



**INEMI**

International Electronics Manufacturing Initiative

Accumulation of  
Particles Near the  
Core during  
Repetitive Fiber  
Connector Matings  
and De-matings

◆  
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Advancing manufacturing technology

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# Presentation Outline

- **Introduction**
- **Experimental Methodology**
- **Experimental Data and Analysis**
  - **Image Analysis**
  - **Electrostatic Charge Accumulation Test**
- **Evolution of Particle Center Position**
- **Conclusions**

# Introduction

- **Continuing iNEMI research on development of a cleanliness specification for single mode connectors.**
- **Quantitative experiments evaluated contamination impact on performance of 1.25 & 2.5 mm ferrules.**
- **Research supported development of IPC-8497-1 “Cleaning Methods and Contamination Assessment of Optical Assembly” standard.**
- **In 60 % of LC and MU connectors examined, five mating cycles increased IL 0.5 to 1.1 dB due to particle movement from the ferrule and cladding areas towards the core, which suggests a risk of signal performance degradation during the service life.**
- **Based on our research, the cleaning process using a standard cleaning cassette may result in an electrostatic charge of the connector end face**



# Objectives

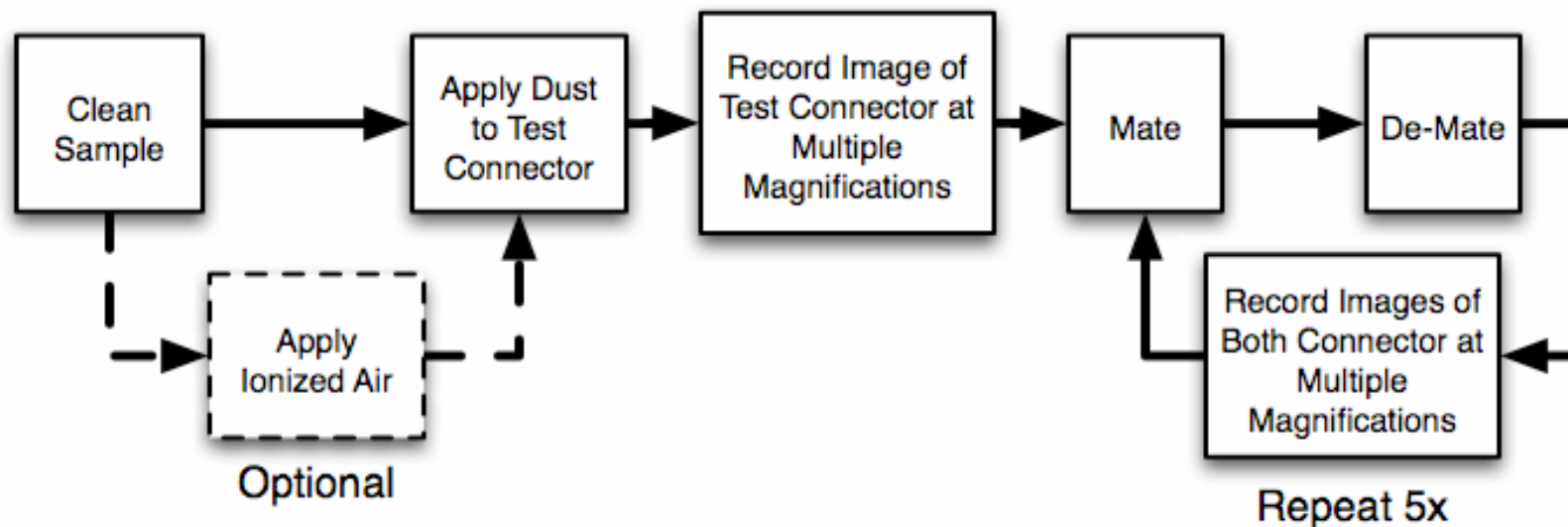
- **Investigate the mechanism of particle accumulation near the core during a series of repeated mating cycles.**
- **Develop potential solutions to prevent this phenomenon.**
- **Perform a series of experiments to determine aggregate dust location.**

# Design of the Experiment

- **Two types of connector end face polishing conditions and one with a non-standard polishing treatment.**
  - SC connector with a standard polishing treatment
  - SC connector with a non-standard polishing treatment
    - An extensive polishing process, creating an extremely smooth fiber/ferrule surface.
- **Two grades of Arizona Dust particles:**
  - 1-5 um and 6-25 um
- **Different types of cleaning process:**
  - Dry cleaning
  - Cleaning solvent

# Experimental Block Diagram

Experimental process followed to investigate any potential correlation between the amount of charge generated during the cleaning process and particle re-distribution after the dust was applied at clean connector end face.



# Cleaning and Measurement Methods

- **All DUTs and reference connectors cleaned**
  - **Cleaning cassettes (type 1 or type 2)**
  - **Fiber wipes with a cleaning solvent**
  - **Two cleaning fluids in the Hydrofluorocarbon (HFC) and Alcohol Blend families were evaluated.**
- **End-face inspected and images were saved**
- **Measured the number of particles, size, and locations and measured Occluded Area (OA)**

**FiberQA™-EFI software from PVI Systems**

- **A Faraday cup was used to measure the charge on a fiber tip (both standard SC and non-standard SC) after the cleaning process.**



# Test Conditions

## Test Conditions for Representative Samples

Exp	Test Connector	Reference Connector	Cleaning Method	Air Ionizer
1	Standard SC	Standard SC	Cleaning Cassette Type #1	No
2	Non-standard SC	Non-Standard SC	Cleaning Cassette Type #1	No
11	Standard SC	Standard SC	Cleaning Cassette Type #1	Yes
16	Standard SC	Standard SC	Cleaning fluid, Type #1 and fiber swipes	No
18	Standard SC	Standard SC	Cleaning fluid, Type #2 and cleaning cassette, Type #2	No



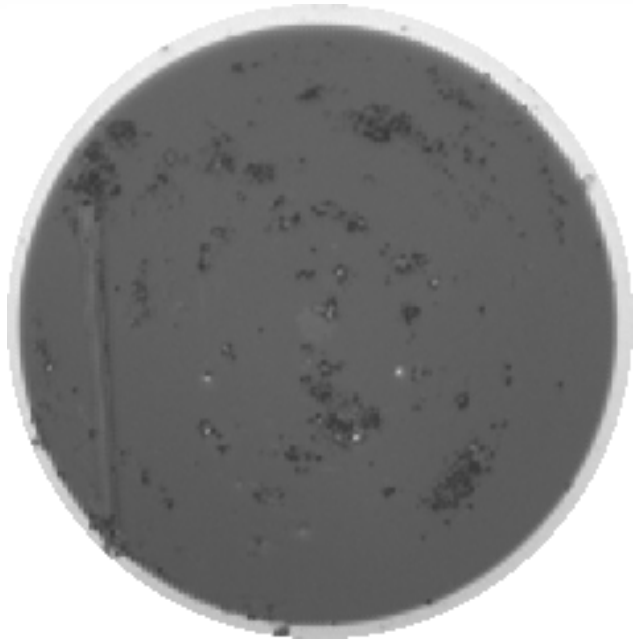
# Image Analysis

- Images from all the experiments were analyzed for particle contamination using FiberQA software from PVI Systems.
- The results included summary spreadsheets for measured occluded area for each connector, cropped raw images, and cropped particle overlay images.
- Occluded area computed using a fine set of annular rings (2.5  $\mu\text{m}$  spacing)
- FiberQA computes the occluded area for annular regions centered on the cladding with the occluded area defined as the total particle area for all particles within that annular region.

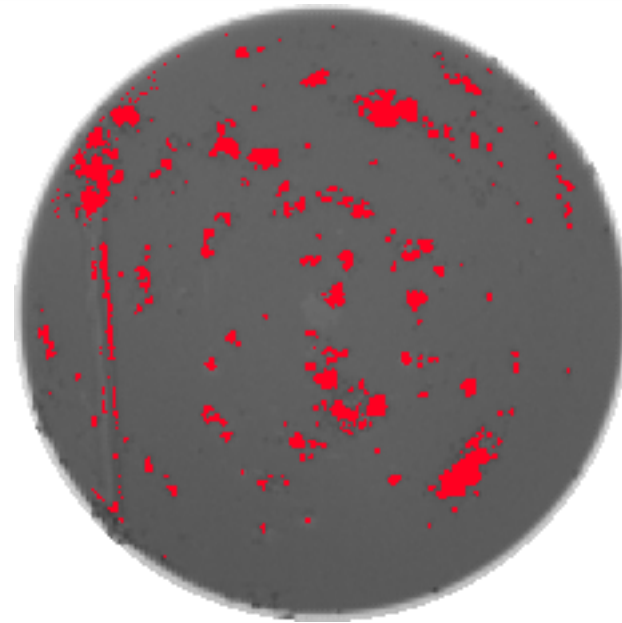
# Image Analysis

- For each connector mating, three magnifications of 400x, 200x, and 100x were used to acquire images of the end face of the connectors for analysis.
- The OA results from the individual magnifications were subsequently merged to form a composite OA result for each connector mating covering the range of 0-350  $\mu\text{m}$ , centered on the fiber cladding.
  - 0- 60  $\mu\text{m}$  range of the composite result was obtained from the 400x magnification results
  - 60-130  $\mu\text{m}$  range obtained from 200x magnification
  - 130-350  $\mu\text{m}$  range obtained from 100x magnification
  - Calculating the composite OA in this manner allowed us to obtain the highest resolution results over the widest possible radius.
- The composite occluded area results were used to calculate the Center of Particles ( $R_c$ ) for each group and each successive mating

# Particle Detection Overlays



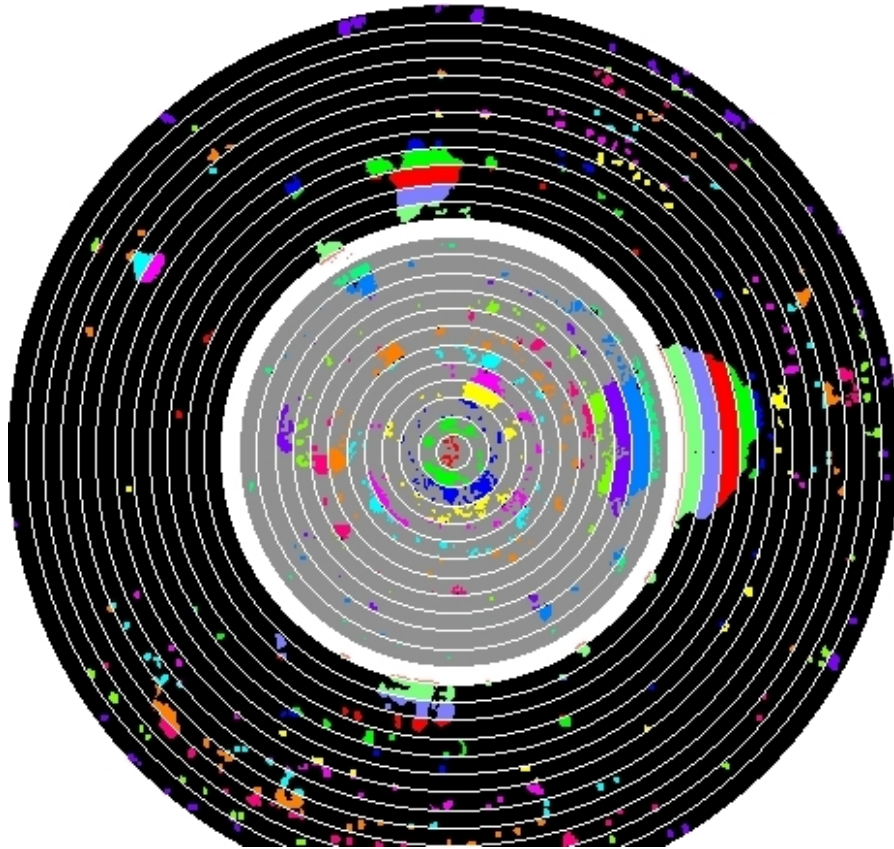
**Raw Cropped Image**



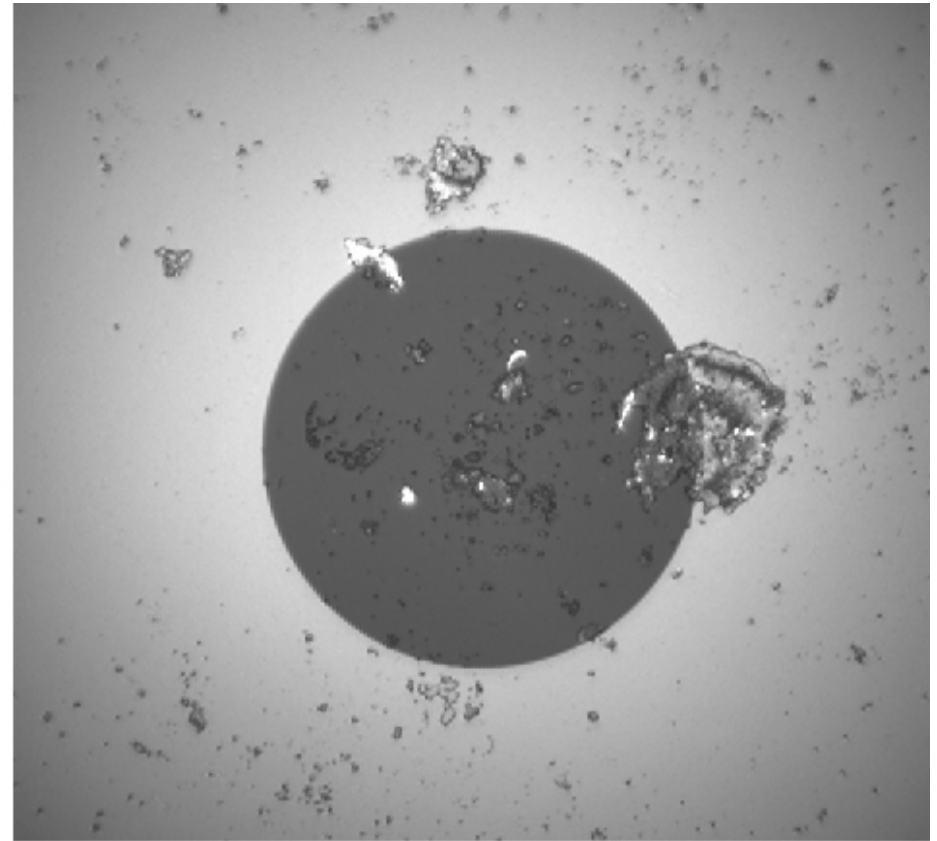
**Detected Particle Overlay**

- The raw image (left) was processed to detect and quantify the particles on the surface, shown in overlay (right).
- Scratch processing was disabled for purposes of this analysis.

# Occluded Area Overlay

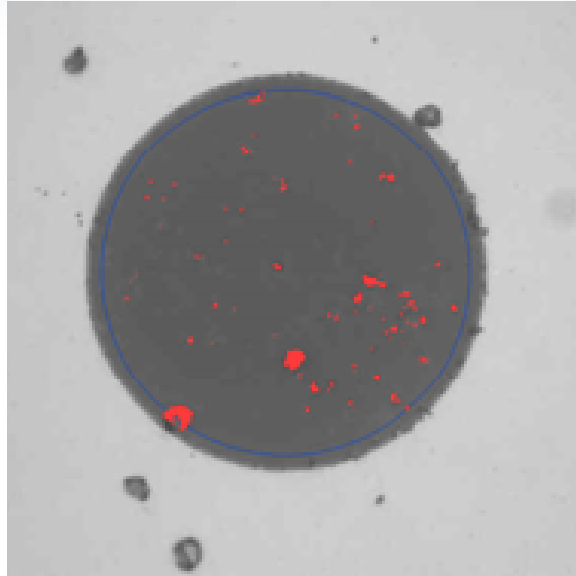


Labeled Detected Particles  
with 5  $\mu\text{m}$  annular rings.  
Black area is ferrule and grey is fiber.

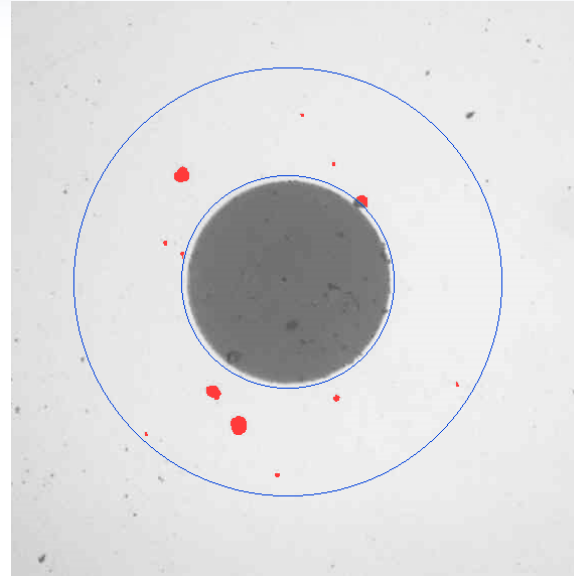


Raw image for LC07-WD-5M taken  
with Westover Microscope

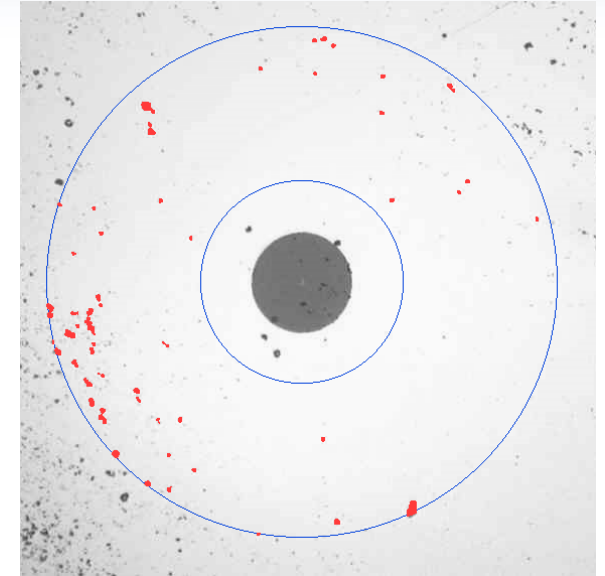
# Image Analysis



(a)



(b)



(c)

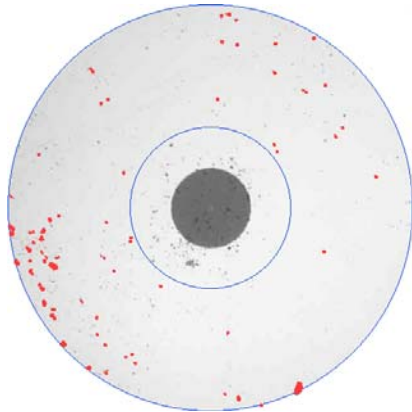
**Experiment 1, “Original A” with Particle Overlay after dust applied at 400x (a), 200x (b) and 100x magnification (c)**

**The 100x magnification image (c), was utilized to reveal quantities of dust particles at distances of about 350  $\mu\text{m}$  from the core center.**

# Exp #1 Standard SC Images

The connector end face was cleaned with the cleaning cassette, Type #1

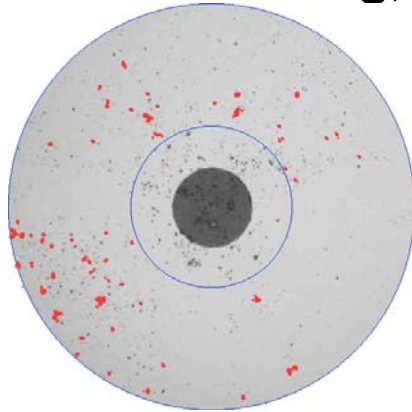
**A. DUT First Mating, 100x**



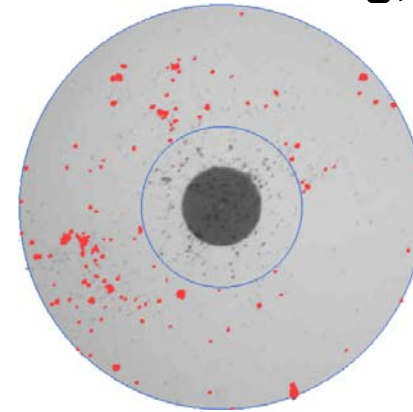
**B. Ref First Mating, 100x**



**C. DUT Fifth Mating, 100x**



**D. Ref Fifth Mating, 100x**



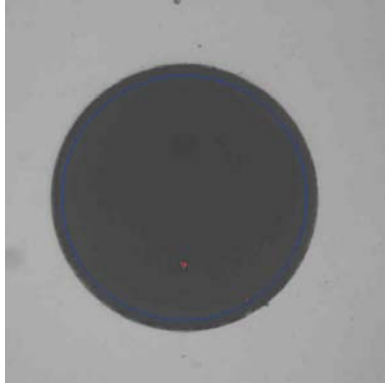
Magnification 100x

**iNEMI**

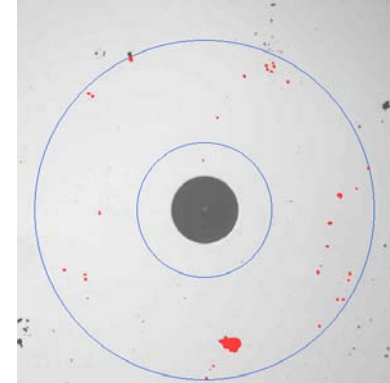
## Exp. #2 Non-Standard SC Images

The connector end face was cleaned with the cleaning cassette, Type #1

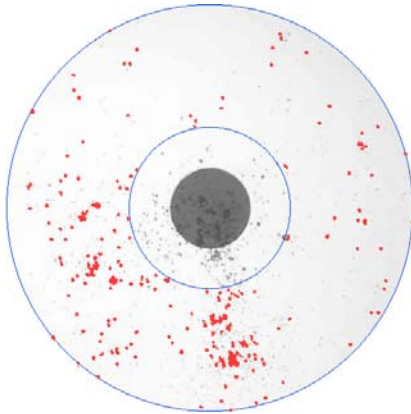
**A. Dust Applied, 400x**



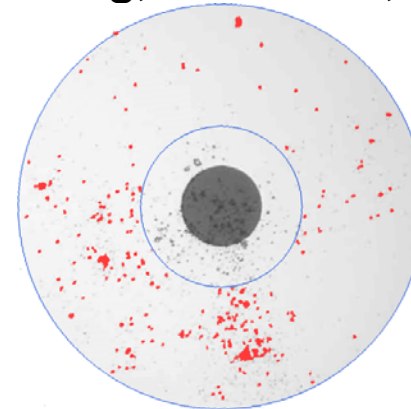
**B. Dust Applied, 100x**



**C. Fifth Mating, DUT, 100x**



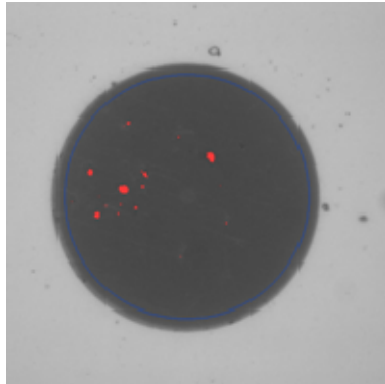
**D. Fifth Mating, Ref. Fiber, 100x**



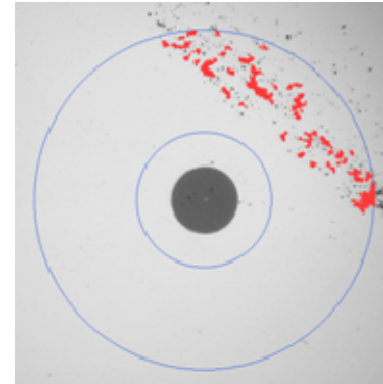
# Exp. #11 Standard SC Images

The connector end face has been exposed to ionized air before dust application

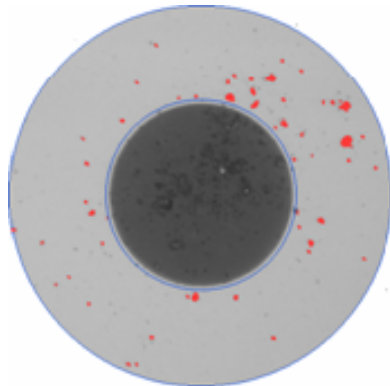
**A. Dust Applied, 400x**



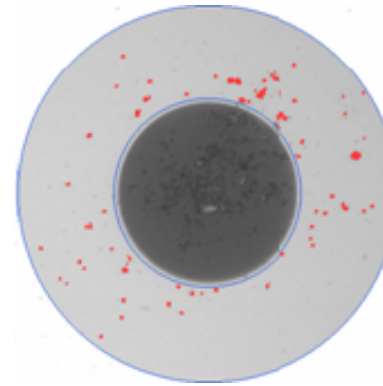
**B. Dust Applied, 100x**



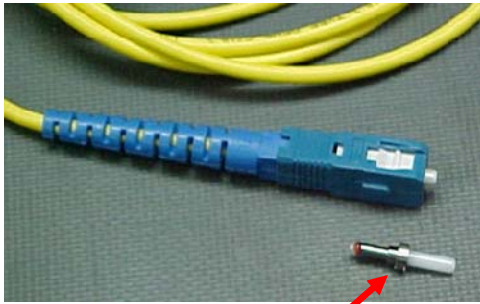
**C. Fifth Mating, DUT, 200x**



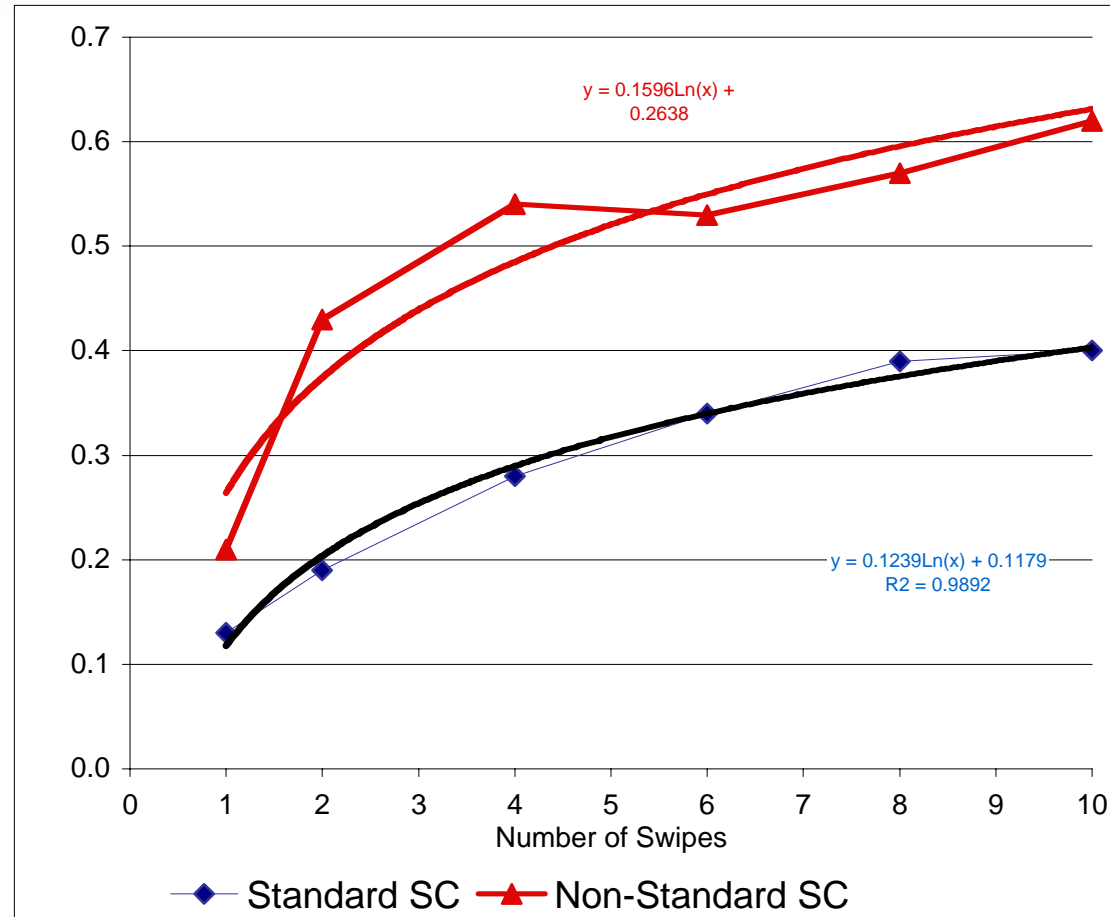
**D. Fifth Mating, Ref. Fiber, 200x**



# ESD effect



Sample preparation



**Electrostatic charges generated from cleaning process with cleaning cassette, Type 1 for standard and non-standard connector samples. Humidity is 28%, room temperature is 24C.**



## Particle Center Equation

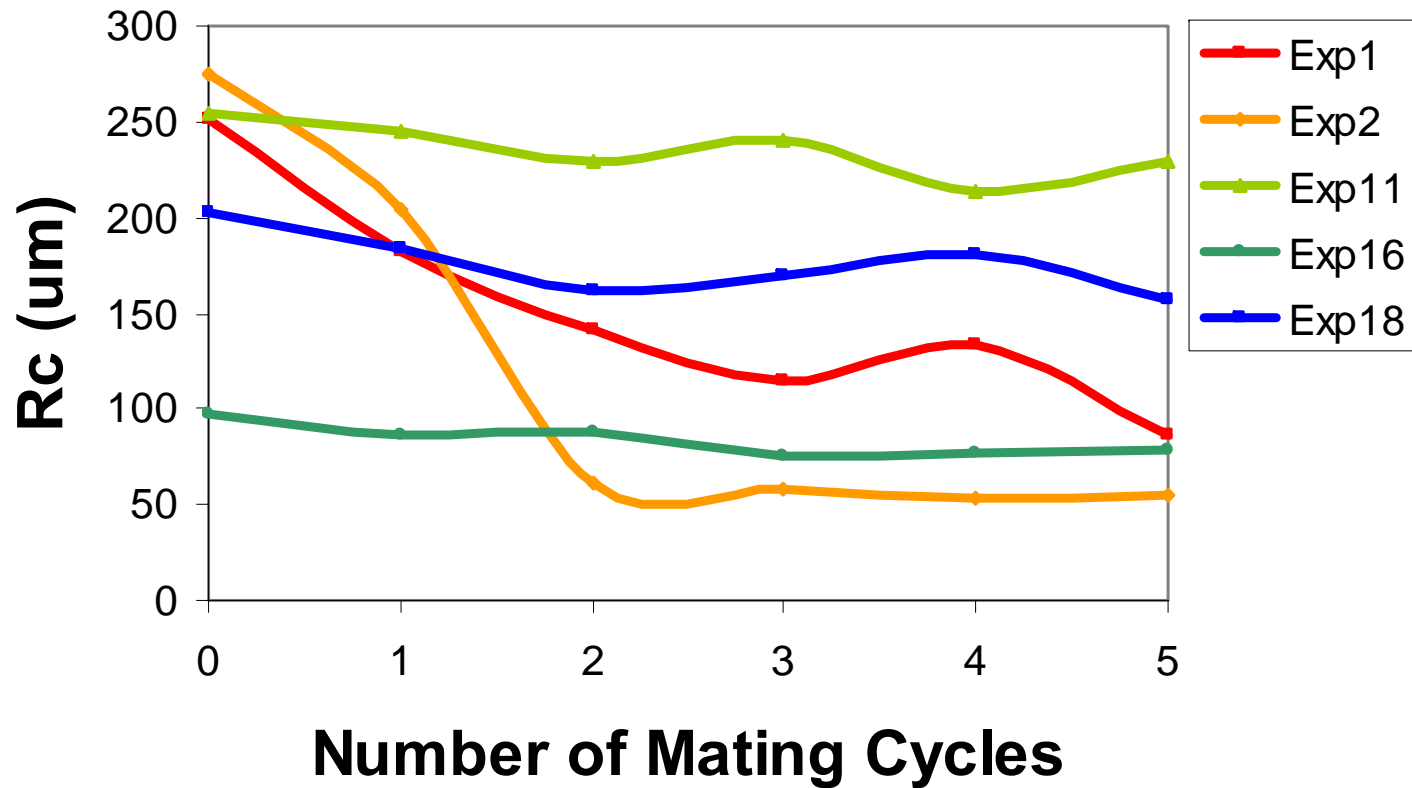
- The dust particle distribution on the connector end faces can be described by a single parameter  $R_c$ , which is called the center of particles.

$$R_c = \frac{\sum_0^N r_i a_i}{\sum_0^N a_i} \quad (1)$$

Where  $r_i$  and  $a_i$  are the  $i^{\text{th}}$  particle radial position and area, respectively.  $N$  is the total number of particles included in the  $R_c$  calculation.

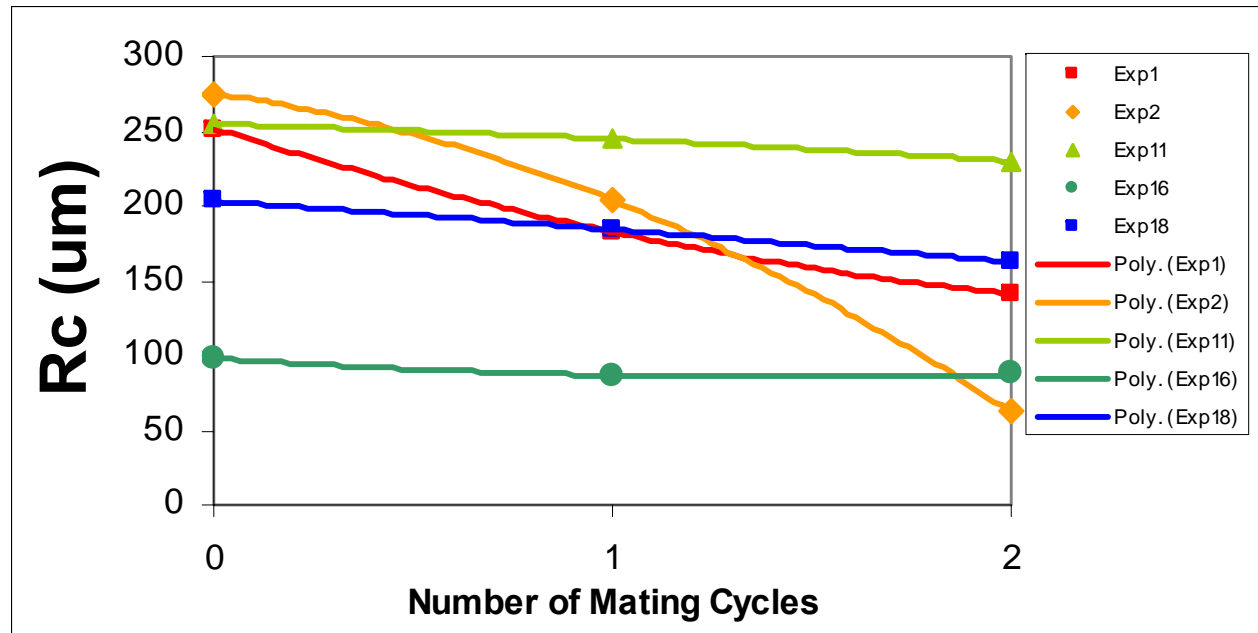
When formula is applied to the occluded area,  $a_i$  is then the total particle area within the  $i^{\text{th}}$  annular region.

# Particle Center vs. Mating



Evolution of Particle Center Position for Experiment 1, 2, 11, 16, and 18  
Exp 1 and 2 show a dramatic decrease in Rc during repeated matings.  
Radius decreases with increasing matings

# Particle Center Curve Fitting



## Fitting the movement of particle center with 2nd order polynomial equation

Between initial dust application and the 2nd mating and de-mating the curves can be fitted nicely with the 2nd order polynomial equation:

$$y = a_2 \cdot x^2 + a_1 \cdot x + a_0, \quad (2)$$

$$Vc = 2 \cdot a_2 \cdot x + a_1 \quad (3)$$

Vc is a particle center moving speed

# Particle Center Curve Fit Data

Table below has fitted values, moving speed, and the amount of charge

Experiment	$a_2$	$a_1$	$a_0$	Vc (um/mating)	Charge (nC)
1	13.883	-83.099	251.760	-55	0.4
2	-34.974	-36.635	275.100	-106	0.6
11	-2.308	-7.708	254.670	-12	0.01
16	6.041	-17.429	98.055	-5	0.01
18	-1.464	-17.499	203.120	-20	0.01

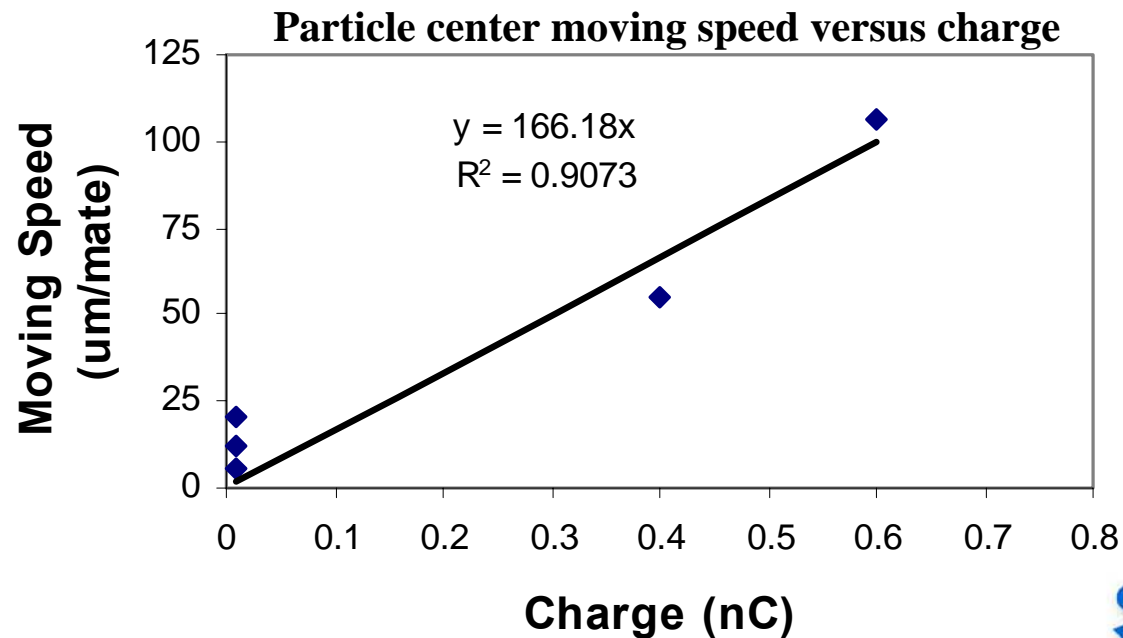
# Correlation of Rc Speed to Charge

- Based on the fact that the electrostatic force  $F$  is proportional to the amount of charge  $Q$ , we describe their relationship by  $F = b \cdot Q$ , where  $b$  is the constant depending on the geometrical configuration and the electrical property of dust particles.

$$F = m \cdot dV/dt \quad (4)$$

$$V_c = c \cdot Q \quad (5)$$

$$c = b \cdot \delta t / m, \quad c = 166 \text{ } \mu\text{m/mate/nC} \quad (6)$$



# Conclusions

- **During repetitive connector mating and de-mating cycles, dust particles can accumulate and re-distribute at the connector end face.**
- **Electrostatic charge force was one of the mechanisms responsible for the particle accumulation, re-distribution and their movement in the core area.**
- **A new metric, Center of Particles,  $R_c$  was developed to characterize the distribution of particles at the connector end face.**
- **$R_c$  decreased during the series of mating/demating cycles, demonstrating movement of particles toward the core, based on our data.**

## Conclusions - Cont'd

- **A correlation between the Rc and the charge that resulted from the connector end face cleaning process was found.**
- **The effect was reduced by application of ionized air or use of a fluid cleaning process, both methods neutralizing the electrostatic charge at the connector end face.**
- **Application of cleaning fluid reduced Particle Center movement speed by at least a factor of three to eleven, depending on fluid type.**
- **Applying ionized air and/or using cleaning fluids were good techniques for minimizing movement of particles during the service life of connectors in optical systems, based on these significant reductions in particle accumulation.**

# Project participants, 2004-2007



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