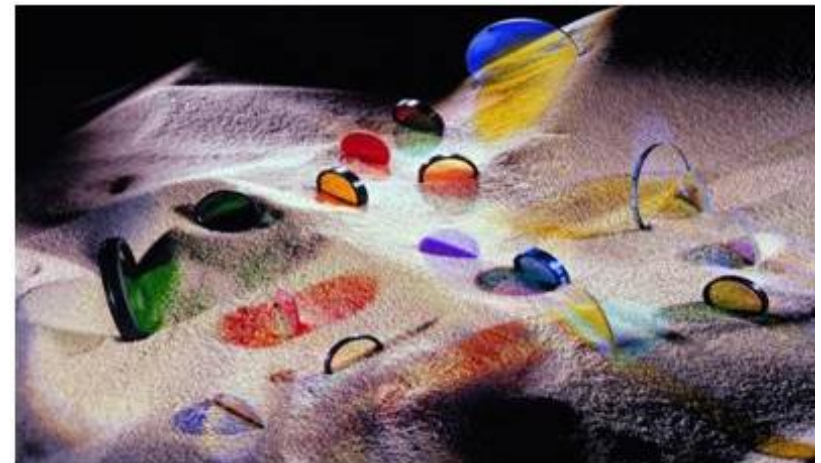


Measuring Sharp Spectral Edges to High Optical Density

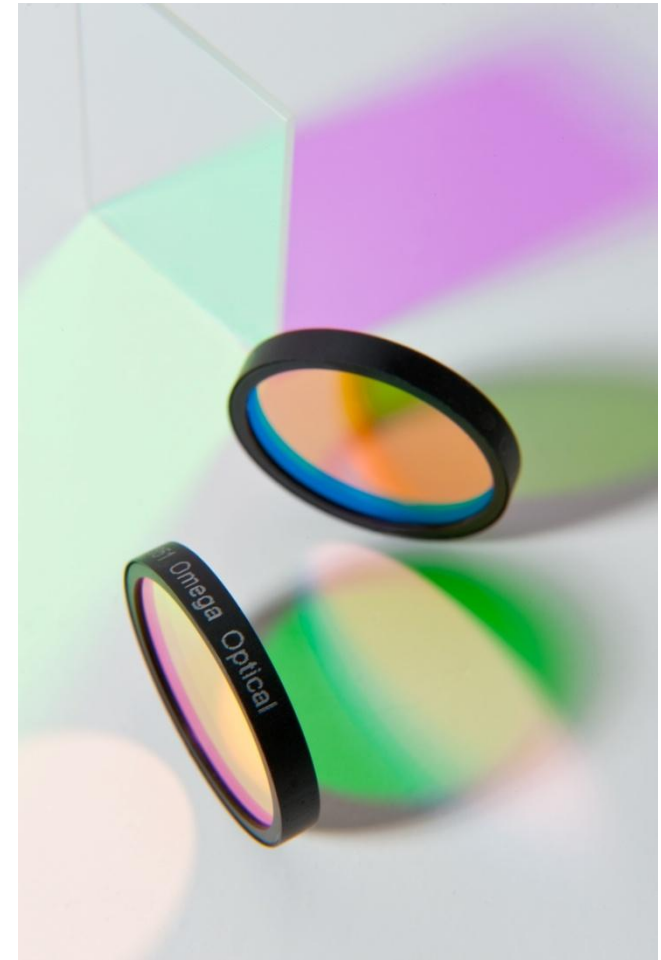
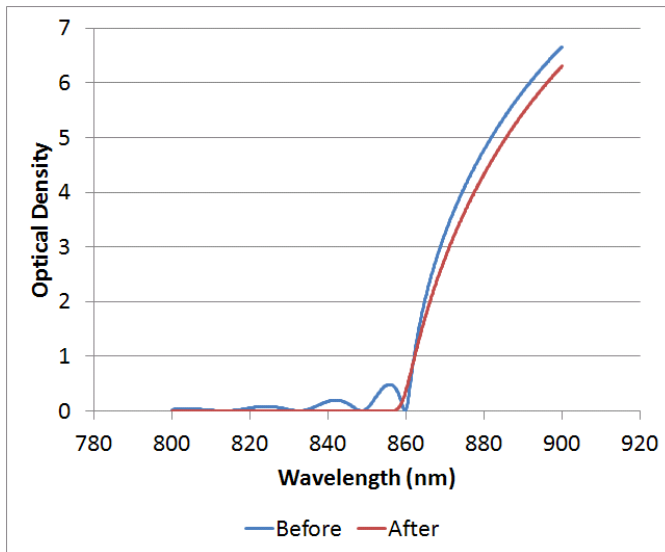
Content of Presentation

- Thin Film Filters Exhibit High Quality
- Limitations of Manufacturing Test Technology
- Laser Based Design Verification Testing
- Perturbation Experiments
- Manufacturing Test Plan
 - Spectral Tests
 - Homogeneity Tests
- Specifying High Optical Density
- Conclusions

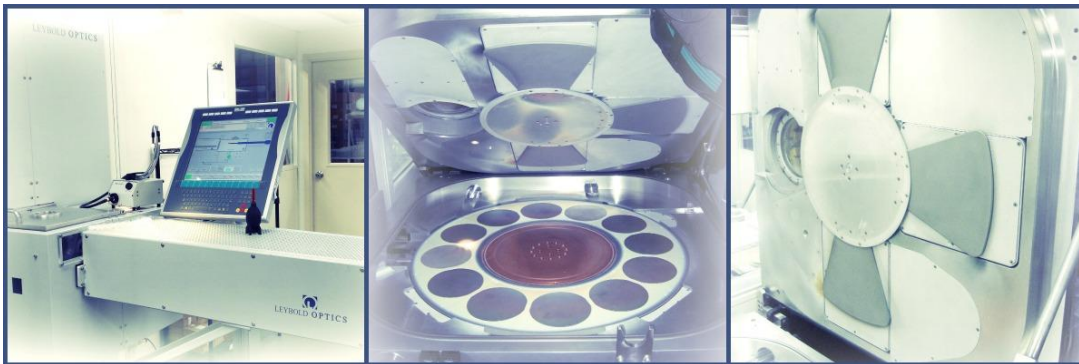
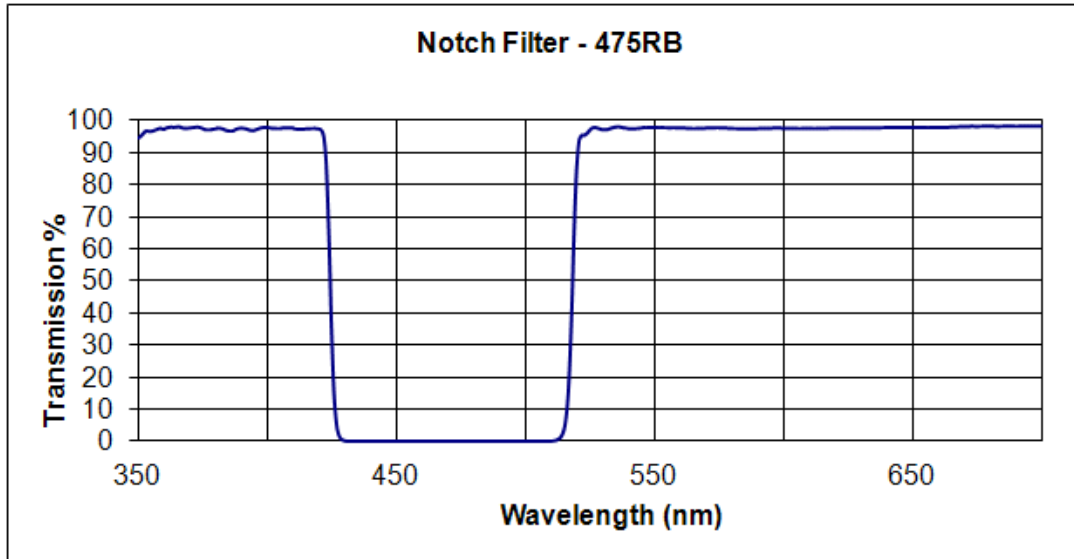


High Quality of Today's Thin Film Filters

- Sharp Spectral Edges: > 1 OD per nm
- Quality Enabled by Optical Monitoring to 0.1%
- Optimization Tradeoffs
 - High Transmission
 - Low Ripple



High Quality in Volume



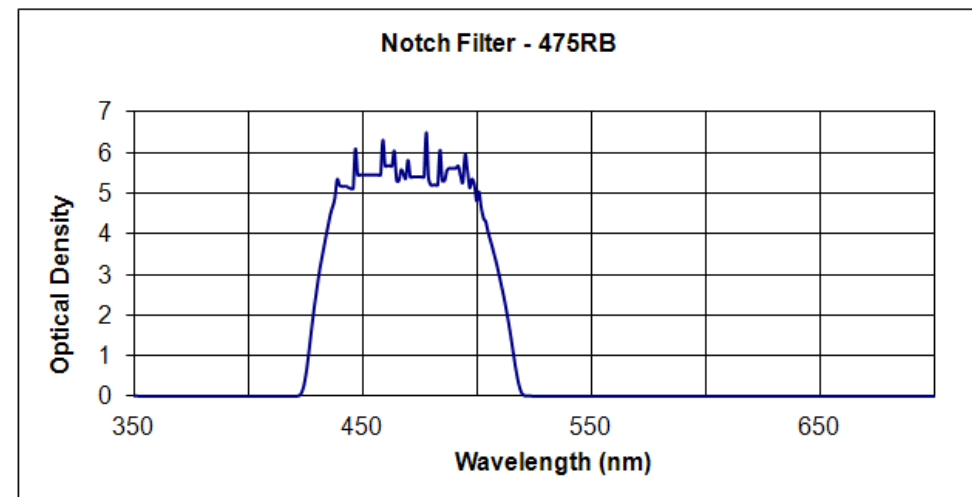
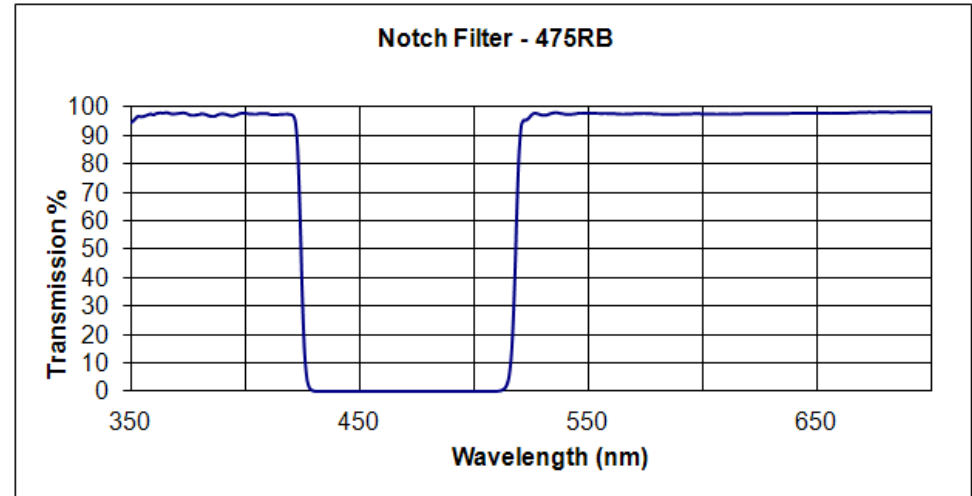
Helios Pro



Syrus Pro 1500 (563 cavities)

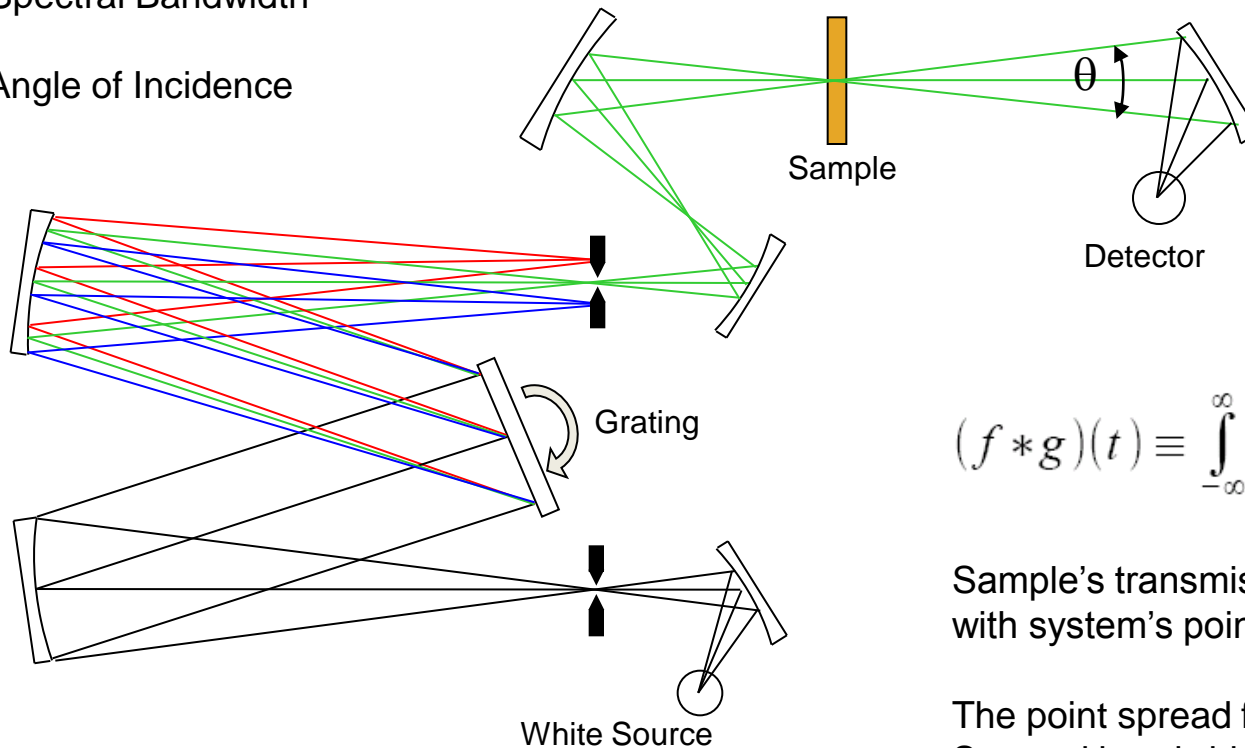
Limitations of Manufacturing Test Technology

- Limited to ~ OD5 by Noise Floor



Limitations of Manufacturing Test Technology

- Spectral Bandwidth
- Angle of Incidence



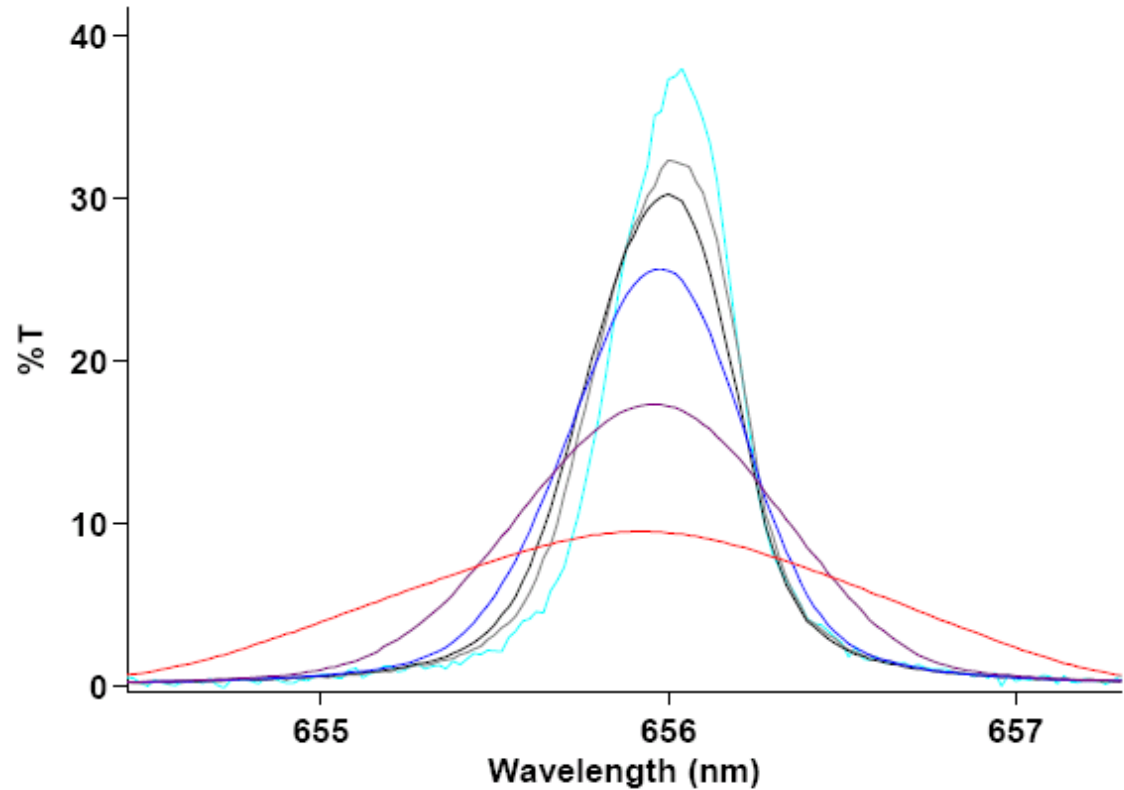
$$(f * g)(t) \equiv \int_{-\infty}^{\infty} f(\tau) g(t - \tau) d\tau$$

Sample's transmission (f) is convolved with system's point spread function (g)

The point spread function is broadened by:
 Spectral bandwidth of monochromator
 AOI distribution in sample chamber
 AOI distribution is different in x and y planes

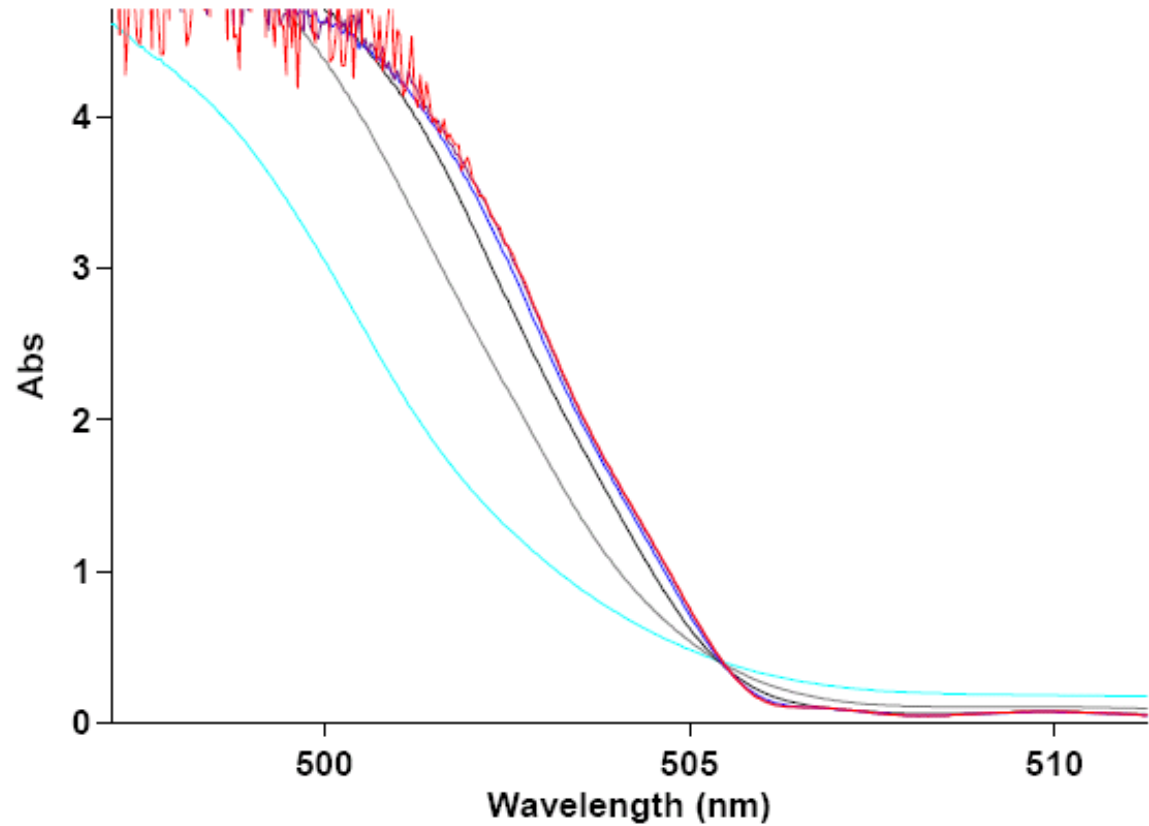
Limitations of Manufacturing Test Technology

- Spectral Bandwidth Varied from 0.04 to 2 nm
- Effect on a Bandpass Filter



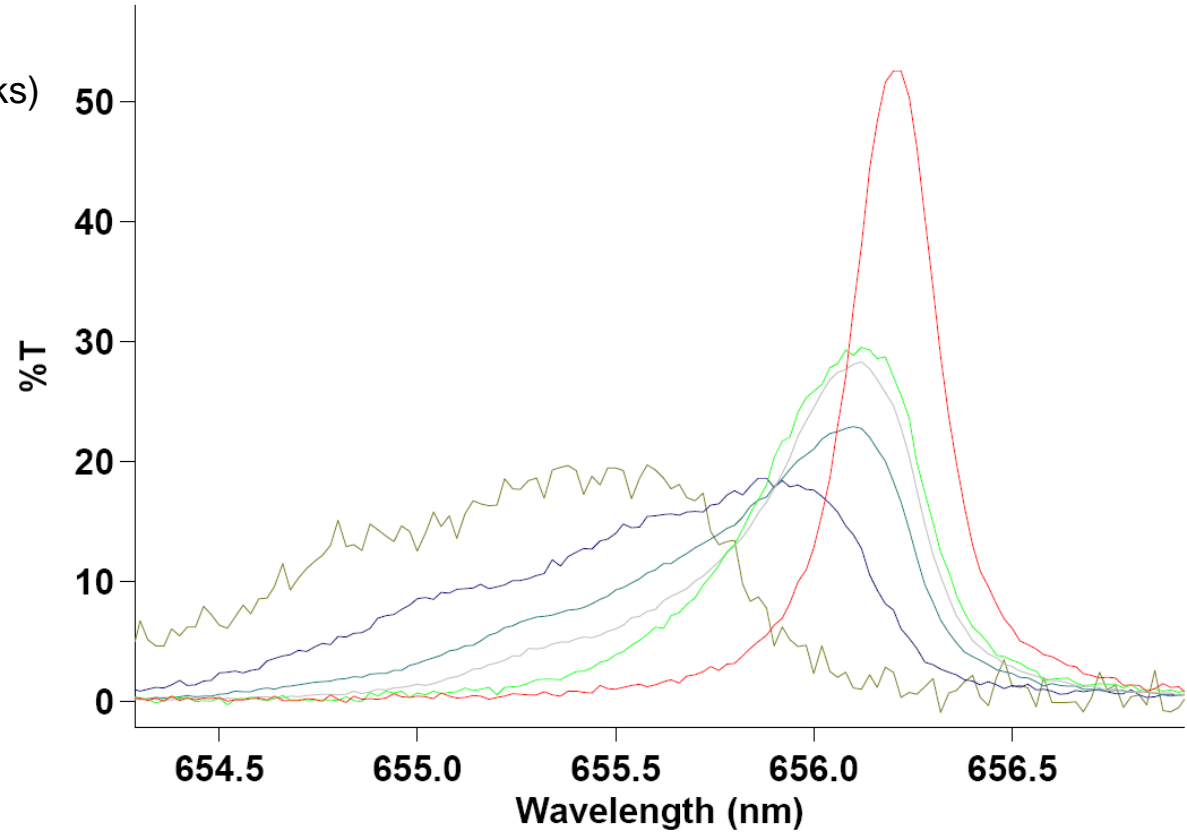
Limitations of Manufacturing Test Technology

- Spectral Bandwidth Varied from 0.32 to 5 nm
- Effect on an Edge Filter



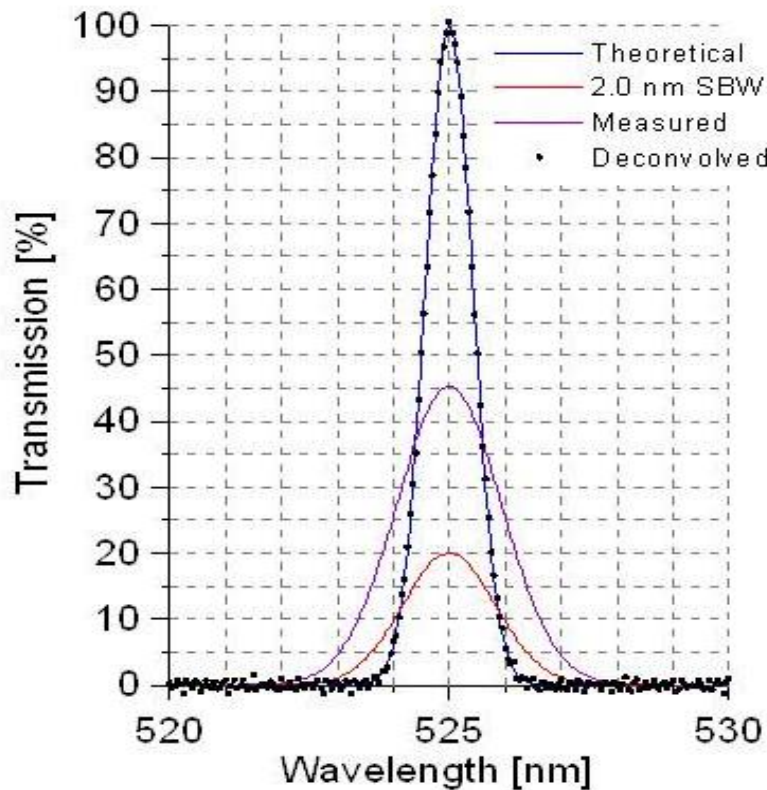
Limitations of Manufacturing Test Technology

- AOI Distribution Limited by 3mm Aperture (5mm clicks)
- Effect on a Bandpass Filter

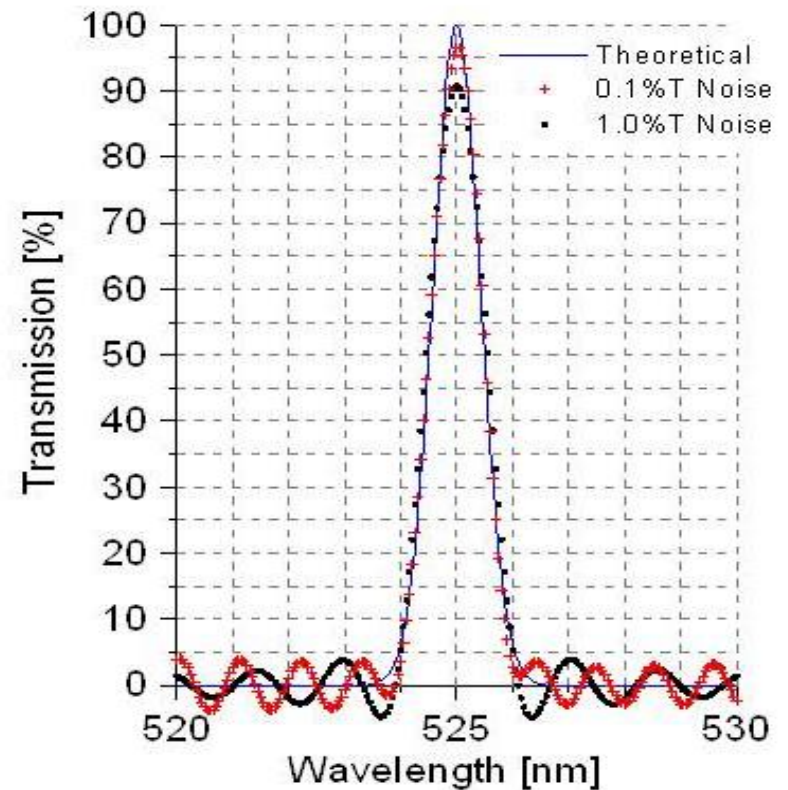


Limitations of Manufacturing Test Technology

Deconvolution of Simulated Measurement
525.0BP1.0 Filter - Truncation Noise Only

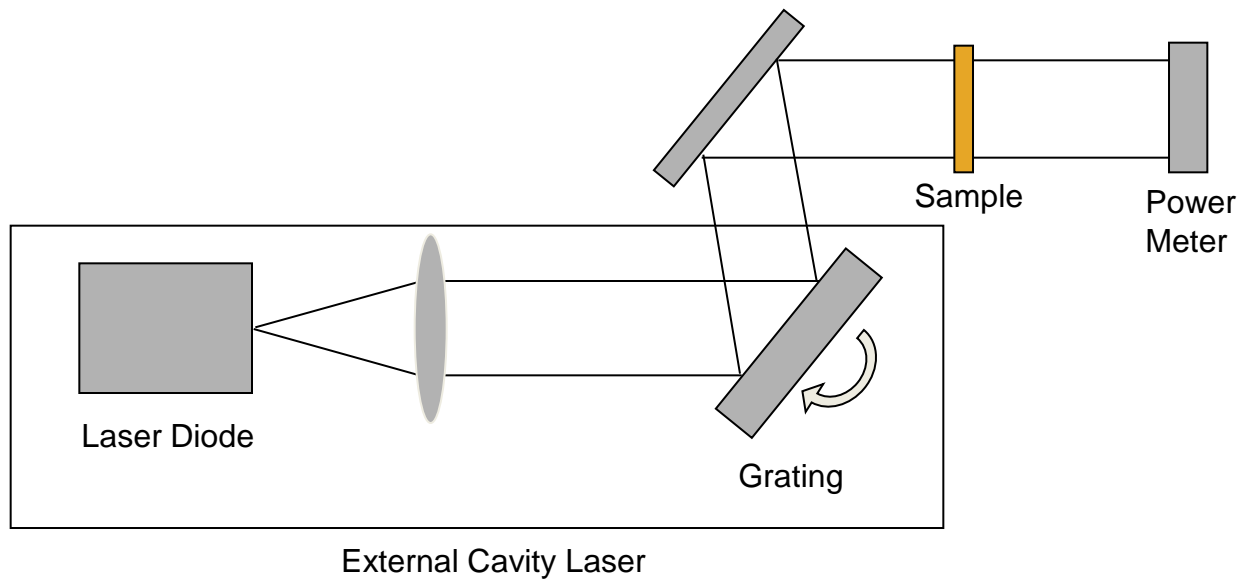


Deconvolution of Simulated Measurement
RMS Noise - Filtered to 32 Frequencies



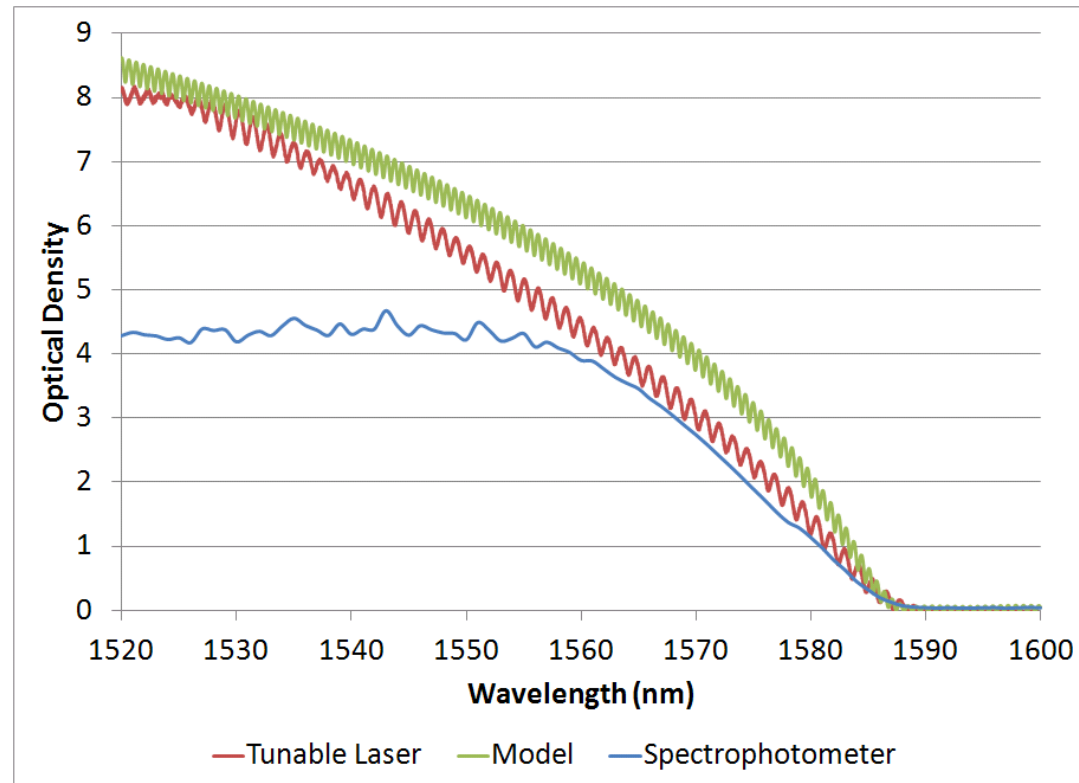
Laser Based Design Verification Testing

- Tunable Laser
- Convolves Laser Line (and ASE floor)
- ASE is 40 to 50 db down



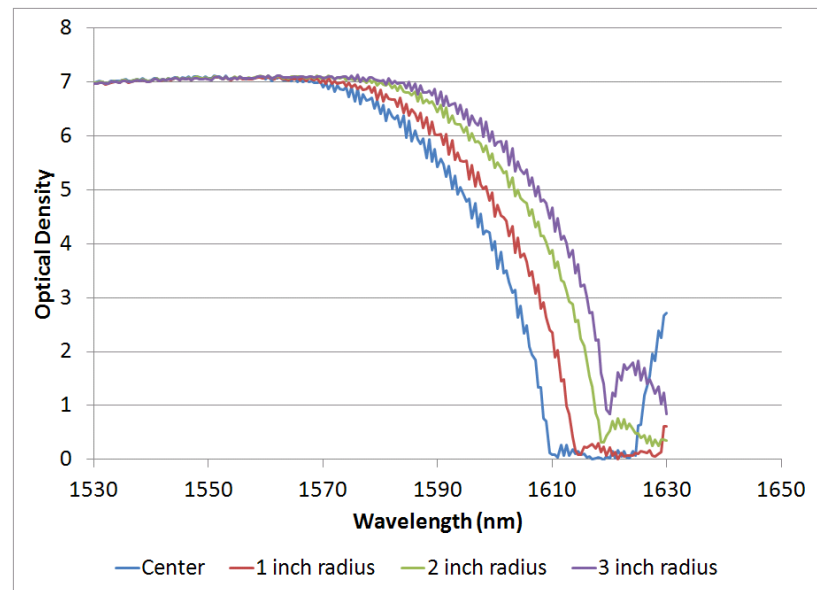
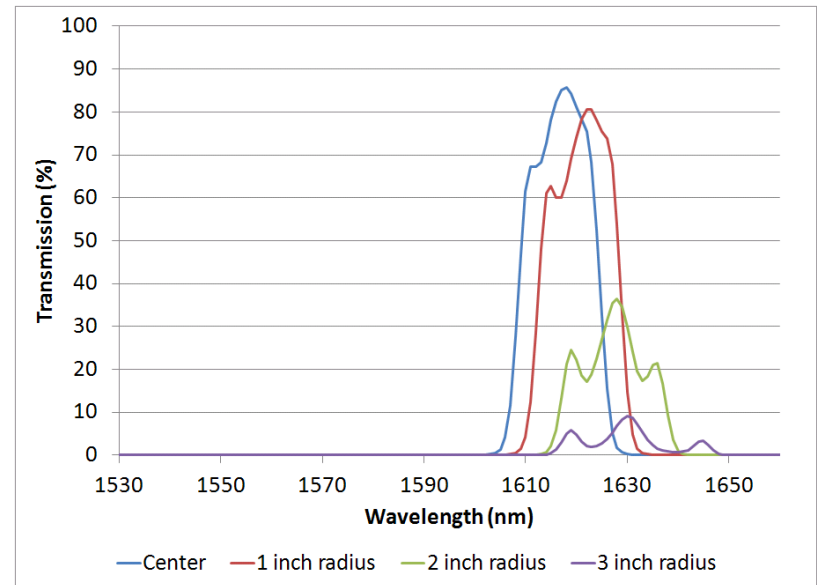
Laser Based Design Verification Testing

- Spectrophotometer Limited to OD4-OD5
- Laser Scan Matches Model at OD8
- Impact of ASE Floor
- Ripples from Back of Substrate



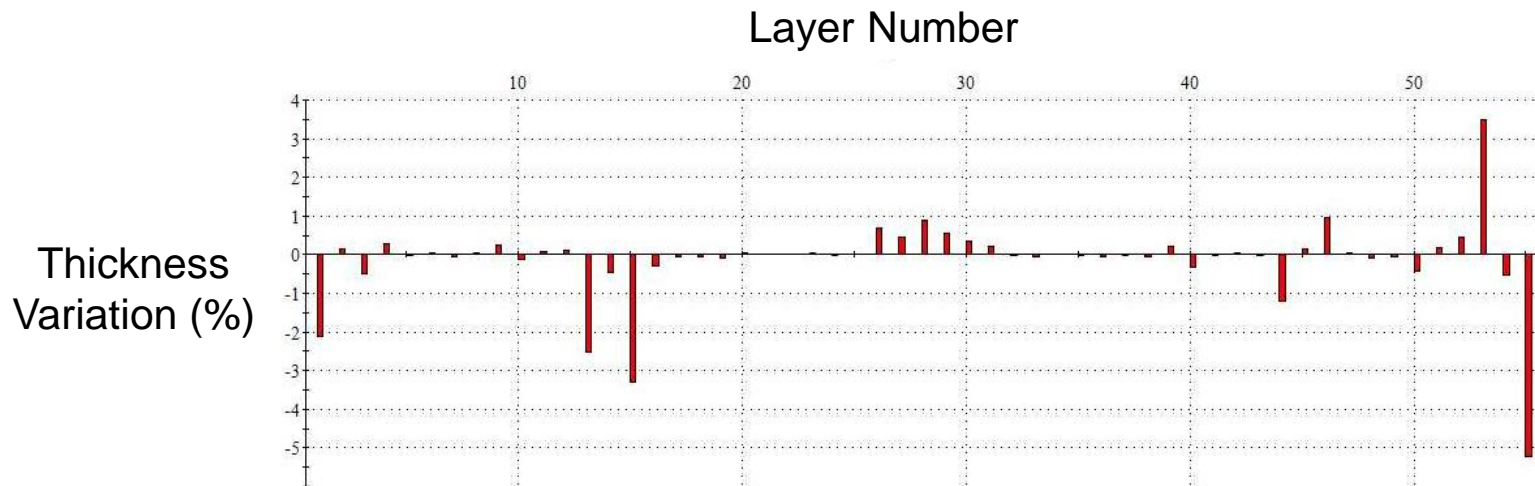
Perturbation Experiments

- All Curves from Same Substrate
- Intentional Use of De-Tuned Deposition System
- Transmission Collapses (at high radius)
- Optical Density does not Collapse
- Transmission fails before OD fails



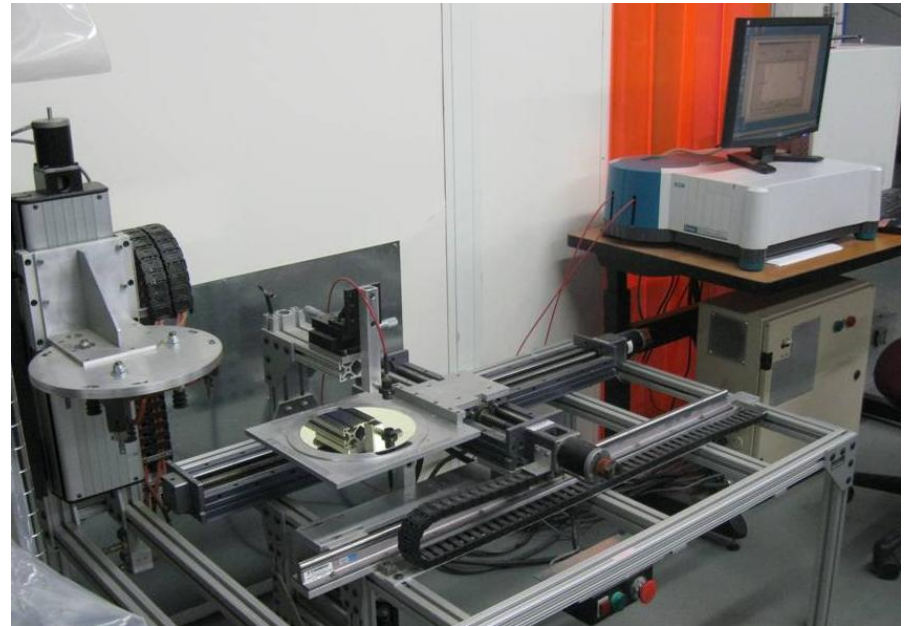
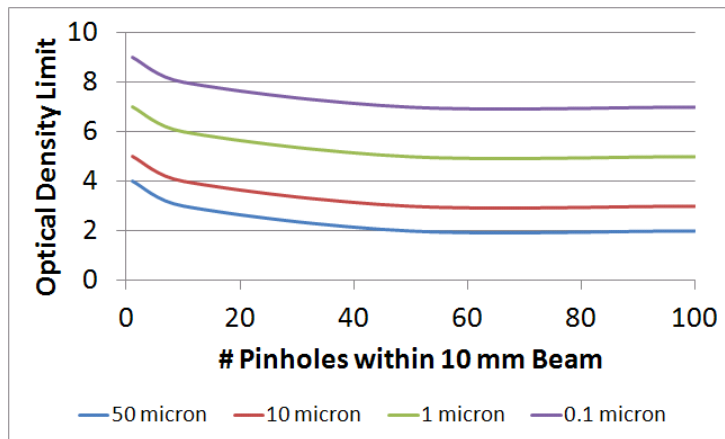
Perturbation Experiments

- One way to simulate collapsed filter
- Typical Depositions have less variation



Manufacturing Test Plan

- Spectral: Measure Transmission with Automated Spectrophotometer
- Spatial: Test OD and Pinholes with Array of High Brightness LEDs



Specifying High Optical Density

- Required Optical Density Depends on J/sec and time of observation

J/sec	sec	Wavelength	J/sec	sec	Wavelength	J/sec	sec	Wavelength	J/sec	sec	Wavelength
0.001	0.1	4.88E-07	0.000001	0.1	4.88E-07	0.001	1.66E-07	4.88E-07	0.000001	1.66E-07	4.88E-07
OD	T	# Photons	OD	T	# Photons	OD	T	# Photons	OD	T	# Photons
0	1	2.5E+14	0	1	2.5E+11	0	1.E+00	4.1E+08	0	1.E+00	4.1E+05
1	1.0E-01	2.5E+13	1	1.0E-01	2.5E+10	1	1.E-01	4.1E+07	1	1.E-01	4.1E+04
2	1.0E-02	2.5E+12	2	1.0E-02	2.5E+09	2	1.E-02	4.1E+06	2	1.E-02	4.1E+03
3	1.0E-03	2.5E+11	3	1.0E-03	2.5E+08	3	1.E-03	4.1E+05	3	1.E-03	4.1E+02
4	1.0E-04	2.5E+10	4	1.0E-04	2.5E+07	4	1.E-04	4.1E+04	4	1.E-04	4.1E+01
5	1.0E-05	2.5E+09	5	1.0E-05	2.5E+06	5	1.E-05	4.1E+03	5	1.E-05	4.1E+00
6	1.0E-06	2.5E+08	6	1.0E-06	2.5E+05	6	1.E-06	4.1E+02	6	1.E-06	4.1E-01
7	1.0E-07	2.5E+07	7	1.0E-07	2.5E+04	7	1.E-07	4.1E+01	7	1.E-07	4.1E-02
8	1.0E-08	2.5E+06	8	1.0E-08	2.5E+03	8	1.E-08	4.1E+00	8	1.E-08	4.1E-03
9	1.0E-09	2.5E+05	9	1.0E-09	2.5E+02	9	1.E-09	4.1E-01	9	1.E-09	4.1E-04
10	1.0E-10	2.5E+04	10	1.0E-10	2.5E+01	10	1.E-10	4.1E-02	10	1.E-10	4.1E-05
11	1.0E-11	2.5E+03	11	1.0E-11	2.5E+00	11	1.E-11	4.1E-03	11	1.E-11	4.1E-06
12	1.0E-12	2.5E+02	12	1.0E-12	2.5E-01	12	1.E-12	4.1E-04	12	1.E-12	4.1E-07
13	1.0E-13	2.5E+01	13	1.0E-13	2.5E-02	13	1.E-13	4.1E-05	13	1.E-13	4.1E-08
14	1.0E-14	2.5E+00	14	1.0E-14	2.5E-03	14	1.E-14	4.1E-06	14	1.E-14	4.1E-09
15	1.0E-15	2.5E-01	15	1.0E-15	2.5E-04	15	1.E-15	4.1E-07	15	1.E-15	4.1E-10
16	1.0E-16	2.5E-02	16	1.0E-16	2.5E-05	16	1.E-16	4.1E-08	16	1.E-16	4.1E-11
17	1.0E-17	2.5E-03	17	1.0E-17	2.5E-06	17	1.E-17	4.1E-09	17	1.E-17	4.1E-12
18	1.0E-18	2.5E-04	18	1.0E-18	2.5E-07	18	1.E-18	4.1E-10	18	1.E-18	4.1E-13
19	1.0E-19	2.5E-05	19	1.0E-19	2.5E-08	19	1.E-19	4.1E-11	19	1.E-19	4.1E-14
20	1.0E-20	2.5E-06	20	1.0E-20	2.5E-09	20	1.E-20	4.1E-12	20	1.E-20	4.1E-15

Conclusions

- Transmission specifications met with index and thickness precision
- Optical density to OD8 met with physical homogeneity
- Quality Control ensured with spectrophotometers and OD test sets
- Most accurate representation: measured T and modeled OD

