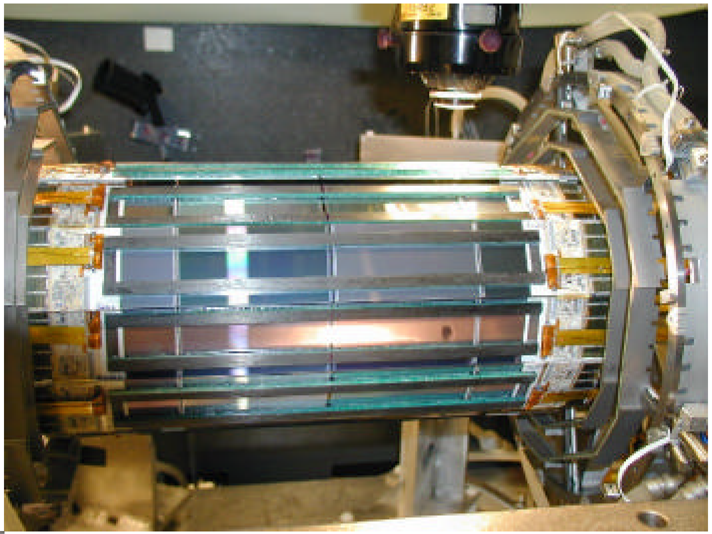
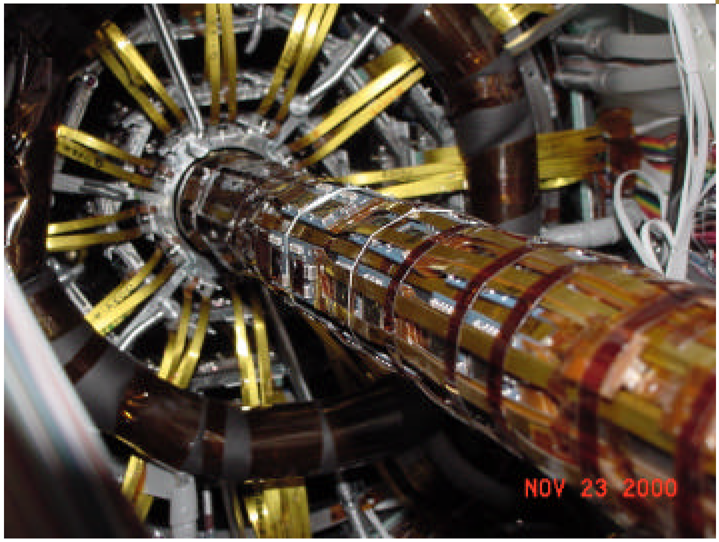
Quality Control Issues in CDF Silicon





Steve Worm
University of New Mexico / CDF

For the CDF Silicon Groups
May 17, 2001

Outline

- CDF Silicon Overview
- Sensor Testing -- Plans vs Actual
  - Testing Reproducibility
  - Interstrip resistance
  - Leakage currents
- Schedule Details
  - Testing Rates
  - Throughput and QA Issues
- Hamamatsu vs Micron
- Final Words

CDF Silicon Collaborations

SVX II Collaboration

Academia Sinica, Taiwan
Fermilab
Harvard University
Hiroshima University
Johns Hopkins
LBNL
University of New Mexico
INFN-Padova
U. Pittsburgh
Purdue University
U. Rochester
Rutgers University
Texas A&M University
Texas Tech University
Toronto University
Yale University

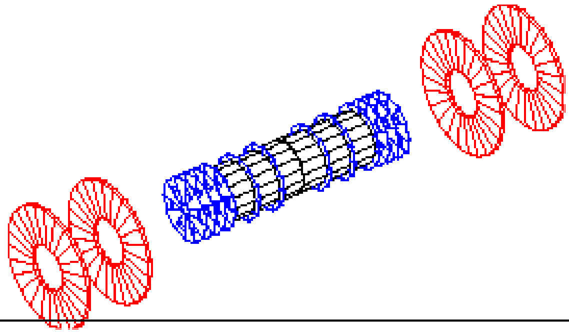
ISL Collaboration

Fermilab
INFN-Pisa
INFN-Padova
INFN-Bologna
LBNL
Texas A&M
U. California-Davis
U. California-Los Angeles
U. Cassino
U. Florida
U. Karlsruhe
U. Rochester
U. Tsukuba
Osaka City University

L00 Collaboration

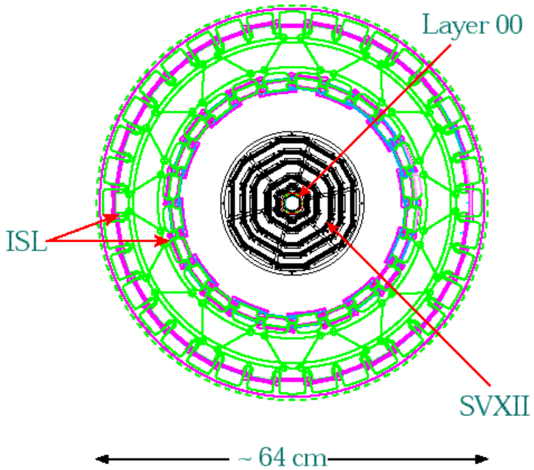
University of California-Davis
Fermilab
University of Florida
University of Glasgow
University of Liverpool
INFN-Pisa
INFN-Padova
Lawrence Berkeley Lab
Purdue University

Fermilab Run I I Silicon

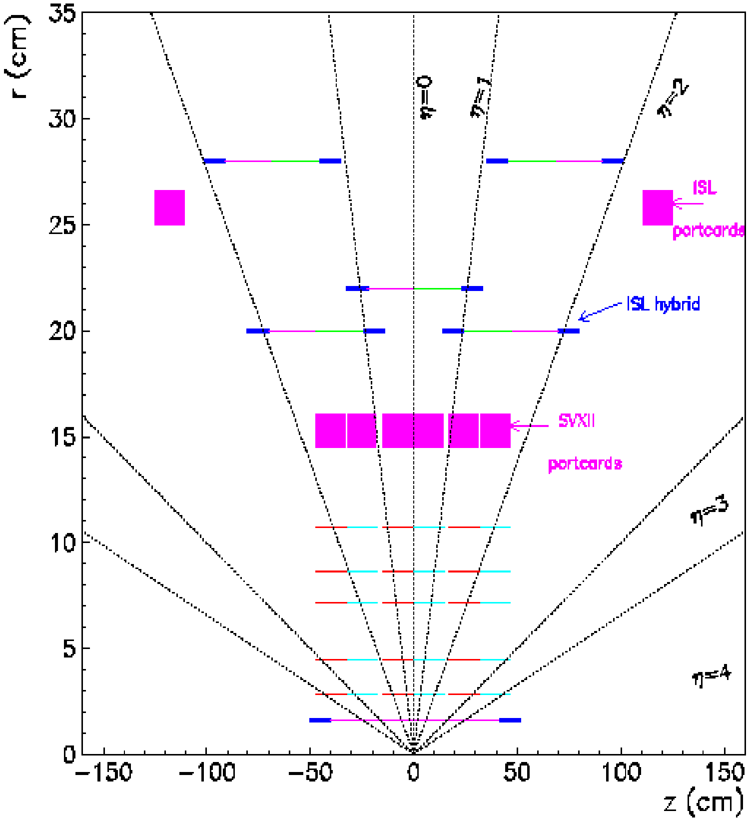


DØ	6 Barrels	F Disks	H Disks	Totals
Layers/planes	4	12	4	
Δz	77 cm	48 cm	10 cm	
Channels	387120	258000	147456	792576
Modules	432	144	192	768
Readout Length	12 cm	7.5 cm	14.9 cm	
Inner Radius	2.7 cm	2.6 cm	9.5 cm	2.6 cm
Outer Radius	9.4 cm	10.5 cm	26 cm	26 cm

CDF	Layer 00	SVX II	ISL	Totals
Layers	1	5	2	8
Length	0.9 m	0.9 m	1.9 m	
Channels	13824	405504	303104	722432
Modules	48 SS	360 DS	296 DS	704
Readout Length	14.8 cm	14.5 cm	21.5 cm	
Inner Radius	1.35 cm	2.5 cm	20 cm	1.35 cm
Outer Radius	1.65 cm	10.6 cm	28 cm	28 cm
Power	~100 W	1.4 kW	1.0 kW	1.5 kW



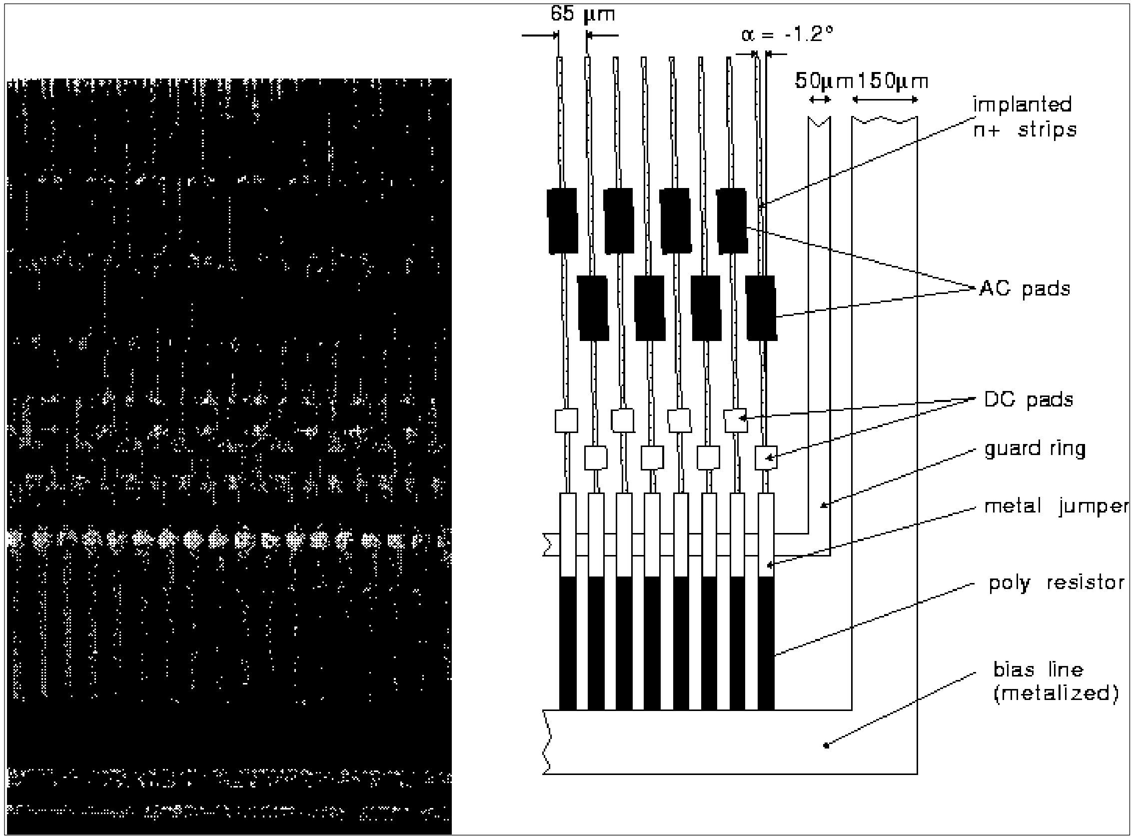
CDF Silicon: Layer 00 + SVXII + ISL



Goals and Features:

- Precise 3D track impact parameters
  - B tagging: top, SUSY, Higgs
  - B Physics
- Improved forward coverage
  - $0 \leq |\eta| \leq 2$
- Level II displaced-track trigger (SVT)
  - Hadronic B decays
  - Calibration triggers
- Improved p_T resolution
- High tracking efficiency with good purity

Silicon Strip Sensor (Micron SVXII SAS)



SVXII Testing Plans (circa 1997)

- Original plan was to use vendor measure as baseline
  - Sensor costs included extensive vendor testing
  - Prototypes extensively studied to verify vendor testing
  - Vendor measured IV, coupling capacitors (on sensor) and CV (test structure)
- University groups to re-measure all sensors IV, CV and inspect
- University groups planned to retest 10-15% of the sensors in detail
  - Complete measure of sensor IV, CV
  - Coupling capacitance
  - Interstrip resistance

Found good agreement between vendors and University groups for prototypes.

But… initial production deliveries had significant problems…

SVXII Testing Plans (Revised)

- Added DC test of each strip for both vendors because of interstrip resistance problems.
  - Problems often never completely understood
  - No other test was sensitive to these problems
  - Many processing problems can lead to poor isolation
- Significant number of leaky strips found.
- Result is a greatly increased testing load at the Vendors
  - DC tests often take a long time; perhaps 2 hours or more
  - Testing load nearly doubles as a result

Net result was to abandon University-based testing and to work more closely with the vendors to solve processing problems *before* the sensors were delivered.

Still, each device was tested, and Fermilab's "SiDet" played the key role.

Testing Reproducibility

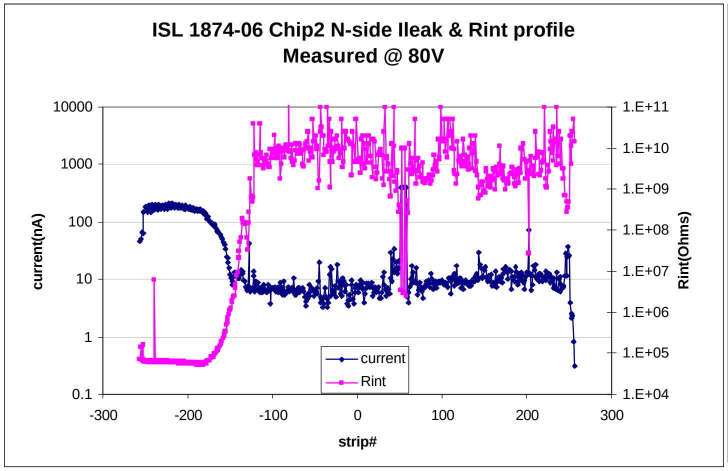
- Measurements were compared between several University testing groups and with the vendors
  - Most problems, such as differences in meters or methods, were explained
  - Differences in testing experience were more significant
    1. Newer testing sites had more trouble
    2. Undergraduate labor can be a source of uncertainty
  - With care, remarkably consistent measurements can be made at remote sites

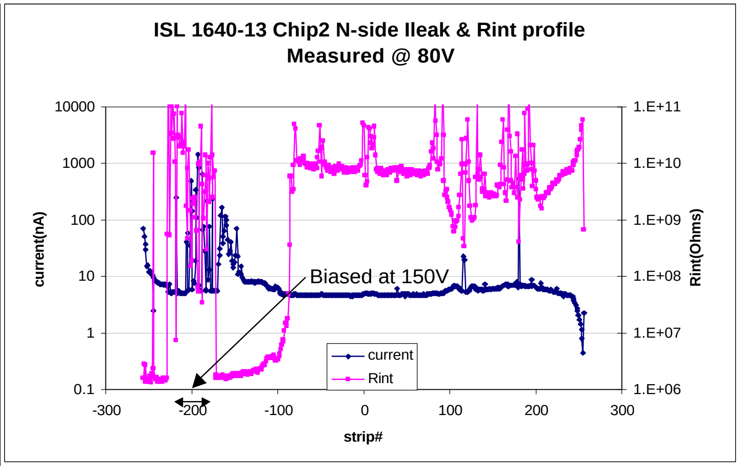
- From comparison among university sites and remeasurement at the vendor, we estimated the expected level of disagreement
  - Includes both probing disagreement and accumulated ESD and handling degradation
  - More than half the data is from remeasurement of devices at Hamamatsu which had significant extra handling – number is probably an overestimate

$\leq$ 0.18% disagreement that lead to bonds being pulled; so $\leq$ 2 bonds in 1000 strips

Interstrip Resistance

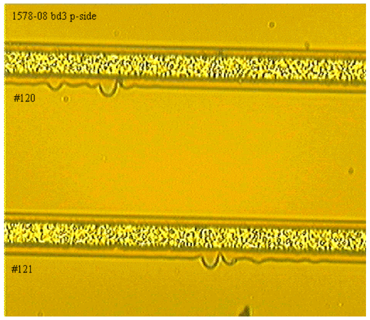
- Many factors lead to isolation problems for CDF
  - Hamamatsu – mobile ionic contaminant
  - Micron – change in cutting film results in poor isolation (localized contaminanat)
  - Micron – process variations and possibly bulk Si
- Test for R_{int} necessitates DC pad probing

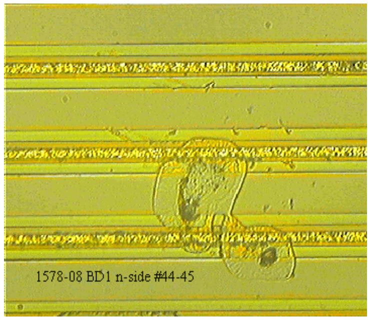


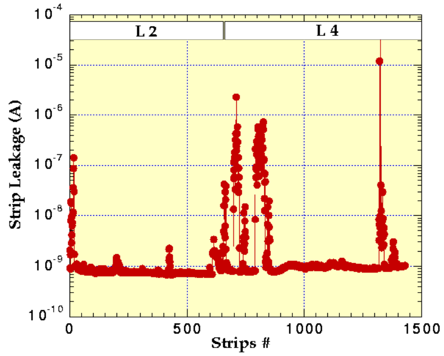


Leaky Strips

- Process defects (and poor handling, cleaning) lead to leaky strips
- Hamamatsu
  - DC shorts seen from scratches during processing
  - Surface scratches (a major problem)
- Micron
  - Lack of cleanliness in the cleanroom drove the generation of leaky strips early on
  - Specification changed to have strips with > 100 nA counted as bad.





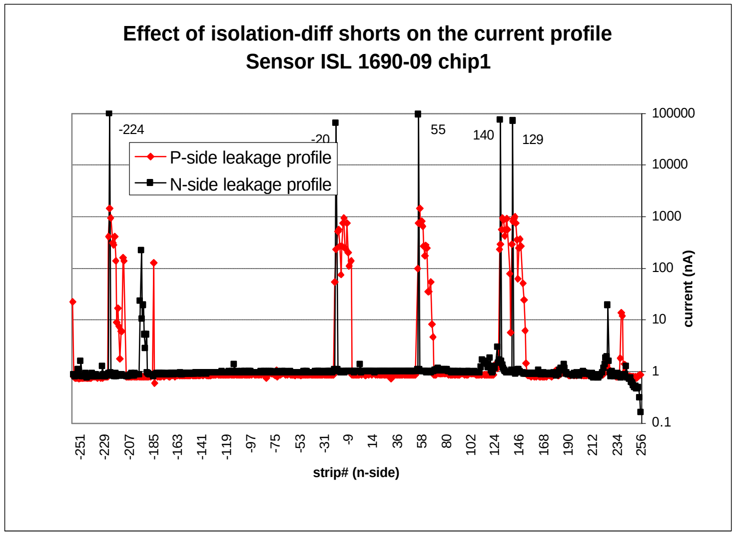


Diff-Isolation Faults

- Micron Photolithography faults between n implant and p-stop
  - Ramp-up of 150 mm production allowed non-optimal (bad) photolithogrgraphy
  - Photoresist surface drying allowed solvent to be trapped (oven, not hot plate)
  - Trapped solvent during exposure led to semi-circular defects near the edges of the p-stops that created one very leaky strip
  - Small angle stereo, plus isolated p-stops, yielded a region of leaky strips on the p-side.

This problem forced significant retesting of all devices from Micron.

Subsequently, working closely with Micron allowed us to see, predict, and fix problems before they reached us.

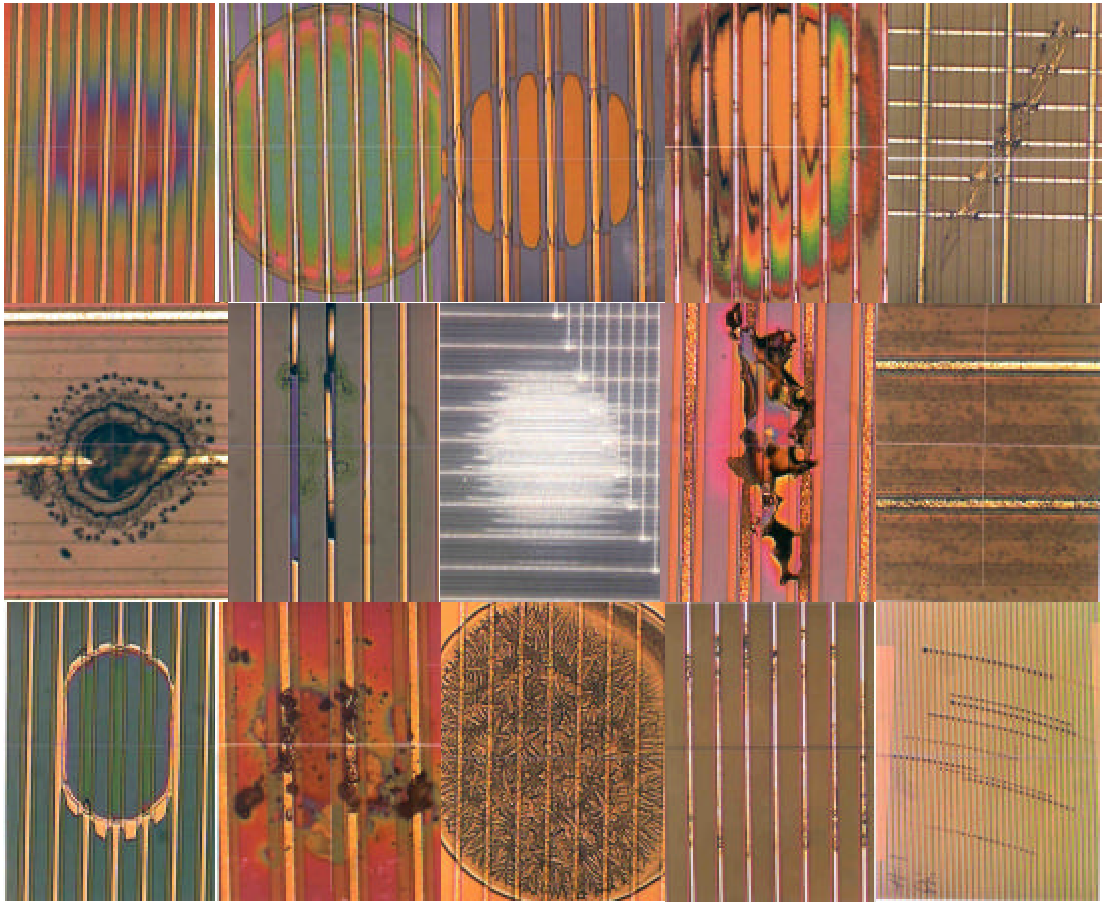


Scratches (SVXII)

- CDF SVXII readout hybrids are glued directly to the silicon
  - Epoxy used does not affect sensor *if passivation is intact*
  - Scratches present on sensors from both vendors
  - Some process flaws also
- Inspection and coating of scratches on every sensor was necessary
  - Very labor intensive (~1 man year)
  - Coating conducted at Fermilab
  - UV cure epoxy (Norland)
- Hamamatsu sensors
  - About 75% needed coating
  - 3.0 or 0.7 µm passivation
- Micron sensors
  - Only about 20% required coating
  - 0.2 to 0.3 µm passivation (LPCVD SiO_2)

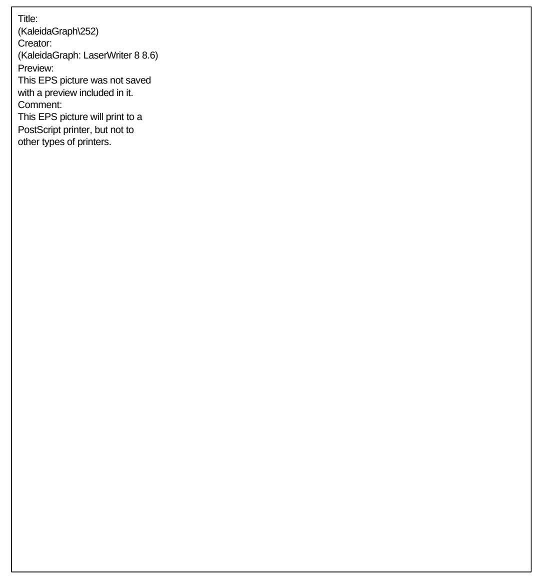
Test (SDX33502-8-0)	Strip current
Initial value	~0.4 nA
After scratch	~0.4 nA
Epoxy near scratch	1.1 nA
Epoxy in scratch	> 40 nA
After epoxy cure	> 40 nA

Process Defects and Scratches



Hamamatsu Deliveries

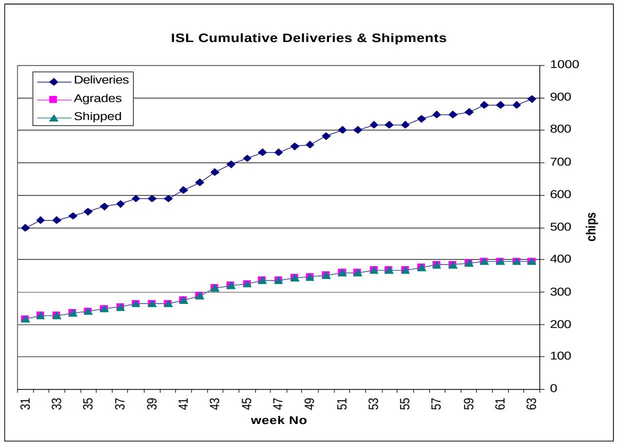
- Hamamatsu deliveries were temporarily suspended after interstrip problems identified
  - Hamamatsu sensor production is highly automated; they had little time or manpower to debug complicated problems
  - As a result of problems, CDF lost it's place in the production pipeline
  - No increase in production rate was possible once production resumed
- Maintaining a higher level of communication and testing feedback improved the situation
  1. Sensor testing established in Hiroshima for faster turn-around
  2. Frequent communication established

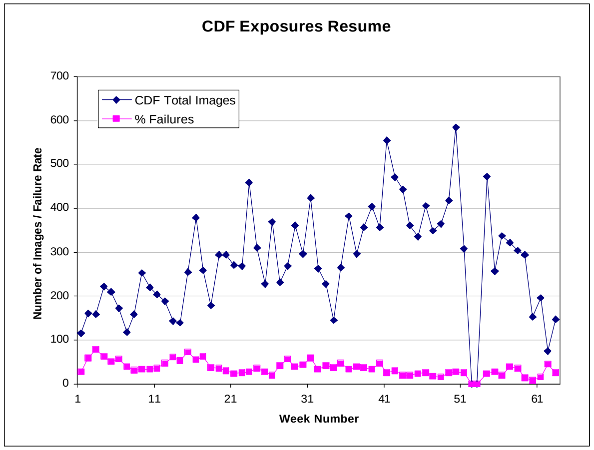


Wafer Inspections and Pipeline Monitoring

- Monitoring the production pipeline is very important
  - With a ~4 month production pipeline, deliveries can be predicted
  - For Micron, it helped us understand and predict persistent problems in photolithography (as well as throughput)
  - Weekly reports of wafer throughput allowed better planning downstream

- Quality assurance should not consist of just a final test





Sample Vendor Data

chip No. 30117

HAMAMATSU PHOTONICS K.K.
SOLID STATE DIVISION
JAPAN

item 1	Poly-Si resistance of monitors of the same processing lot (kohm).
item 2	Full depletion voltage of 3 monitor diodes of the same processing lot (V).
item 3	Total ID of this detector at each VR (nA).
item 4	NG channels of this detector by checking at 120V, 1/6 sec.
item 5	NG channels of this detector by checking DC pad at 1V.

Thickness of passivation on P side. : 0.7 micron

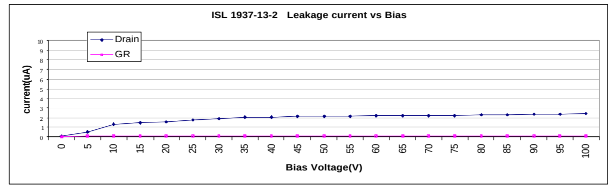
item 1	P side	N side
Max	3700	3730
Min	2194	2920
Avg.	2611	3142

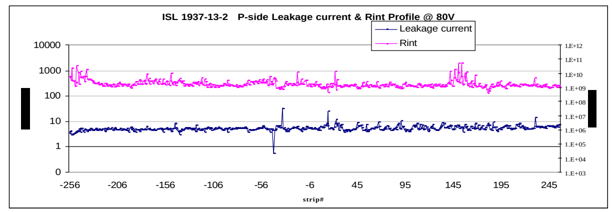
item 2		
68	66	62

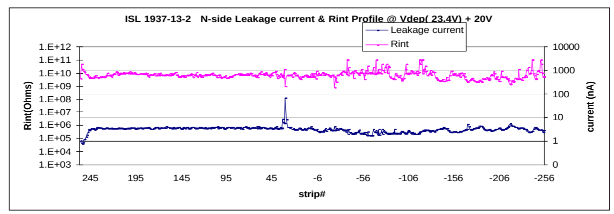
item 4	
total NG channel(%)	
P side	N side
2.0833333	0

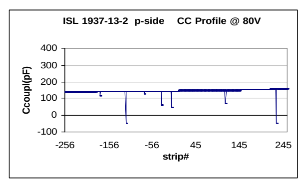
item 3		NG channel No.						item 5
		coupling short		AC short		AC open		DC NG
VR	ID	P side	N side	P side	N side	P side	N side	P side
0	0.00176	208				479		435
5	151.65	336				629		
10	232.1	406				712		
15	291.2	409				732		
20	343.5	414						
25	391.1	415						
30	435	425						
35	476.1	455						
40	515.2	623						
45	558.1	713						
50	612.4	764						
55	665.3							
60	697.5							
65	711.3							
70	718.1							
75	724.4							
80	730.7							
85	737.7							
90	745.4							
95	754.8							
100	764.4							
105	776.1							
110	788							
115	802.3							
120	819.5							
125	834.4							
130	856.4							
135	876.5							
140	900.3							
145	920.9							
150	948.1							
155	987.8							
160	1018.3							
165	1065.2							
170	1106.3							
175	1146.8							
180	1198.9							
185	1261.8							
190	1350.8							
195	1474.8							
200	1759.1							

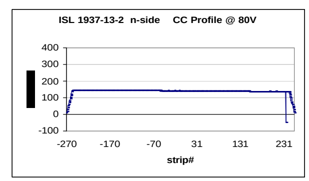
Hamamatsu









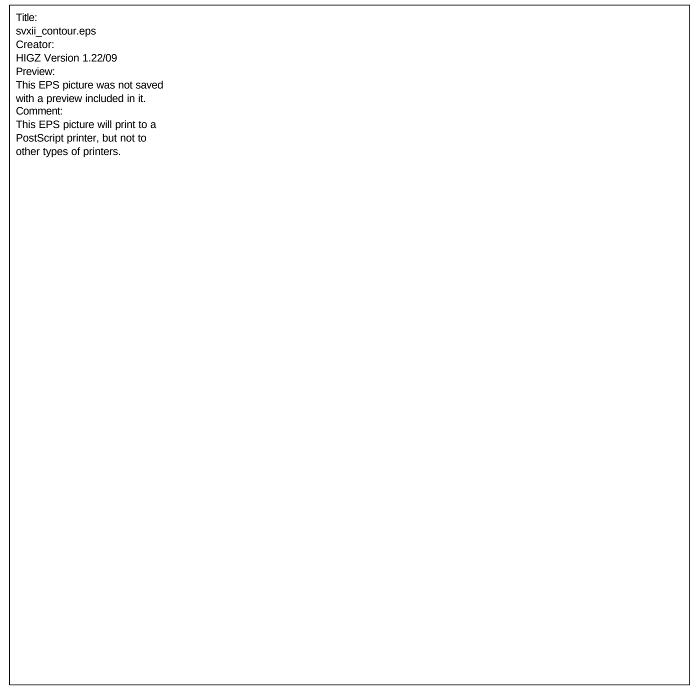


Micron

IV vs Bad Strips, Hamamatsu vs Micron

- QA needs can vary between vendors, even with similar specifications
  1. Hamamatsu is highly automated; very little rework
  2. Our Micron sensors were ‘hand-crafted’; 14 mask steps and maybe 6 more rework

- Our two vendors were very different; we found that the methods to monitor QA needed to adapt to each vendor



Conclusions

- Given our time constraints, farming out production testing to many different locations was a bad idea.
  - Production testing needed to be accomplished as quickly and as closely to the vendor as possible.
  - Feedback needed to be immediate, and the production pipeline needed to be closely monitored.
  - Having many different sites makes for logistical and data-sharing difficulties.
- Different vendors require different methods, but working closely with the vendors is very important.
- QA for CDF was not a simple comparison with specifications; we needed to go a little deeper to understand the problems and of have some flexibility to adapt to the devices being produced.