Crystal Detector Element (CDE) Development Studies

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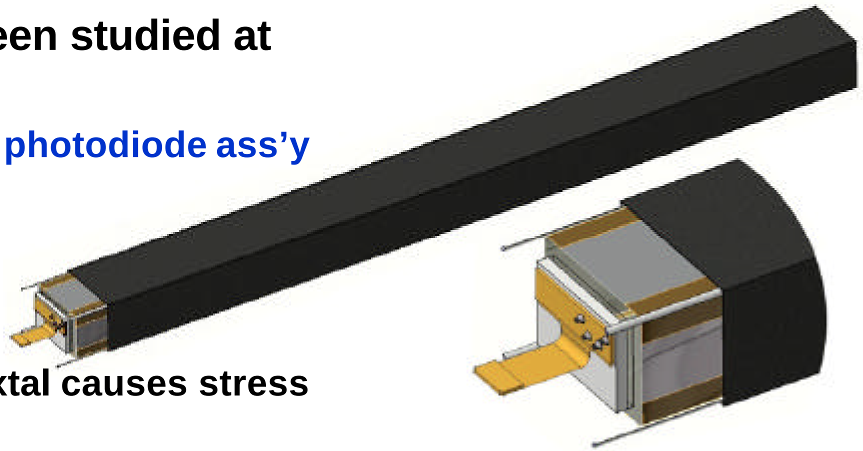
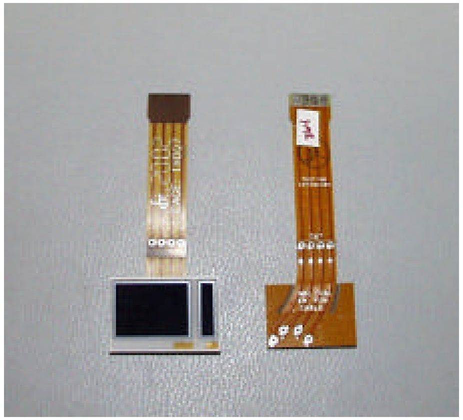
CDE Development

- Fabrication processes for CDE have been studied at NRL and selected for EM fabrication.
  - CDE = wrapped CsI Crystal bonded with photodiode ass'y (PDA) at each end.
  - Processes defined since PDR
    - Bonding of PDA to CsI xtal
      - CTE mismatch between PDA and xtal causes stress in bond
        - » Hard epoxies fail, silicones (without primer) don't adhere
      - Need soft, flexible bond with strong adhesion
      - Solution: Silicone elastomer with primer. Bond laid up in mold that defines geometry.
    - Wrapping of xtal
      - Material is 3M VM2000 non-metallic, specular, reflective film
        - » High light yield, good optical properties
        - » Material is stiff, difficult to fold or wrap
      - Solution: Mold in mandrel at 120C for 2 hrs at final shape





Dual PIN photodiode with flex cable = photodiode assembly

Scope of Bonding Studies

- **Assumptions**
  - **The bond shall be made with DC93-500 silicone encapsulant, with DC92-023 primer applied to all bonding surfaces.**
  - **The bond thickness shall be 0.7 ± 0.1 mm.**
  - **The bond material shall not extend past the edges of the diode, lest it interfere with the bumper.**
  - **The crystal surface shall be roughened to improve adhesion.**
- **Parameters studied**
  - **Method of bond lay-up**
    - **Selected one-stage mold with mask to define bond geometry**
    - **Encapsulant is injected into bounded volume**
  - **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**

Bonding Methods Studied

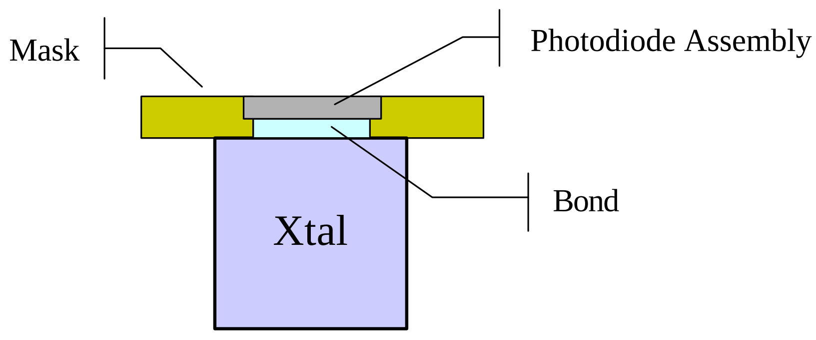
- Four bonding methods studied at NRL and Swales
  - "Spacer" method (at NRL).
    - Deliver measured amount of 93-500 between diode and xtal held fixed distance apart.
    - OK, but susceptible to measurement errors. Rejected.
  - "Two-stage" method (at NRL).
    - Create pad of 93-500 on diode face, cure for one day, wet surface of 93-500 and apply to xtal.
    - OK, but susceptible to incomplete curing. Rejected.
  - "Two-stage" method (at Swales).
    - Similar to NRL version, but uses more 93-500 in 2nd stage and more precise volume.
    - OK, but complex. Rejected.
  - "One-stage" method (at Swales).
    - Form bond within break-apart Teflon mold holding diode and xtal.
    - Makes very strong and precise bonds. Selected.

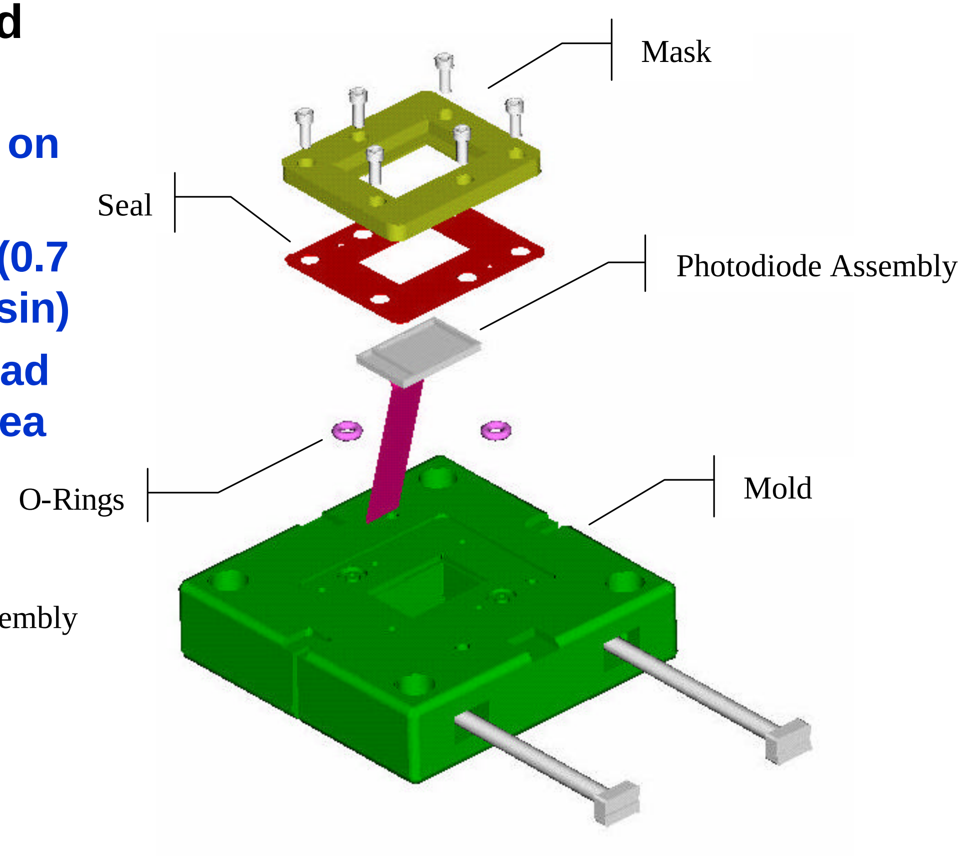
Bonding Method Selected

- 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-00385-01

Bonding fixtures

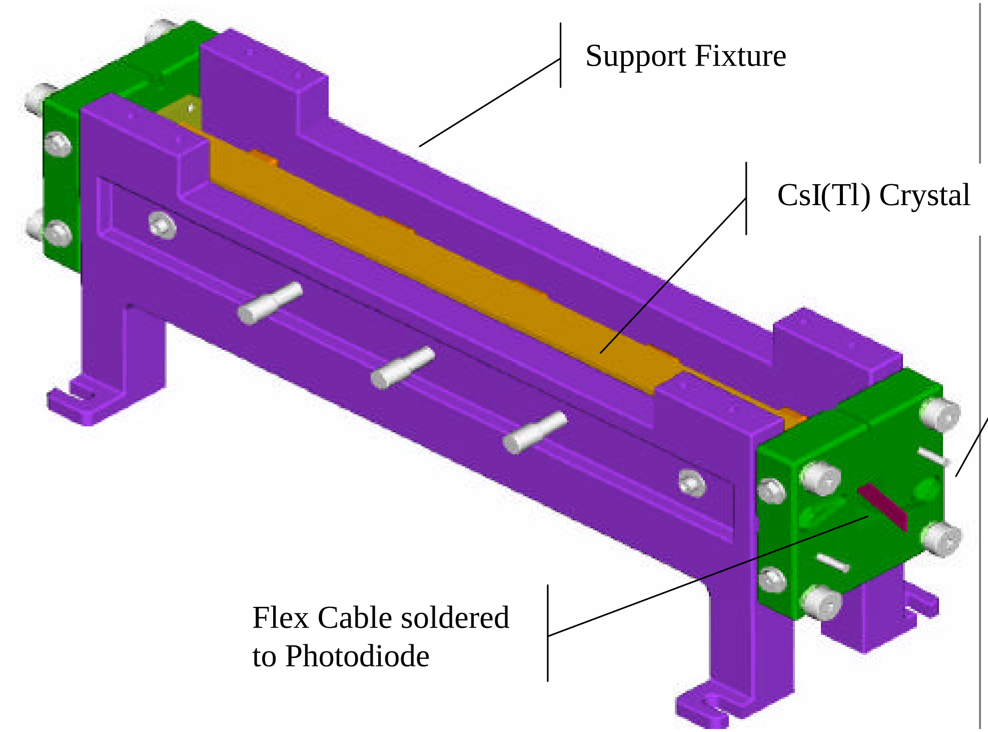
- **Exploded view of PDA and Mold subassembly**
  - **Mold: defines location of bond on xtal (referenced to xtal corner)**
  - **Mask: defines bond thickness (0.7 mm) and area (covers epoxy resin)**
  - **Seal and O-rings: prevent spread of encapsulant outside bond area**





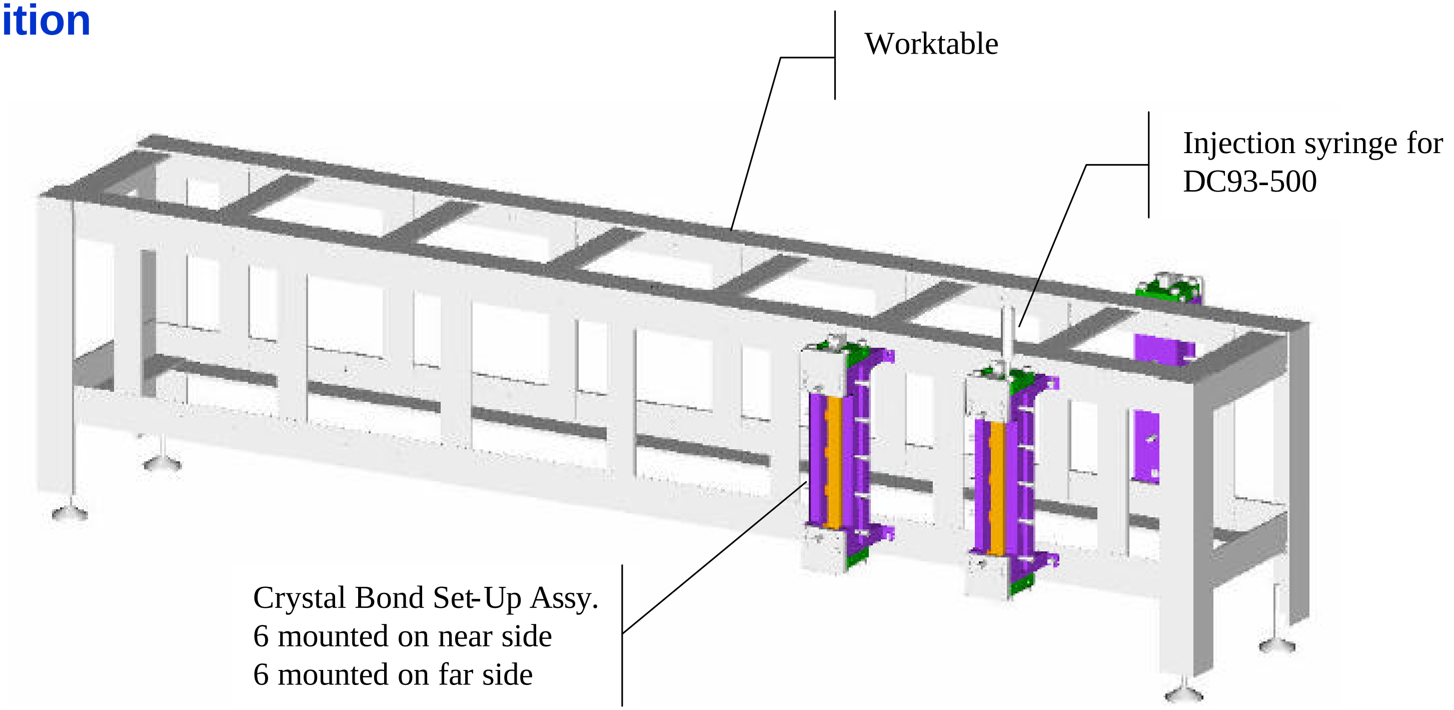
Bonding fixtures

- **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 each side**
  - **Encapsulant is injected with CDE in vertical position**



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

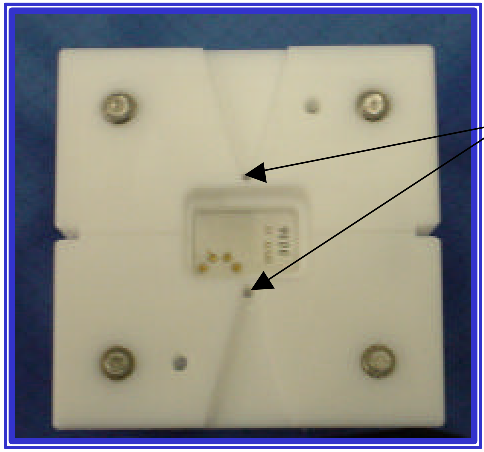


Figure 1: Diode in Mold, Top Side of Mold

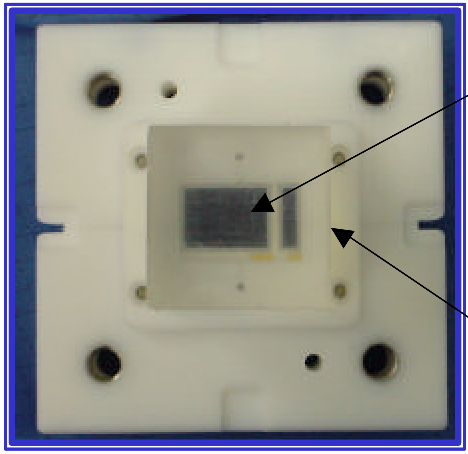


Figure 2: Diode & Mask in Mold, Back Side of Mold

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

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

Mechanical Test Sample Bonds

(All Bonds Displayed No Bubbles & Desired Bond Profile (Area & Thickness; Bond Maintained in Ceramic Frame)

Figure 13: EM Diode on Xtal, Side View

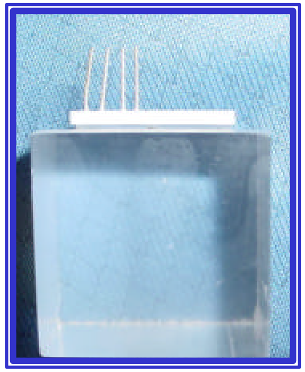


Figure 14: EM Diode on Xtal, Front View

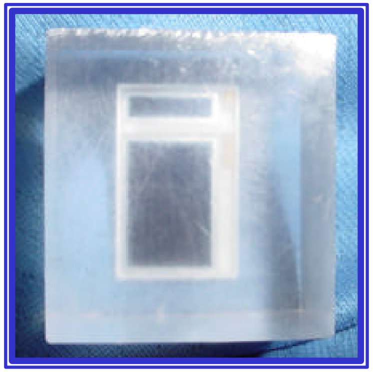


Figure 15: EM Diode on Xtal, Back View

Figure 16: EM Diode on Xtal, Side View

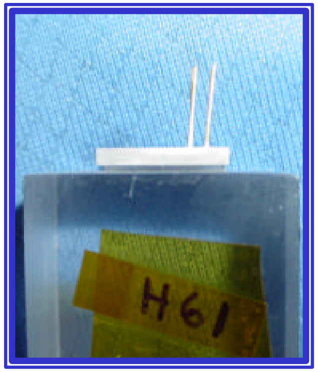


Figure 16: EM Diode on Xtal, Side View

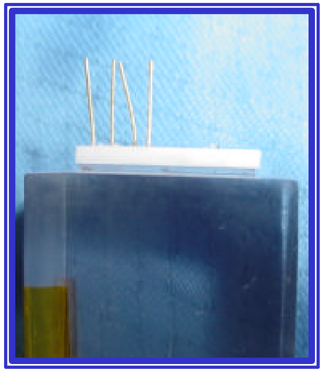


Figure 17: EM Diode on Xtal, Front View

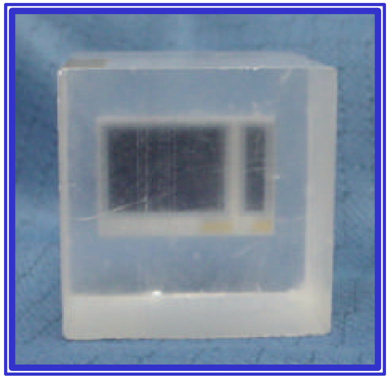


Figure 18: EM Diode on Xtal, Back View

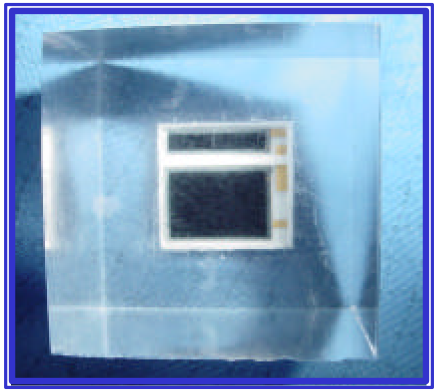


Figure 19: EM Diode on Plexiglas, Back View

Light Yield

- Light yield tests were performed on sample xtals 3 x 3 x 19 cm
  - Requirement on CDE
    - >6000 e/MeV in large PIN photodiode
  - Tests were performed on sample xtals
    - Xtal size = 3 x 3 x 19 cm
    - EM photodiode
    - Tetratex wrap
  - Samples exposed to radioactive source with known line energy
  - Measured yield (after 50 thermal cycles)
    - 6200 – 7000 e/MeV
  - Expect yield of >7500 e/MeV for EM dimensions with VM2000 wrap

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**

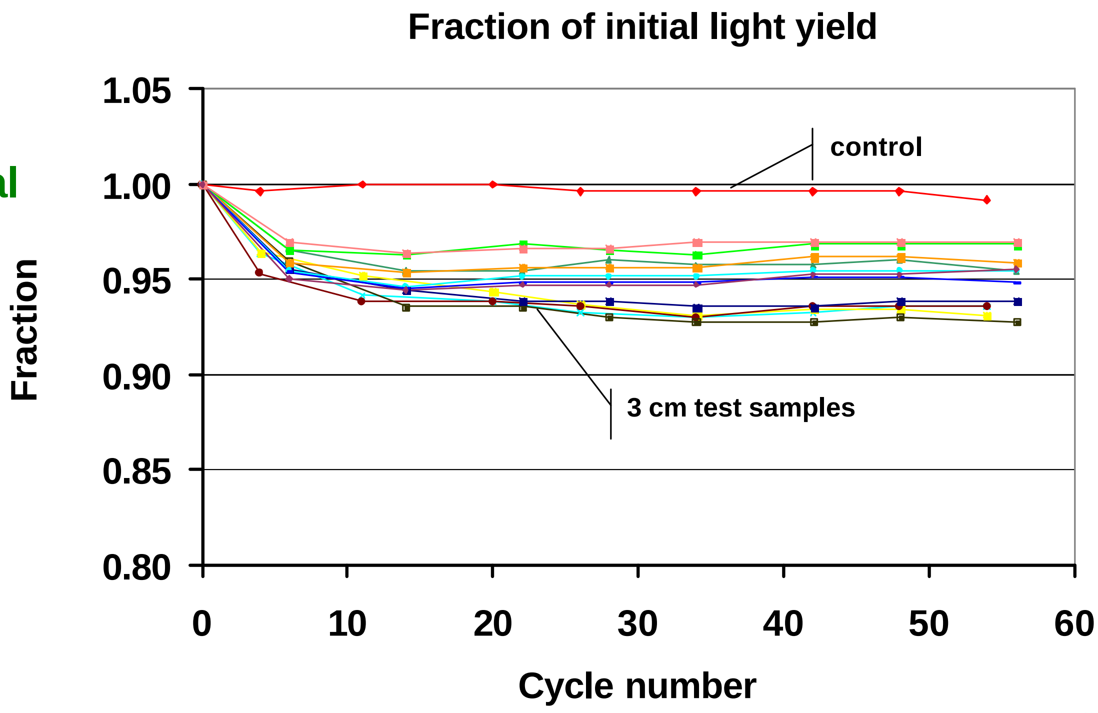
- **How do we know a bond has survived?**
  - **A bond can be mechanically strong and show no visual evidence of separation, at the same time that it has optically failed!**
  - **Bond process qualification plan *must* include readout of scintillation light.**
    - **Visual inspection is inadequate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

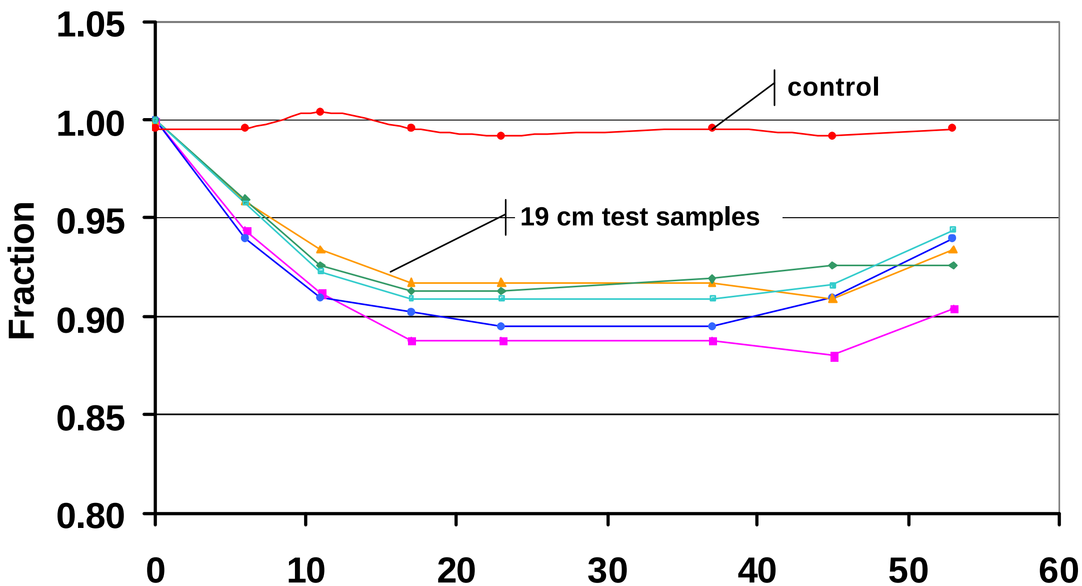


Thermal Cycling

- **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**

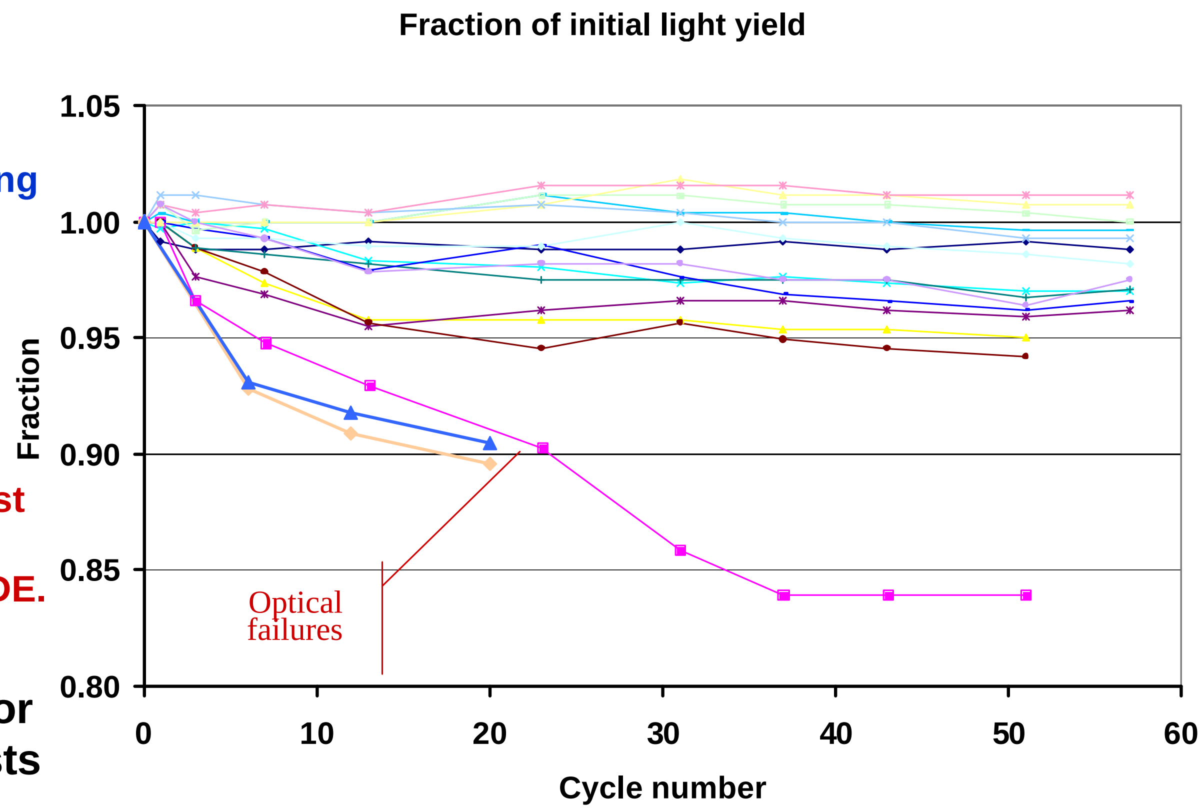
- **Again, bonding process creates thermally stable bonds**
- **Adhesion problem is solved**

Fraction of initial light yield



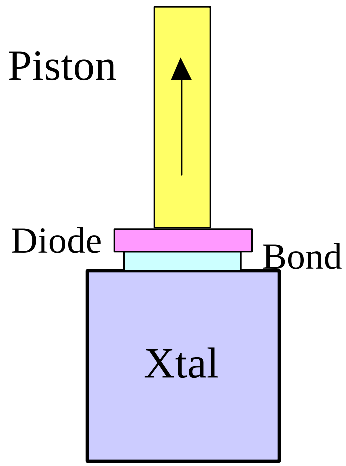
Early Thermal Cycling Tests

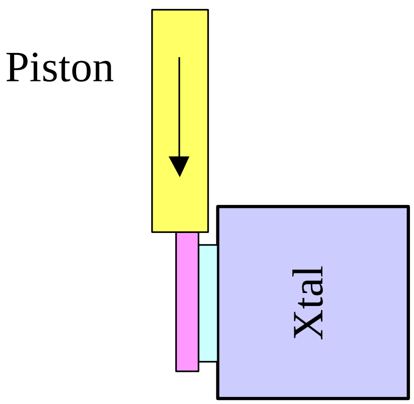
- **Prior to creation of stable bonding process**
- **16 sample bonds**
  - **Created with several methods early in bonding study**
  - **13 survive cycling**
  - **3 have optical failure**
- **Optical failures**
  - **~15% degradation in test sample is equivalent to ~50% degradation in CDE.**
- **We extracted samples for mechanical strength tests *after* optical failure…**



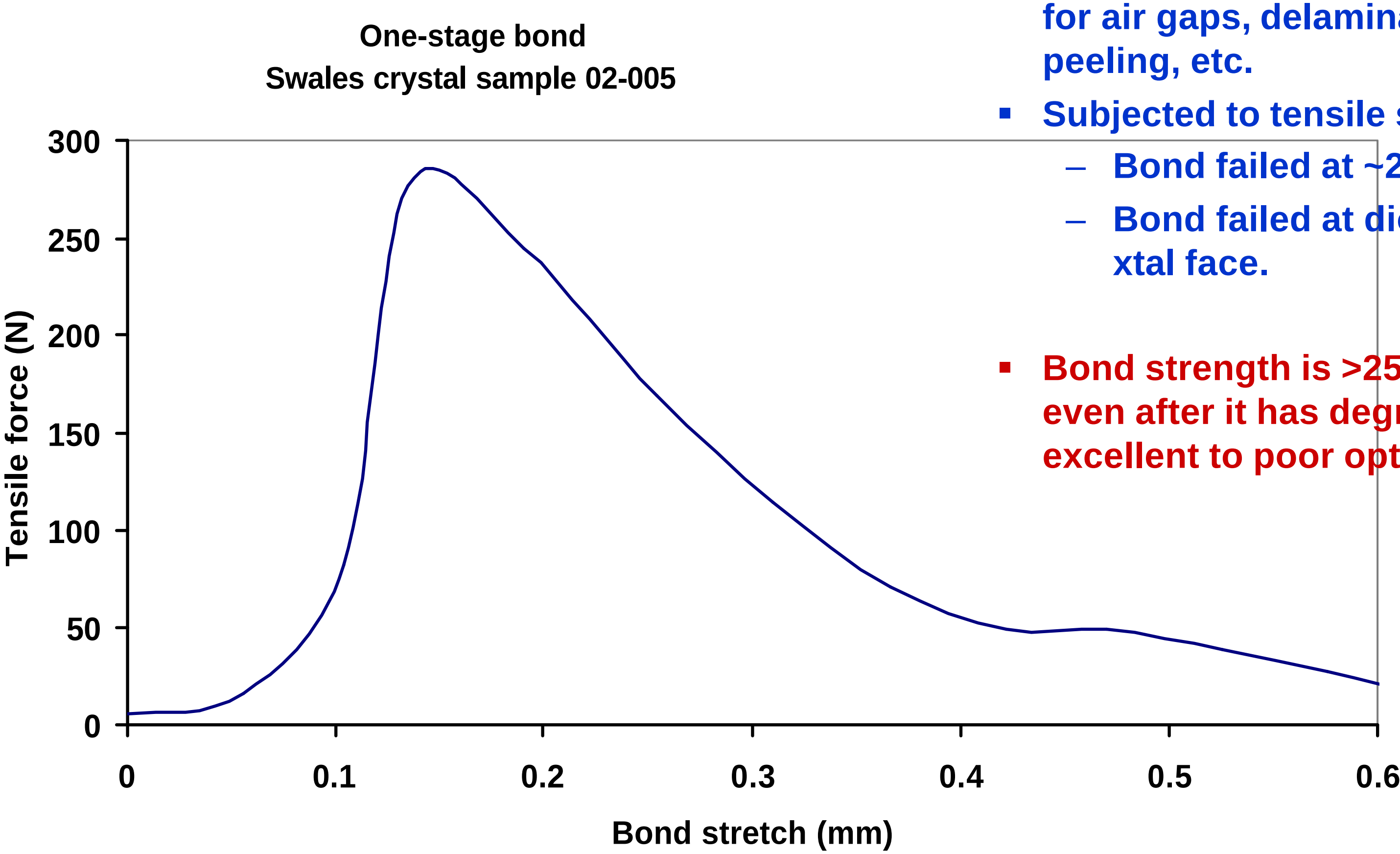
Mechanical Strength Tests

- 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



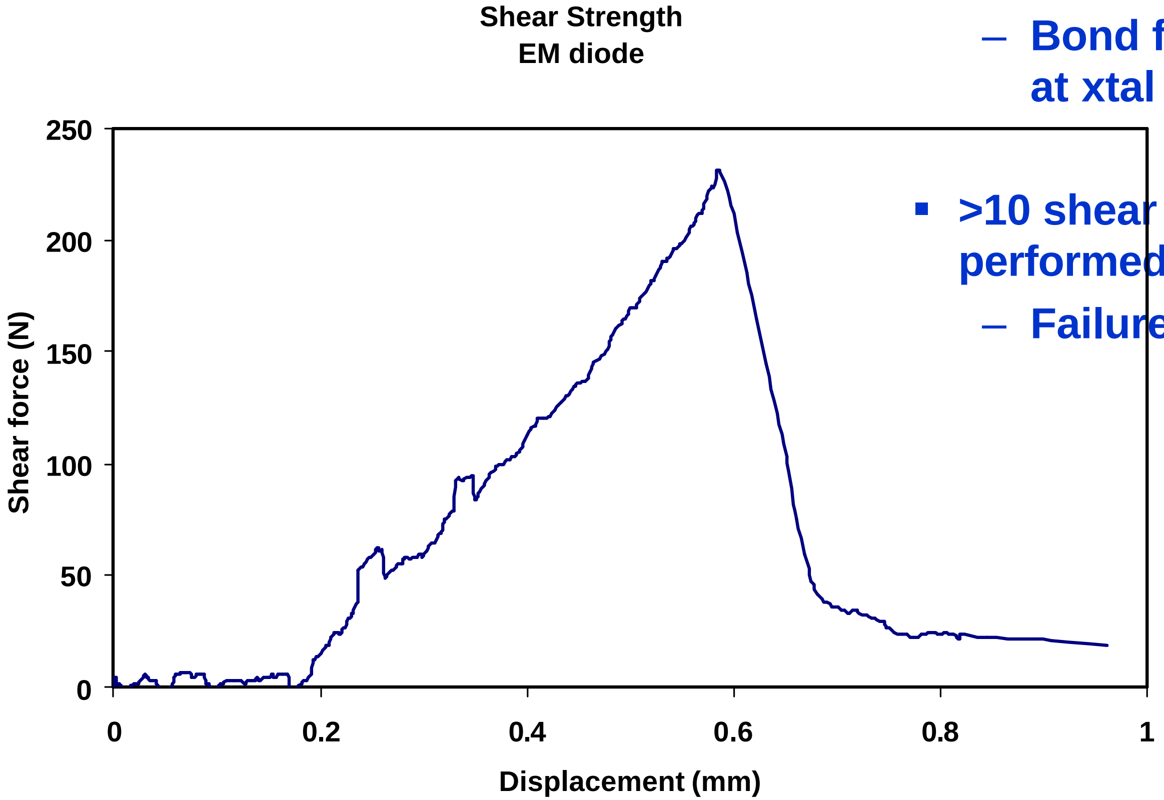


Tensile Strength Test



- **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-00795-01)

- **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