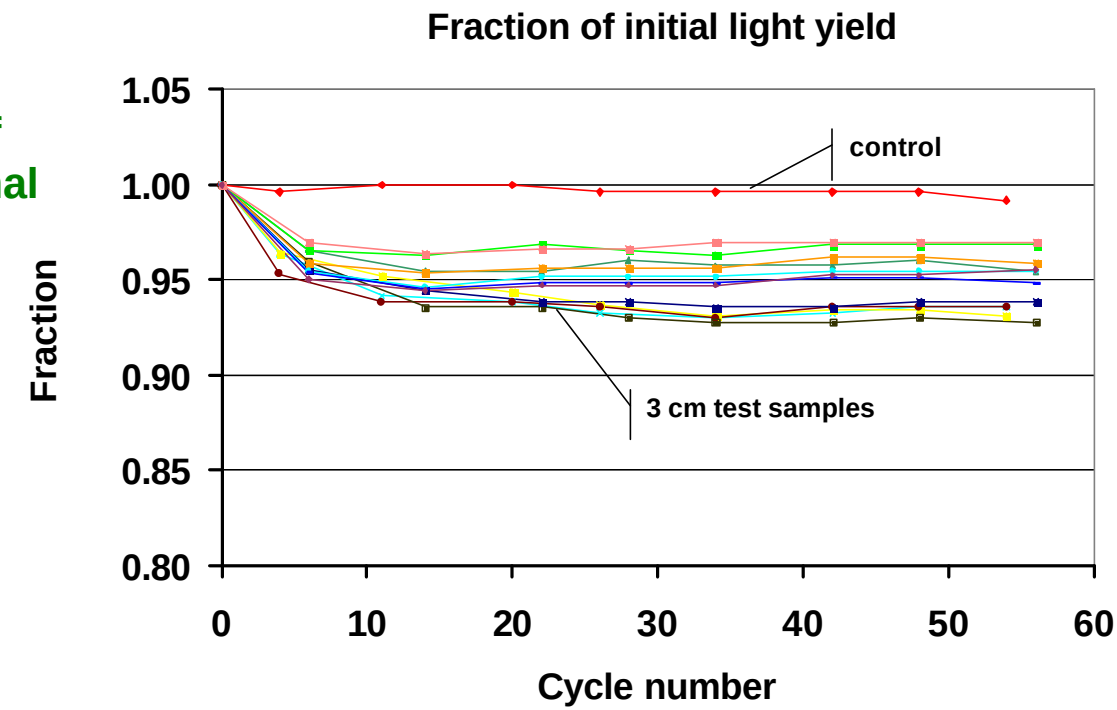
- **How do we know a bond has survived?**
  - **A bond can be mechanically strong and show no visual evidence of separation, at the same time that it has optically failed!**
  - **Bond process qualification plan *must* include readout of scintillation light.**
    - **Visual inspection is inadequate and unacceptable as proof of bond quality.**

- **Thermal cycling**
  - **Full qualification range: –30C to +50C**
  - **Gradient: 20C per hour (if much steeper, xtals can't keep up)**
  - **Soak: 1 hour at –30C, 1 hour at +50C**
  - **Irradiate xtal sample with ^{137}Cs, monitor 662 keV centroid after series of thermal cycles**

Thermal Cycling

- Optical performance of test samples under thermal cycling
  - Test samples are 3 x 3 x 3 cm cubes with single EM photodiode
  - Test samples typically decline ~5% from their initial light yields and reach plateau
  - Expect this to translate to ~10% decline in CDEs

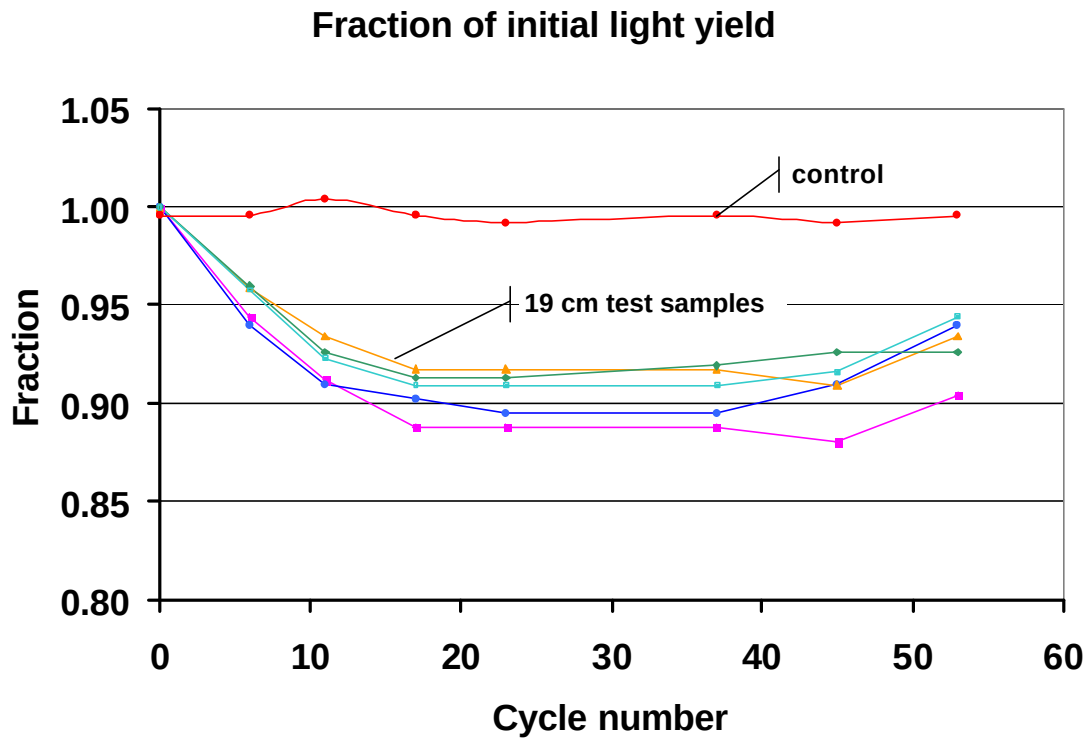
- Optical properties of bonds survive thermal cycling
- Bonding process creates thermally stable bonds



Thermal Cycling

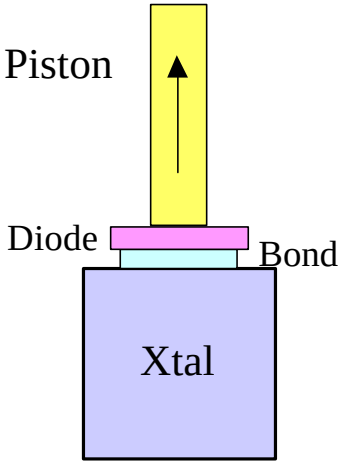
- **Optical performance of longer xtal samples**
  - **Longer xtals samples are 3 x 3 x 19 cm with EM diodes on both ends**
  - **Typically decline ~10% from initial light yield**
  - **Expect same performance from CDEs**

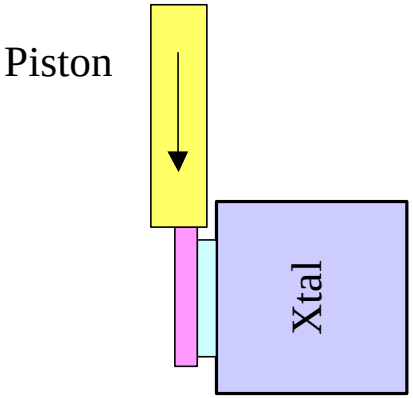
- **Again, bonding process creates thermally stable bonds**
- **Adhesion problem is solved**



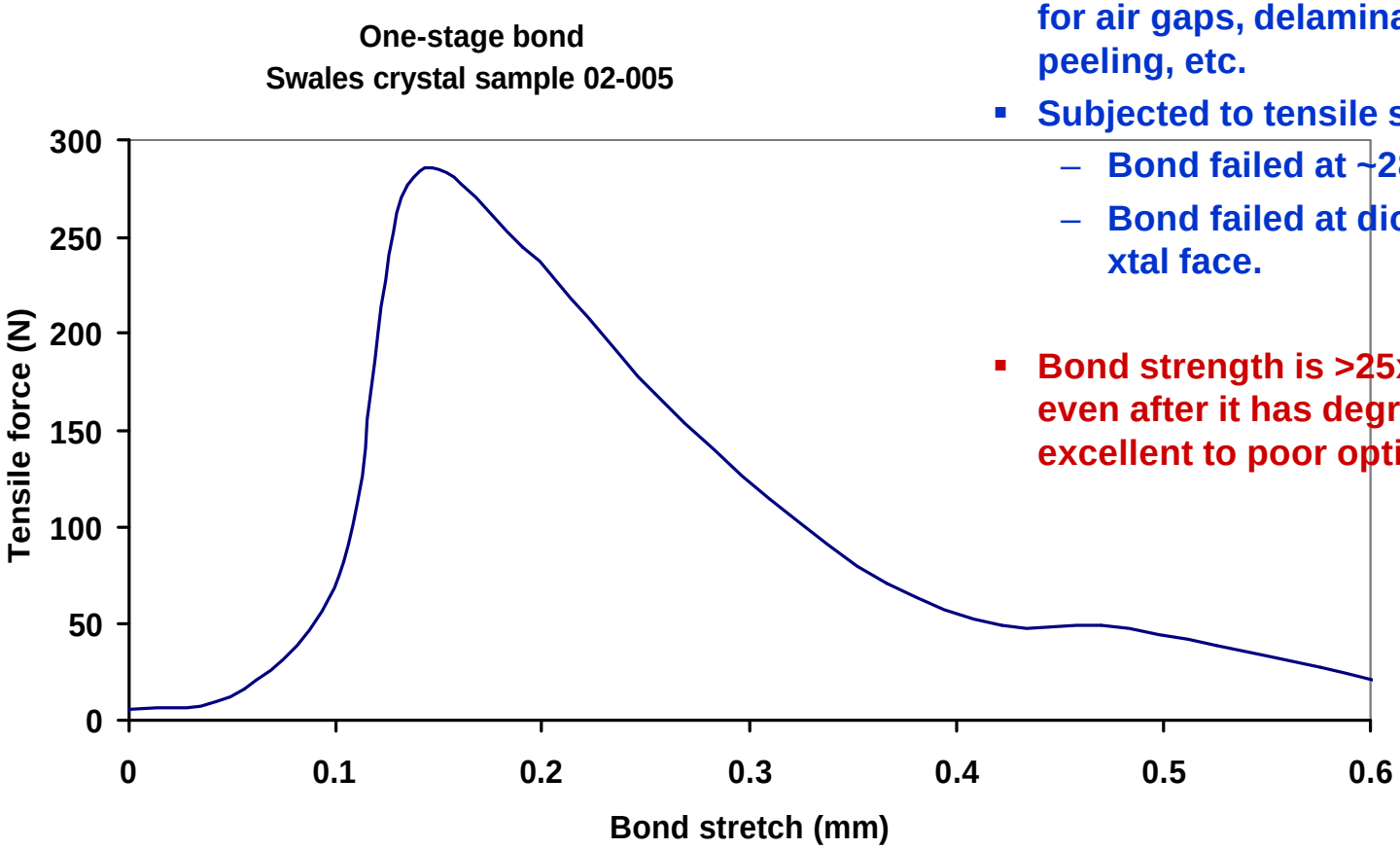
Mechanical Strength Tests

- Two types of destructive tests have been performed at NRL
  - Tensile strength
    - CETIM requirement: 10 N (2.2 lbf)
  - Shear strength
    - CETIM requirement: 0.12 N/mm^2 (8 lbf = 35 N for EM diode)
  - >35 samples tested
- Samples are pulled or sheared to failure in Dynamic Load Test Stand





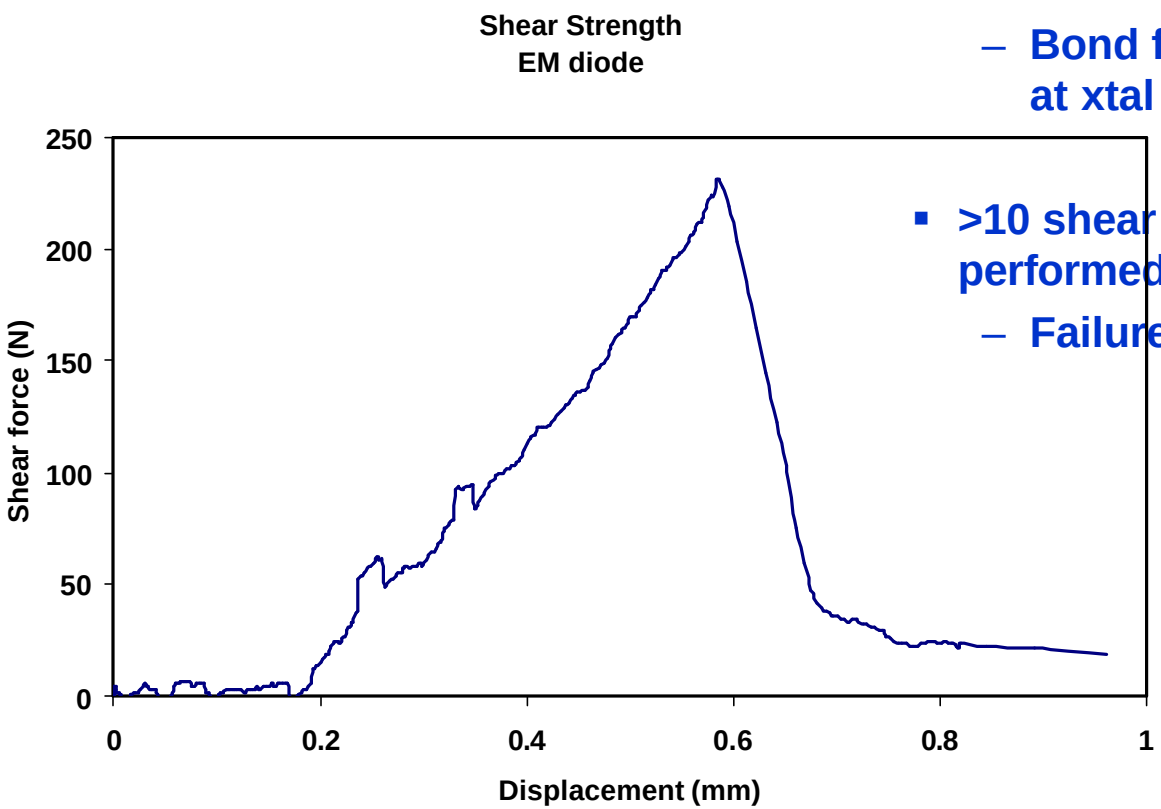
Tensile Strength Test



- Swales one-stage bond
  - After optical failure in thermal cycling
  - Visual inspection showed no evidence for air gaps, delamination, separation, peeling, etc.
  - Subjected to tensile strength test
    - Bond failed at ~280 N.
    - Bond failed at diode face, not at xtal face.
  - Bond strength is >25x requirement, even after it has degraded from excellent to poor optical contact.

Shear Strength Test

- Swales one-stage bond
  - Subjected to shear strength test
    - Bond failed at ~240 N.
    - Bond failed at diode face, not at xtal face.



  - >10 shear tests have been performed
    - Failure occurs typ. at >300 N

Crystal Wrapping (LAT-PS-00795)

- **VM2000 specular film**
  - Gives 20-30% more light than standard diffusive white wraps (e.g. Tyvek, Tetratex)
  - Stable, rigid material will not wet xtal surface as Teflon-based wraps can (e.g. Tetratex)
  - Non-metallic, so no grounding issues
  - Rigid, so awkward to wrap
    - Tried rolling, folding, spiral winding…
    - All created loose, awkward wraps
- **Solution: Hot molding**
  - Method
    - Form VM2000 around aluminum mandrel in xtal form (with chamfers)
    - Heat at 120 C for 2 hrs
  - Material takes and holds sharp corners of mandrel
  - Trivial to wrap around xtal, simple Kapton tape tacking
  - No loss in light yield or mechanical stability from hot molding

Wrapping Studies & Conclusions

- **VM2000 Max. Molding Temperature as Specified by 3M is 125ºC for 5 hrs.**
  - **At this temperature or any other temperature below, material properties (mechanical, physical and optical) are NOT compromised as long as material is mechanically supported.**

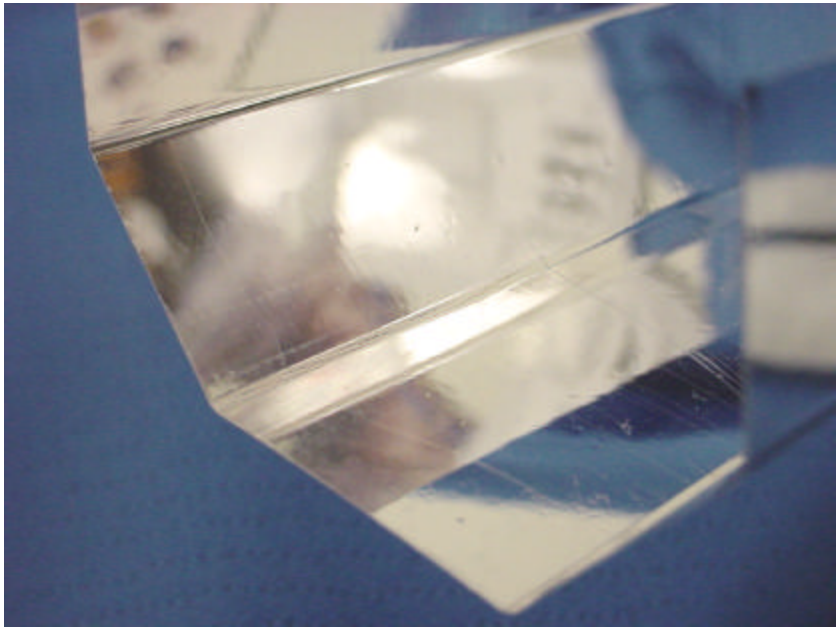
- **Temperatures Studied For VM2000 Molding**
  - **50ºC, 75ºC, 100ºC, 120ºC, 150ºC**

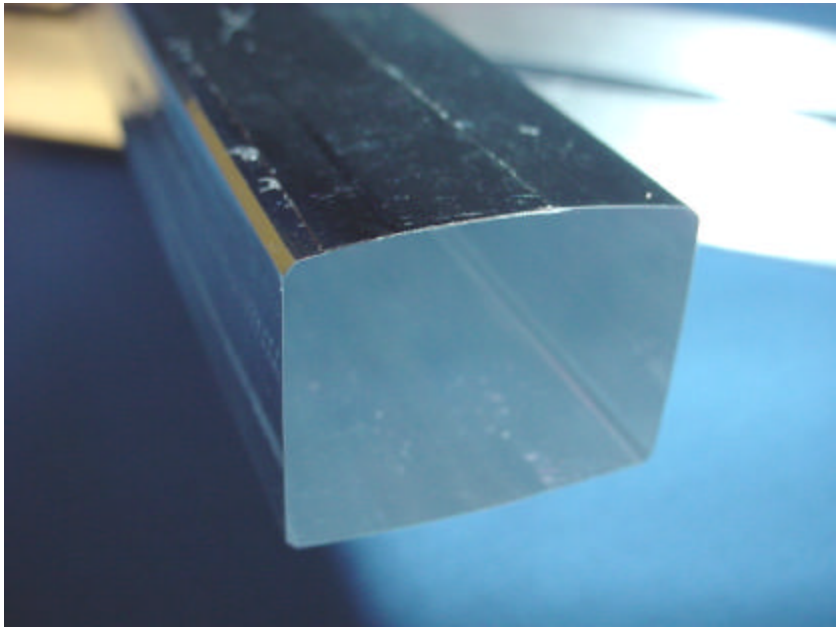
- **Duration of Time for Molding Process at all Temperatures**
  - **1 hour, 2 hrs., 3 hrs.**

- **Conclusions:**
  - **the higher and the longer the temperature, the more defined the wrapping form**
  - **150ºC is too high for any duration of time tested**
  - **100ºC and 120ºC for 3 hours and 2 hours respectively is ideal**
  - **Molding VM2000 in oven allows wrap to be preformed days/weeks before actual wrapping process on real crystal has to be performed.**

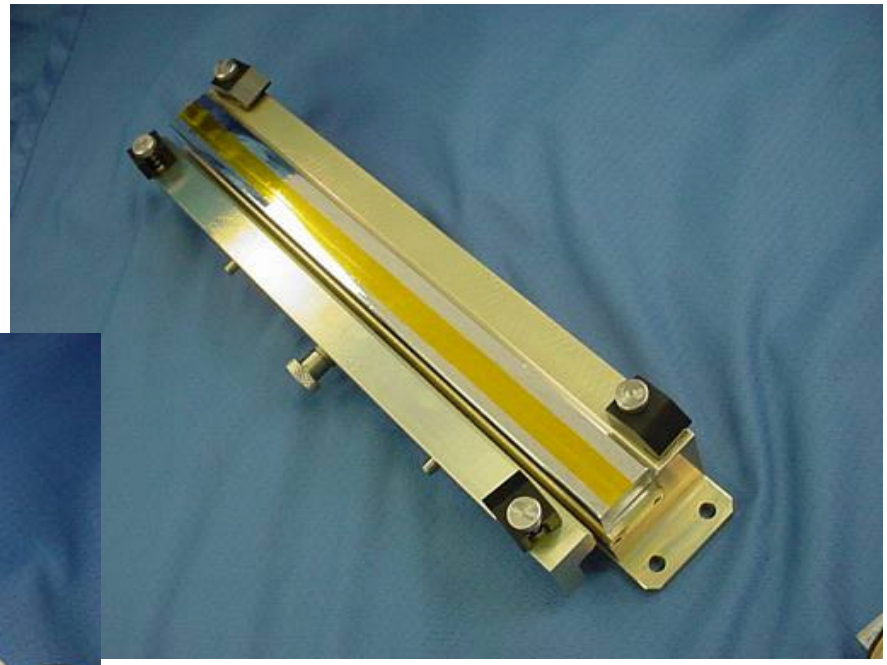
Wrapping Mold Set-Up

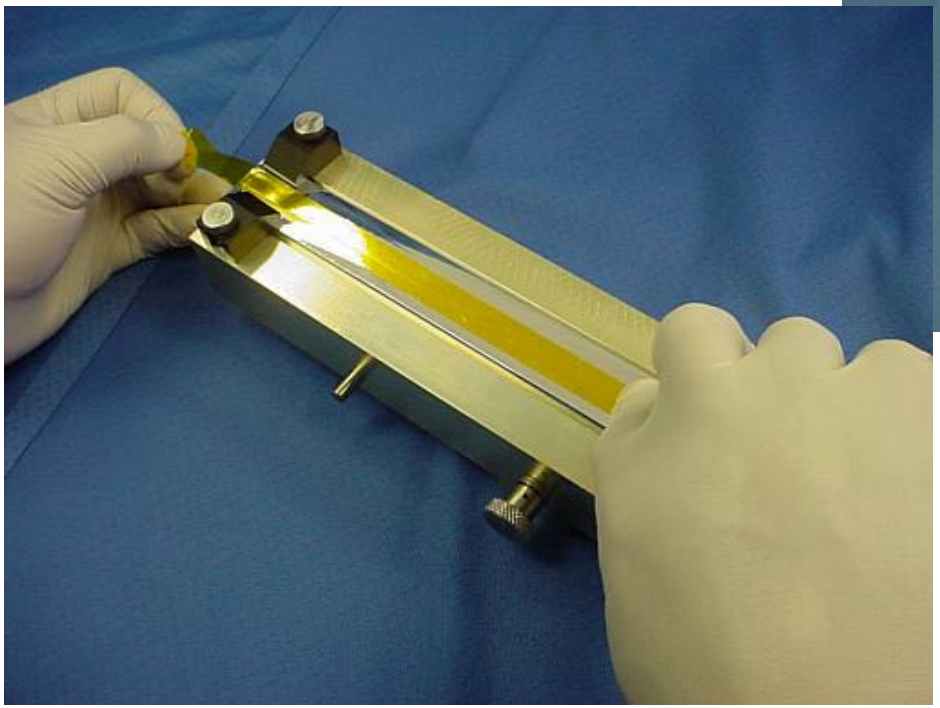
Wrap & Chamfer Close-Up





Completing the Wrapper





Repeat of Manufacturing Status

- **Engineering Model CDEs**
  - 55 completed (i.e. bonded and wrapped), in storage at Swales
  - 6 spares completed, in test at NRL
  - All 108 CDEs will be completed by mid November

- **Components of CDEs**
  - CsI(Tl) crystals
    - 94 xtals have been received at NRL
    - 24 xtals are in transit from Kalmar to NRL
  - Photodiode assemblies
    - ~190 PDAs have been completed (i.e. wires soldered and staked)
    - Minimum 218 diodes are needed for EM build
  - VM2000 wrappers
    - ~120 wrappers have been cut to size at Swales
    - ~90 wrappers have been heat-formed at Swales