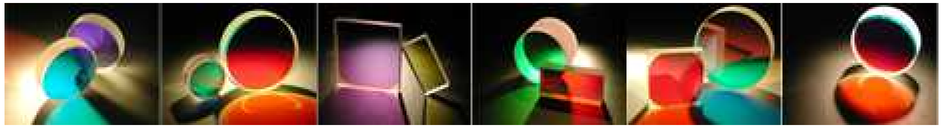


NANEO Precision IBS Coatings GmbH

NANEO®

Ion-Beam Sputtering in Industrial Production

Dr. Volker Scheuer

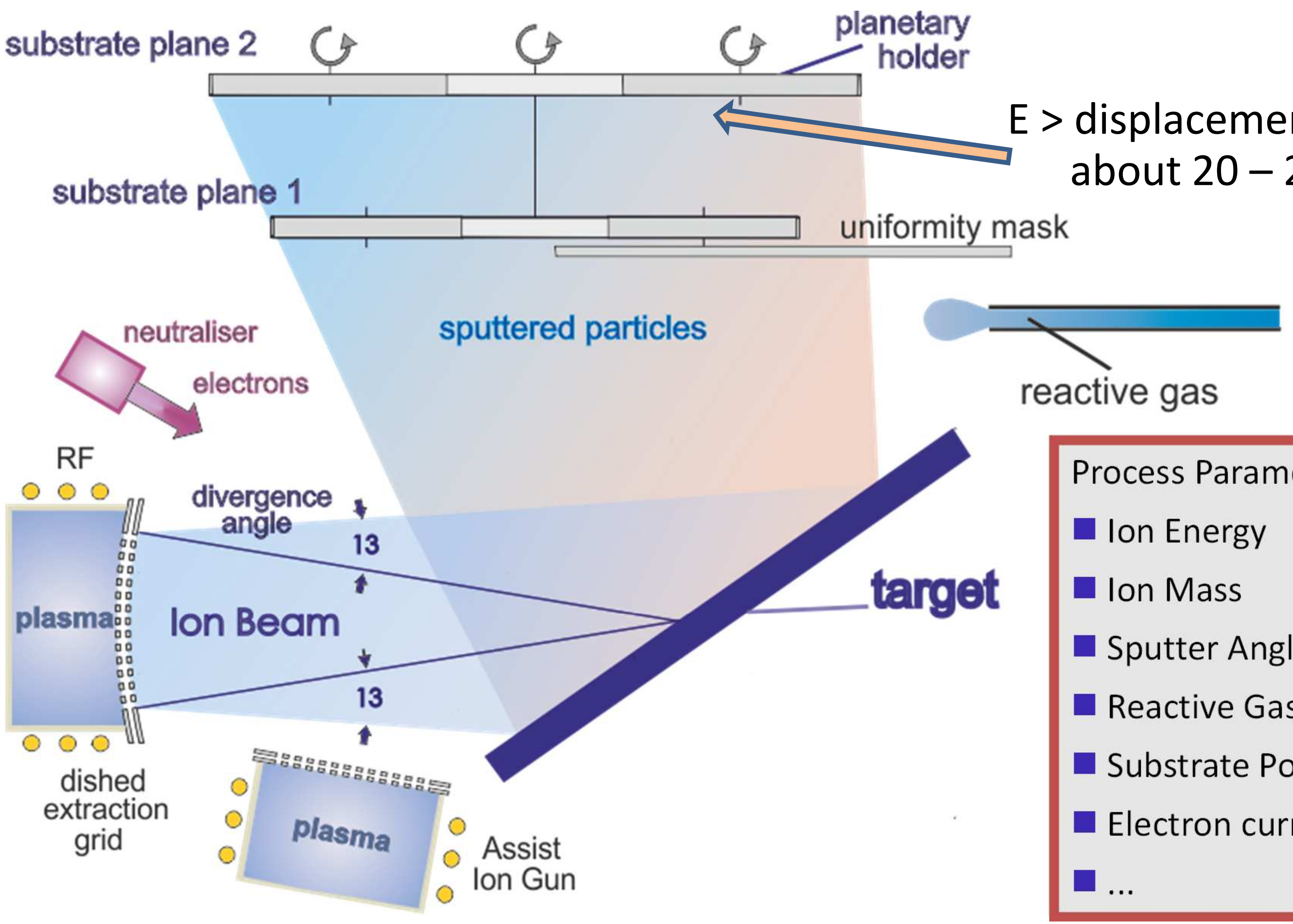
Part 1

- Basics of Ion Beam Sputtering (IBS) Technology
- Breakthroughs by IBS coatings

Part 2

- IBS Technology at NANEO
- Examples of IBS Coatings by NANEO
  - Broad Band Gain Flattening
  - High Power Beam Combining
  - High negative Dispersion
  - High Damage Coatings

Process of Ion Beam Sputtering

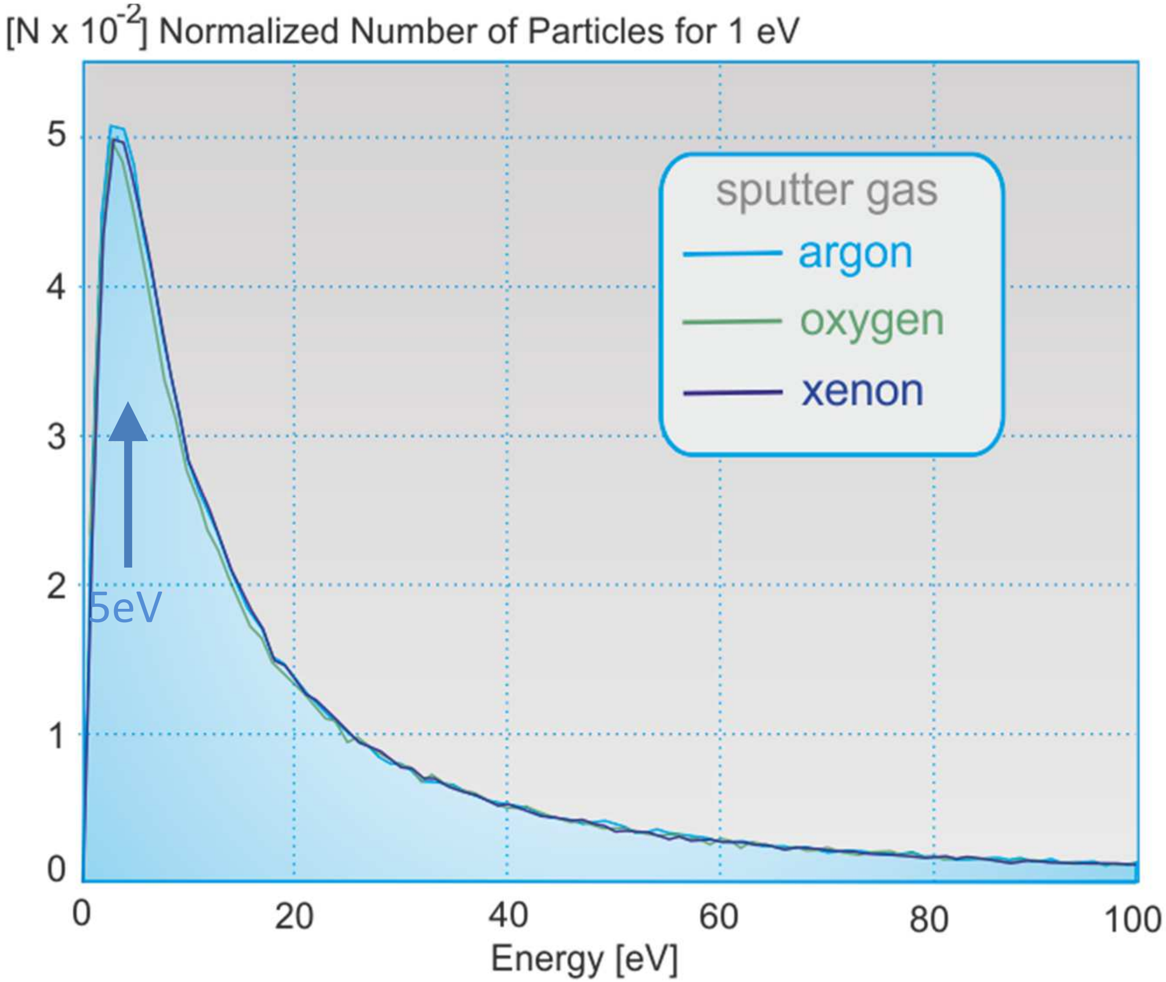


E > displacement energy
about 20 – 25 eV

Process Parameters:

- Ion Energy
- Ion Mass
- Sputter Angle
- Reactive Gas Pressure
- Substrate Position
- Electron current
- ...

Energy distribution of sputtered particles



Computer Simulation

Program SRIM

Stopping and Range of Ions in Matter

by

Jochen P. Biersack and James F. Ziegler

Primary Energy: 1200 eV

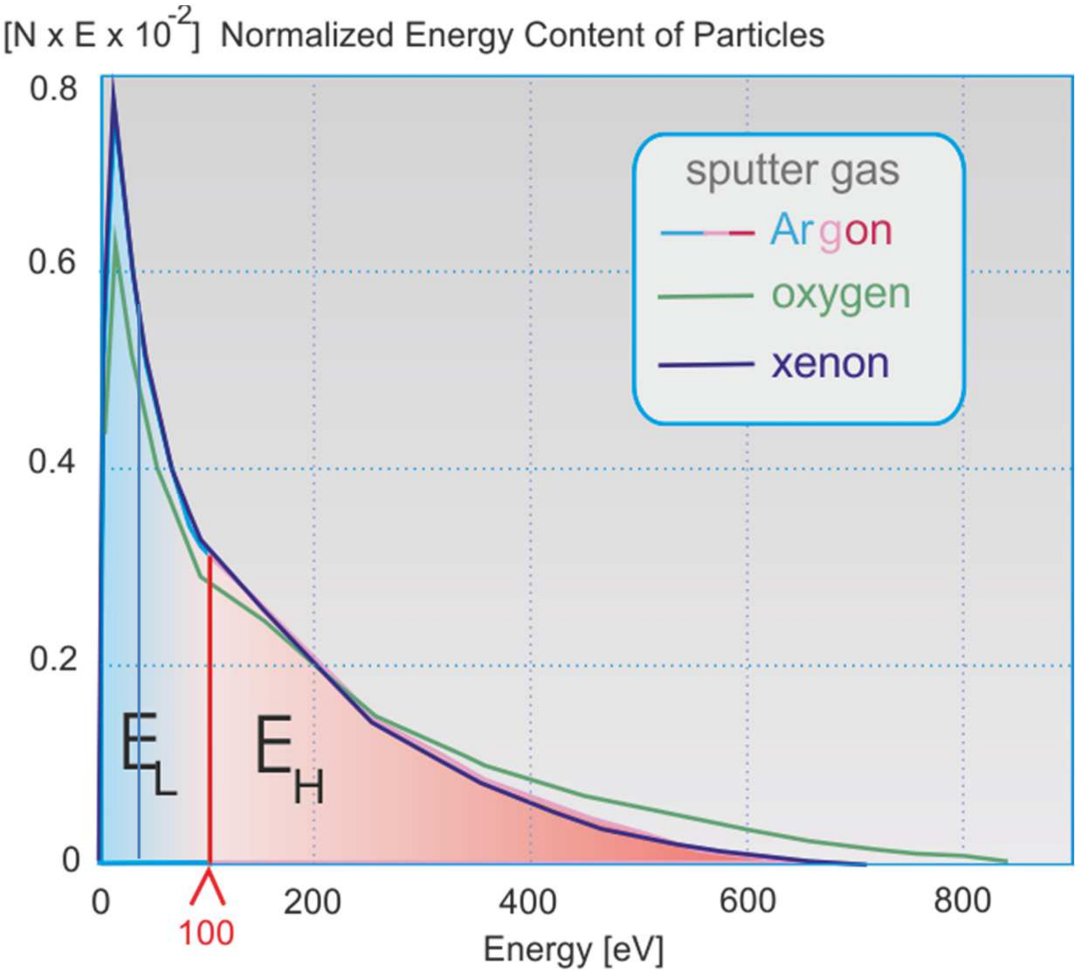
Sputter Angle: 55 °

Target: Titanium Oxide

Maximum:~ 5 eV

Most particles = 5 eV but many particles have higher energy

Energy transport of the particles



Energy Contend in % for

Low Energy Particles EL

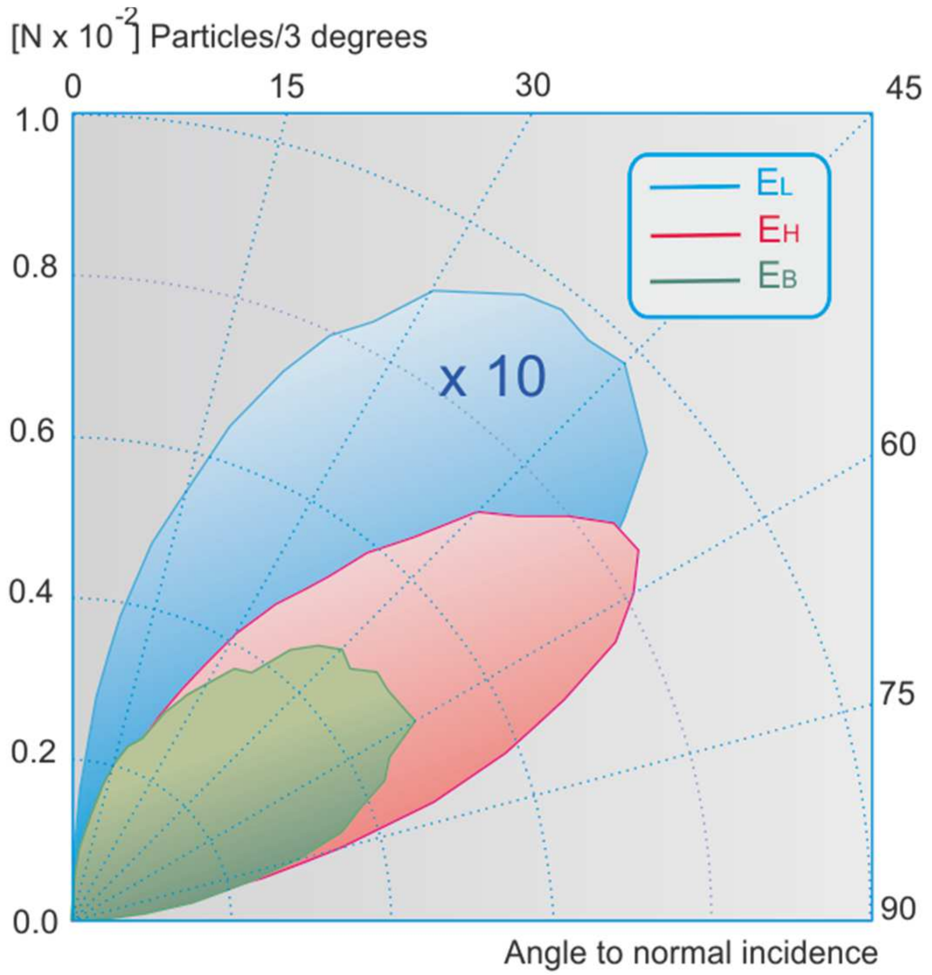
High Energy Particles EH

sputtering from Ti Target

Gas	E_L	E_H
O	40.1	59.9
Ar	48.8	51.2
Xe	49.5	50.5

50% Energy Input by Particles with Energy > 100 eV

Sputter angle of different particle groups

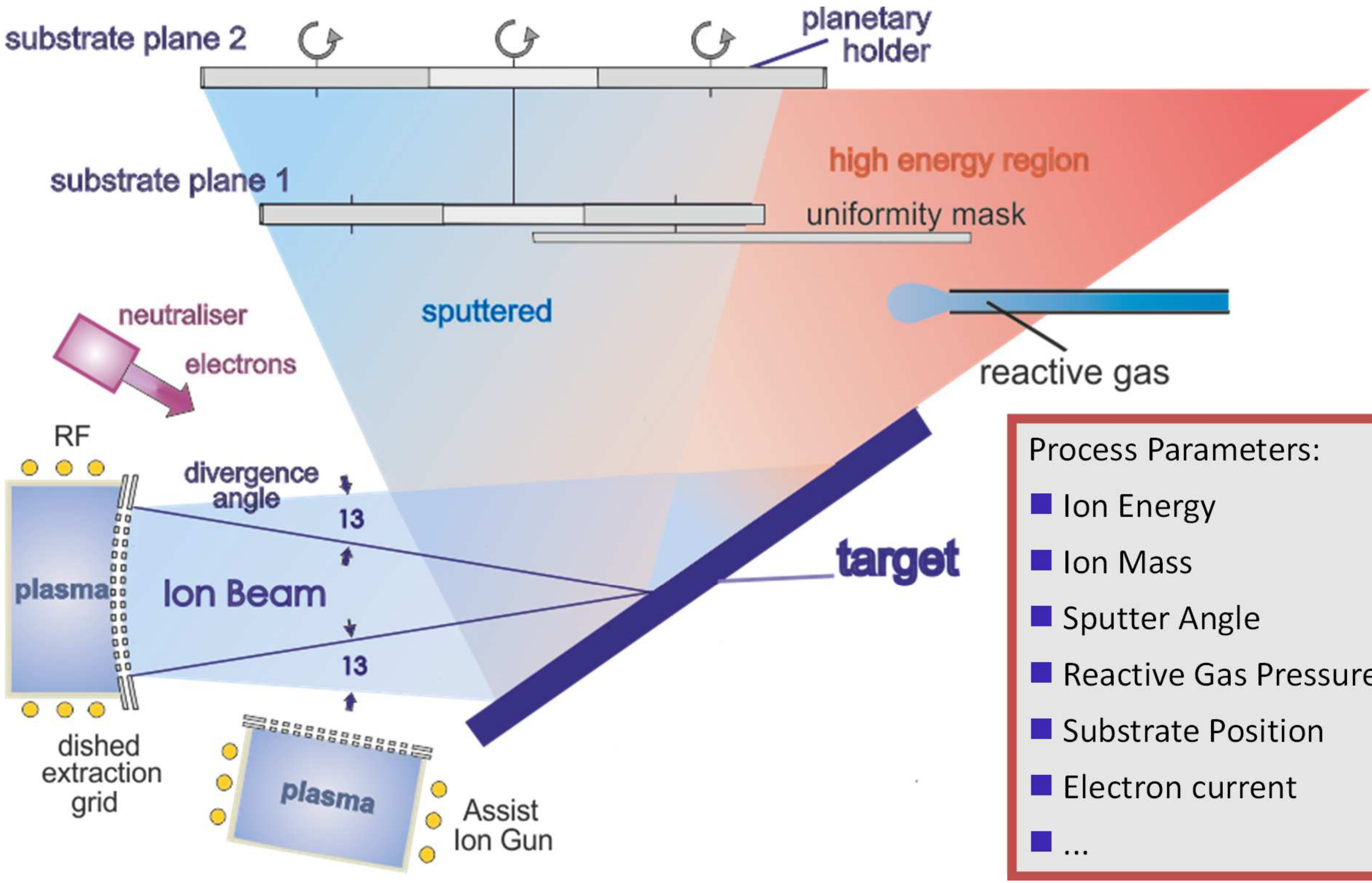


Particle Groups:

- EL : Low Energy Particles Ti
- EH :High Energy Particles Ti
- EB :Back Scattered Primary Particles of Argon

High Energy and Back Scattered Particles are sputtered to larger angles

Process of Ion Beam Sputtering



Process Parameters:

- Ion Energy
- Ion Mass
- Sputter Angle
- Reactive Gas Pressure
- Substrate Position
- Electron current
- ...

Summary: Basics of IBS

- **Energy necessary for high quality coating**
  - **> displacement energy: 20-25 eV**
  - **< defect creation**
  - **Values differs for coating materials**

- **IBS Energy input to coating is controlled by**
  - **Energy of primary ions**
  - **Mass of the primary ions**
  - **Position of the substrate area**
  - **Assist beam**

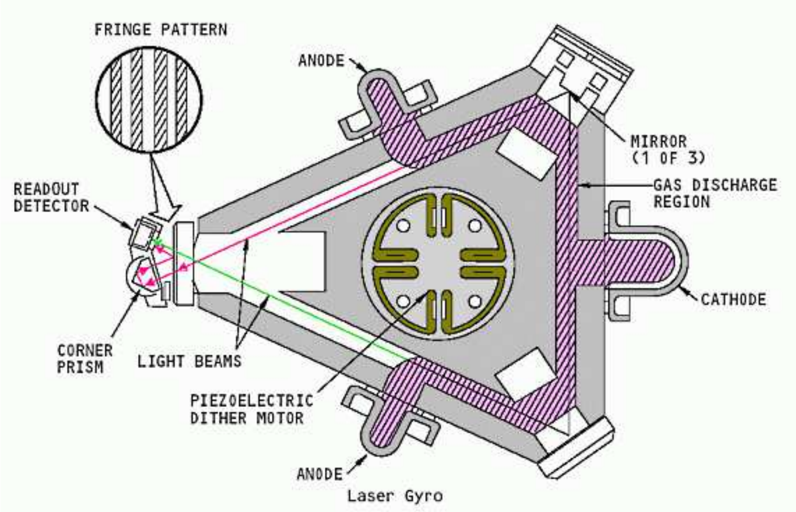
- **Standard IBS Materials: Oxides from Si, Ta, Ti, Nb, Hf, Zr**

Breakthroughs by IBS coating technology - 1 (since 1980)

Mirrors for Ring Laser Gyroscopes (RLGs) for Navigation since > 1980

Honeywell GG1320AN digital ring laser gyro

Height: 45 mm, diameter: 88 mm, weight: 450 g
Random Walk < 0.04 degree/hour



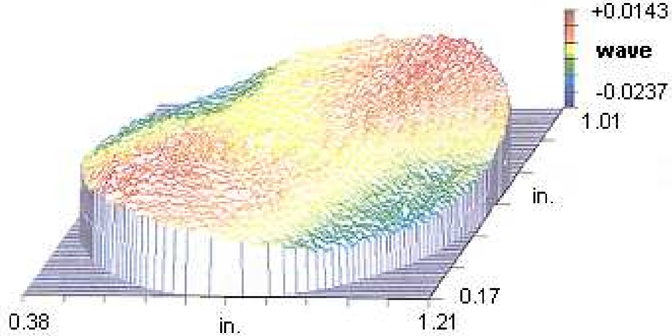
Sagnac effect

- 2 counter propagating waves
- platform rotation > phase shift
- shift detected interferometric
- 3 mirrors with very low losses
- scatter losses very important

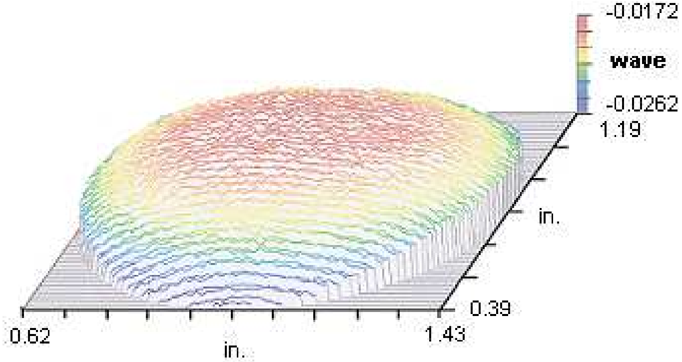
Breakthroughs by IBS coating technology - 1

Super polished Substrates: Roughness < 1 A are necessary

Mirror	AOI [°]	T (ppm)	# of layers	Reflection
1	30	90 ± 10	30	>99.9890
2	30	90 ± 10	30	>99.9890
3	30	< 20	34	>99.9960



Before Deposition (rms = 0.52 Angstroms)



After Depostion (rms = 0.53 Angstroms)

Measured by PSI: Phase Shift Interferometer

Recommended Losses: Scattering (TIS) < 10 ppm
Absorption < 10 ppm

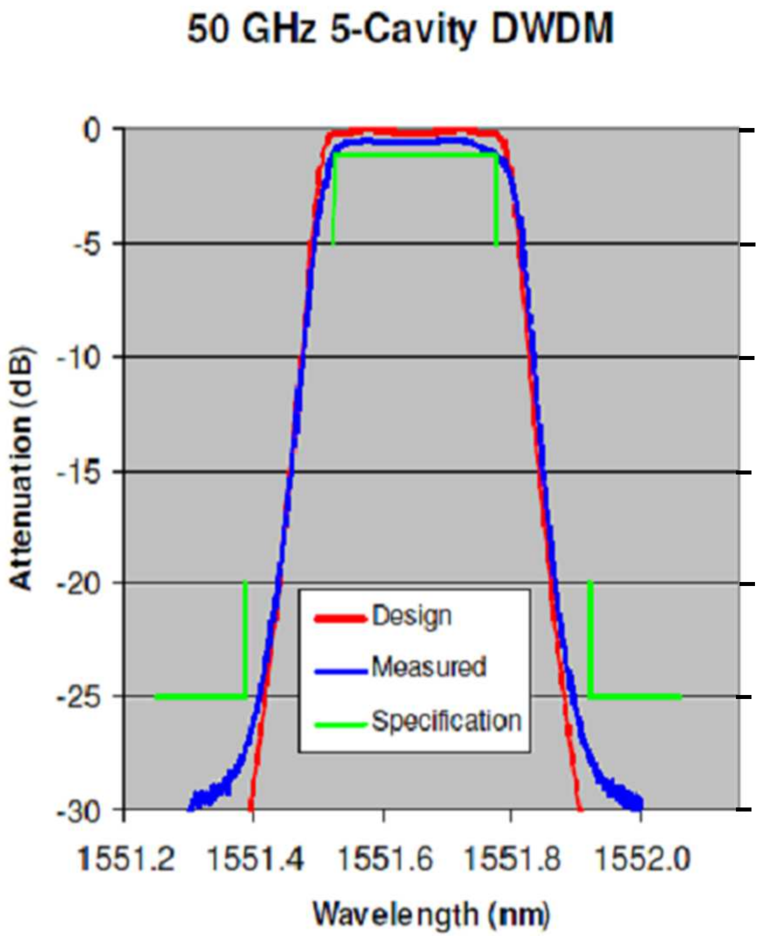
Loss values of a 45° mirror given by Vecco

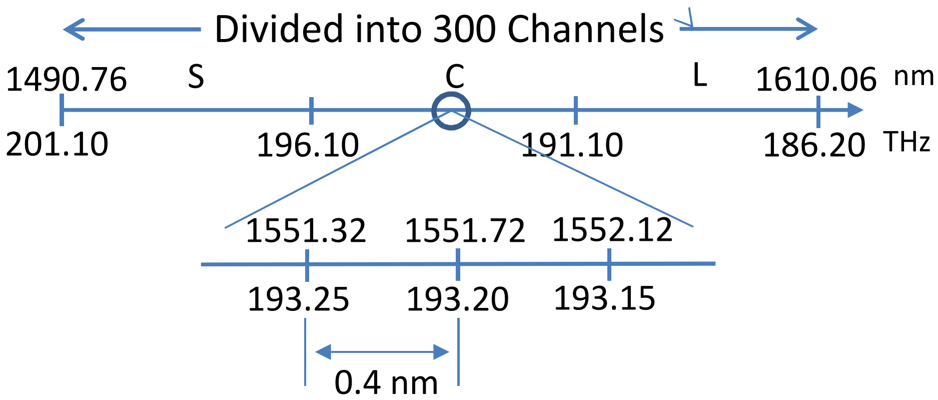
Materials	Total Loss	Transmission	Scatter	Absorption
SiO_2, Ta_2O_5	7.8	3.9	0.8	3.1
SiO_2, Ta_2O_5	8.5	3.9	0.9	3.6

Values given in parts per million (ppm) @ 633 nm (He Ne Laser)

Breakthroughs by IBS coating technology – 2 (since 1995)

DWDM Filters: Wavelength Multiplexing for Fiber-Communication

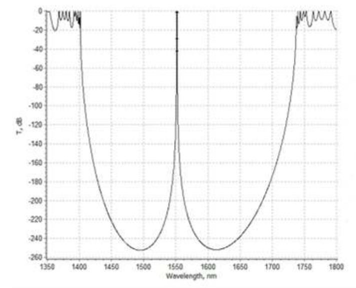




System design: N = 189
D = 50 000 nm

System Stability: 0.1 nm humidity change

System total view →



Similar Systems: Raman filters

Summary Part 1: High Quality of IBS coatings

- **Very low scatter losses**
- **Very low absorption losses**
- **Very dense and stable**

→ **Best applicable for Laser Coatings**

Mission of NANEO®

We provide for our customers

- **Highest coating quality by IBS Coating Technology**
- **Highest coating precision by in house Broad Band Optical Monitoring**

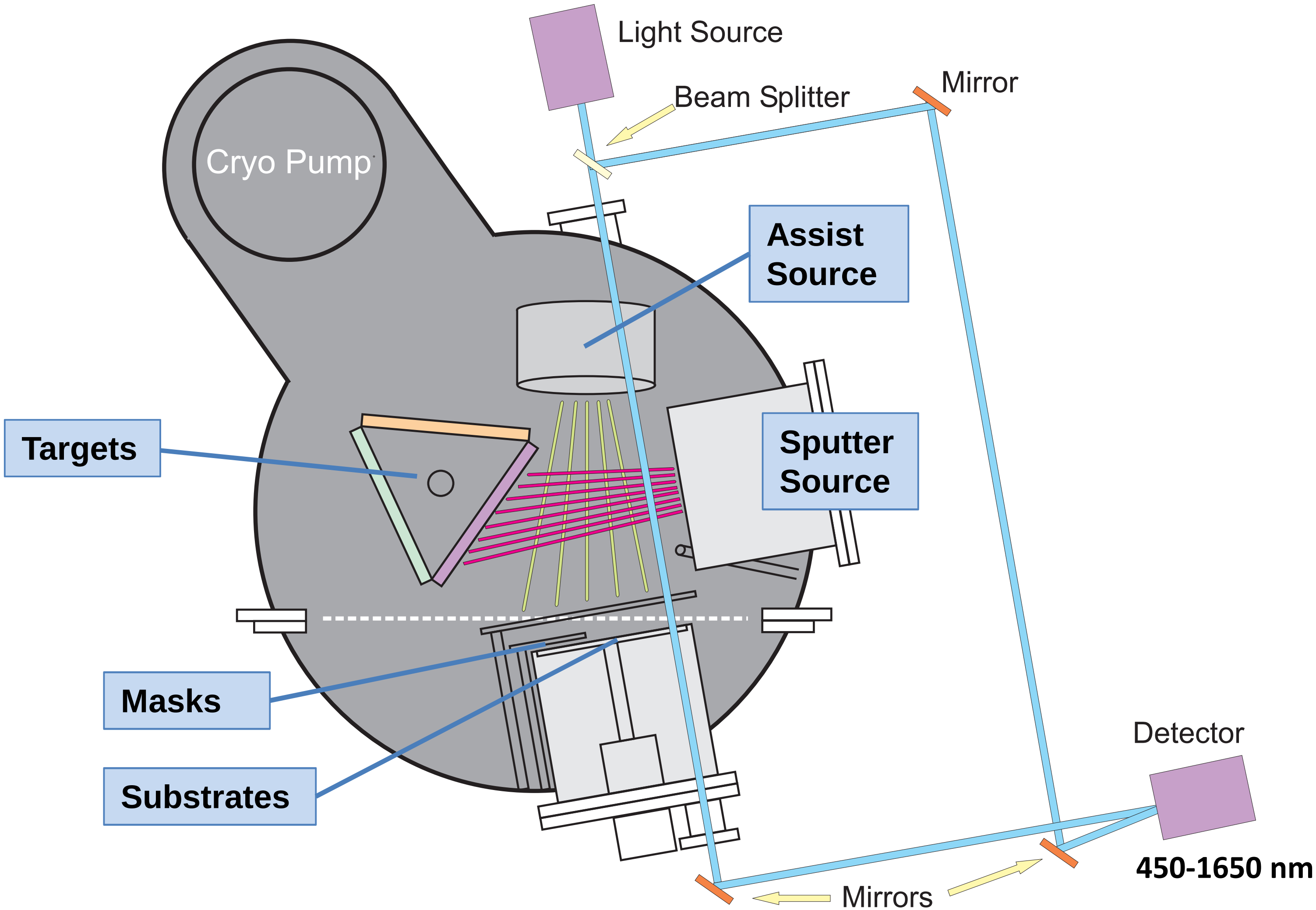
1. IBS Coating Machine

2. IBS Coating Machine

IBS in industrial production

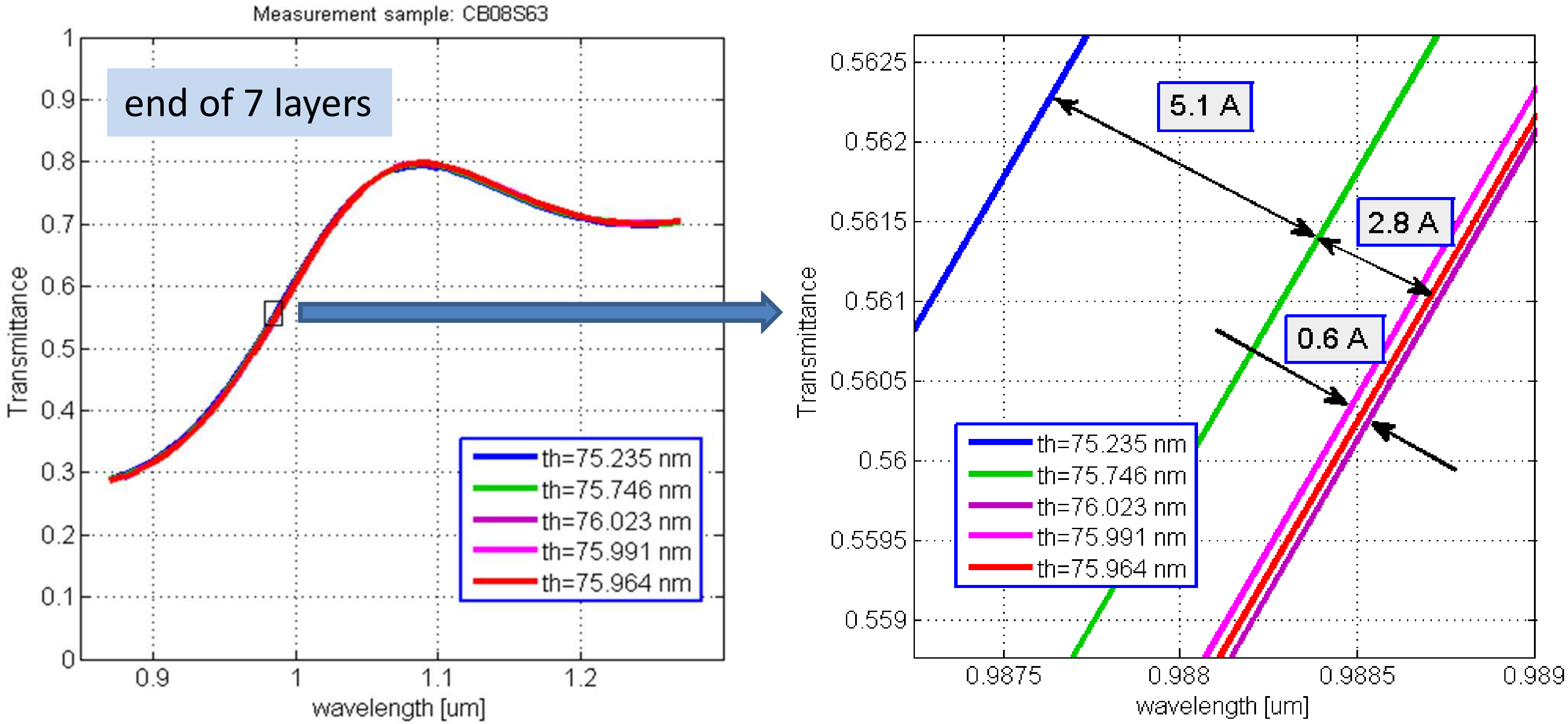
- **Very stable process**
  - **coatings rates < 0.5%**
  - **material dispersions < 0.1%**
- **Coating rates 2 – 3 A/sec**
- **Fully computer controlled operation in 24 hour modus**
- **Routinely Maintenance**
  - **source grids 200-300 h**
  - **neutralizers > 1000 h**
  - **shields 50 - 500 h**

IBS Coating Machine with Optical Monitoring System



Resolution Demonstration of Optical Monitoring

Measurement of 2 very thin coating steps within one layer



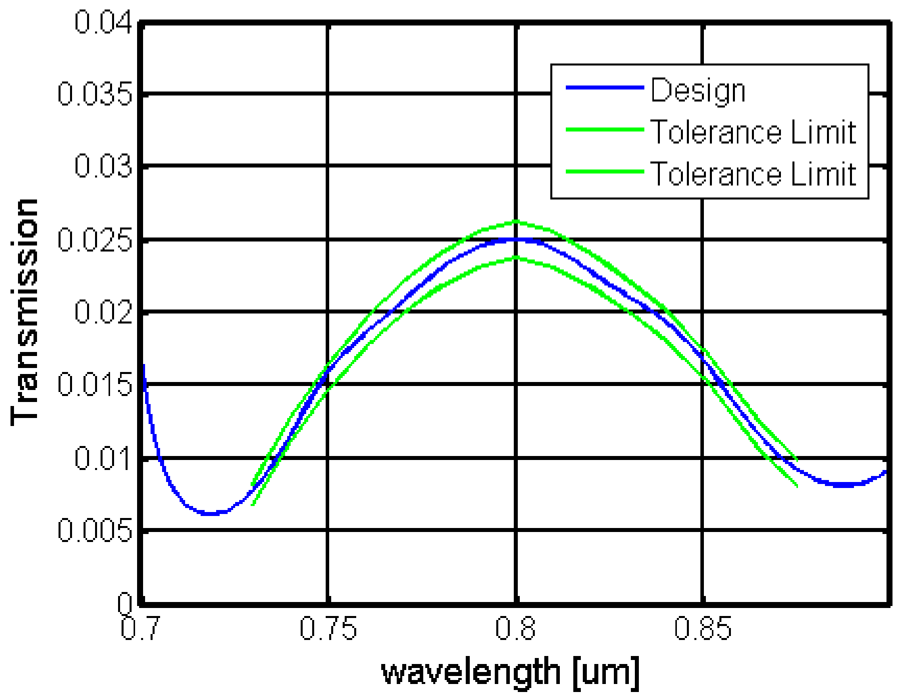
2 Measurements on coating steps + 3 at the end

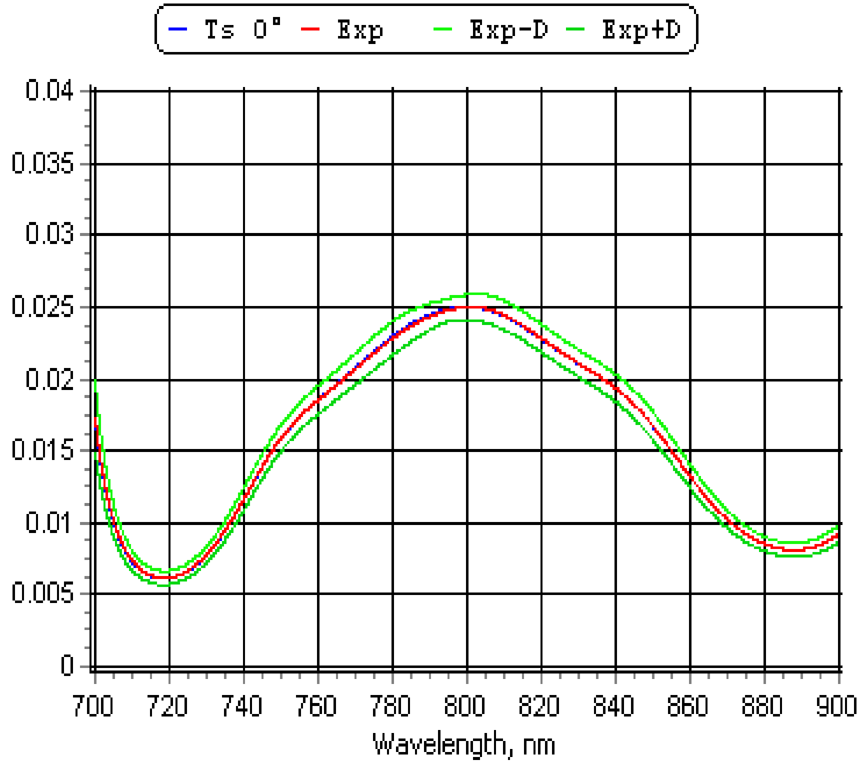
Details of the 5 measurements

Resolution below 1 Angstrom <==> Δth <0.001

Output Coupler for Gain Flattening

- Mirror Output is matched with laser gain for uniform output power
- Low tolerances over broad bandwidth





Design Date and Tolerances

System data: no layers: 37

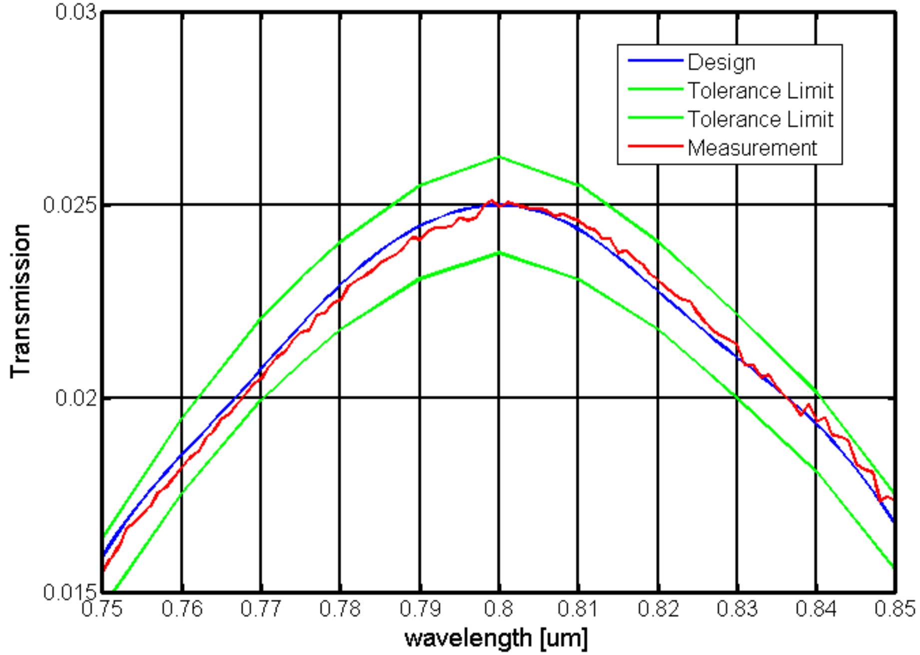
total thickness: 3900 nm

Statistical Error Calculation

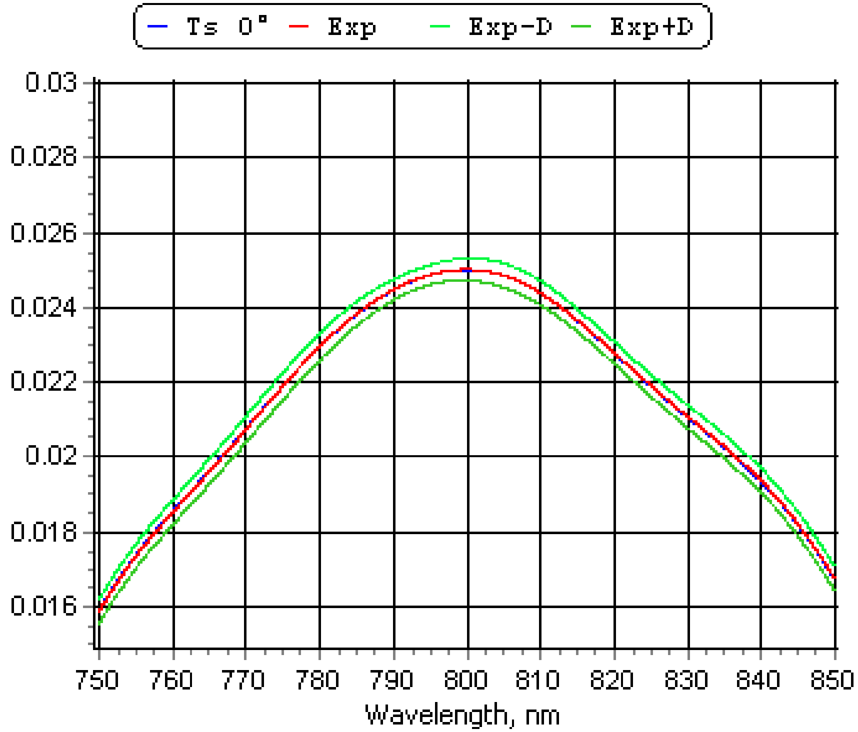
Δn=0.003, Δth=0.003, N=200

Output Coupler with Gain Flattening

Production result and statistical error sensitivity



Measurement by Transmission Spectrometer



Statistical Error Calculation

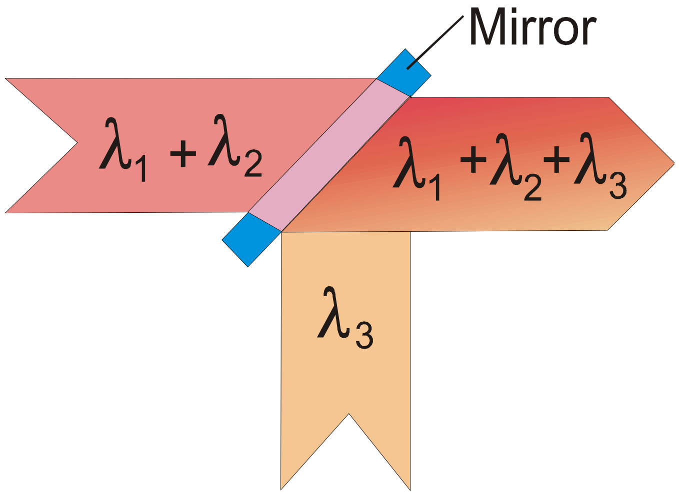
Δn=0.001, Δth=0.001, N=200

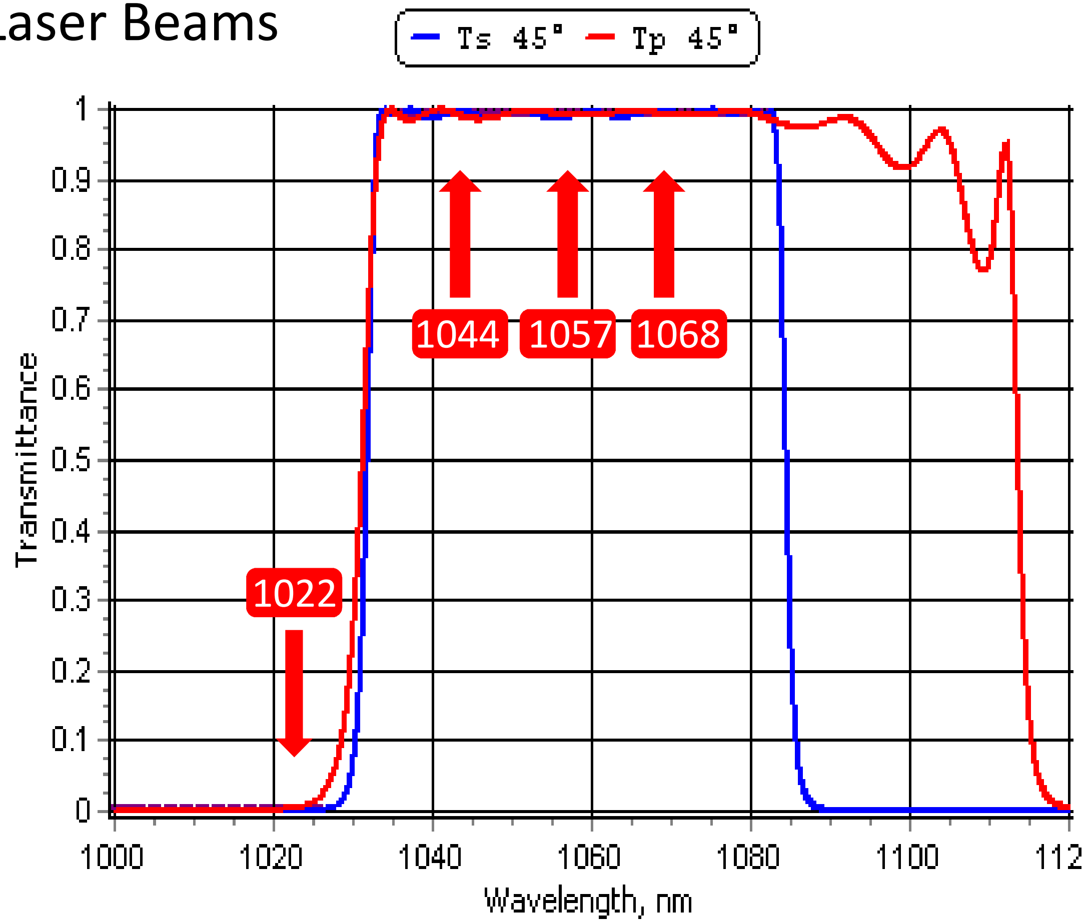
Production result within statistical error region Exp +/-D

Statistical Thickness and Dispersion Error <= 0.1%

High Power Beam Combiner

Wavelength Combining of Laser Beams





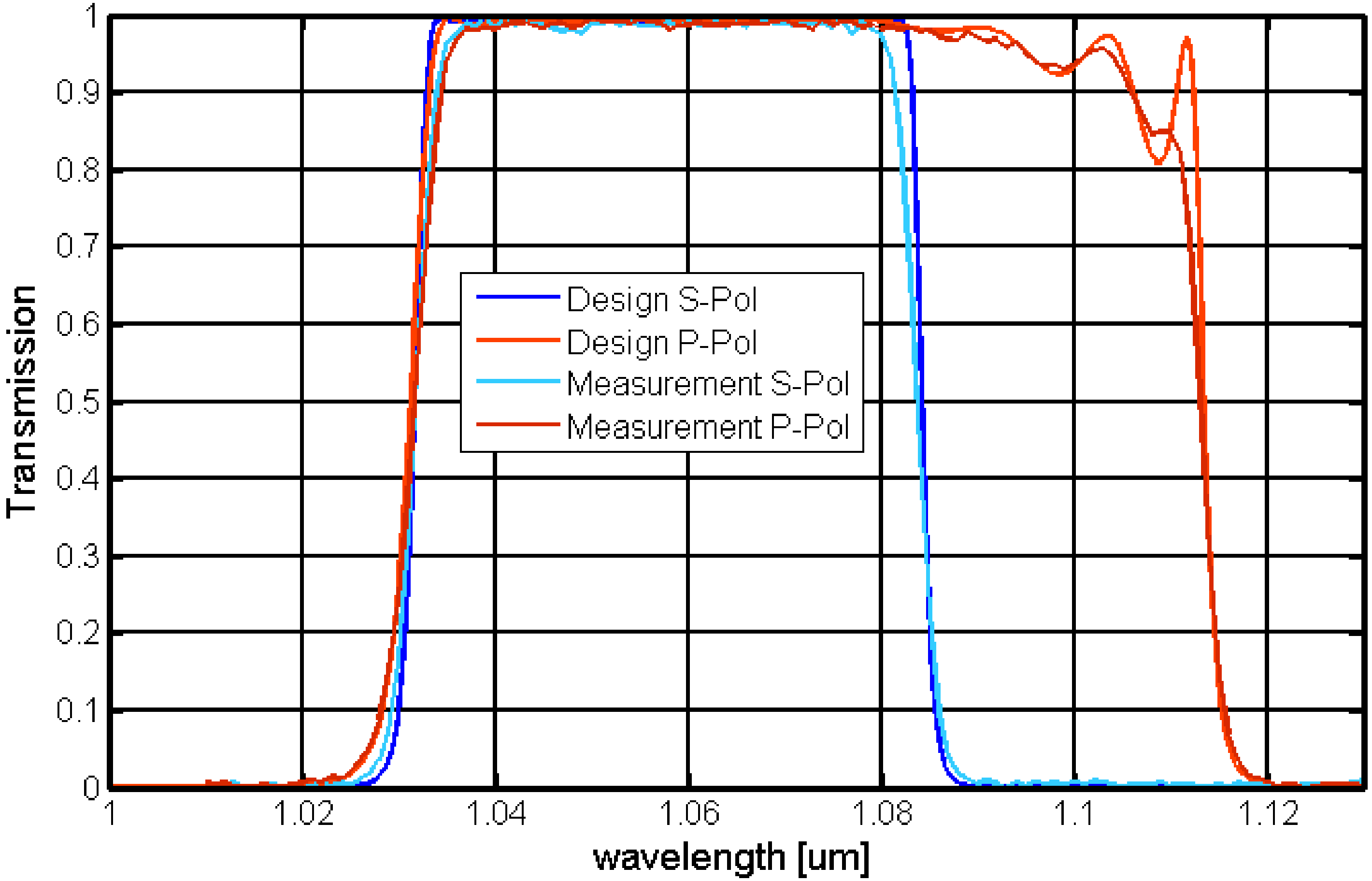
$\lambda_i = \lambda_i(\text{s-pol}) + \lambda_i(\text{p-pol})$

$P(\lambda_i) \sim 5\text{kW}$

System Design Data: no layers: 87
total thickness: 16650 nm

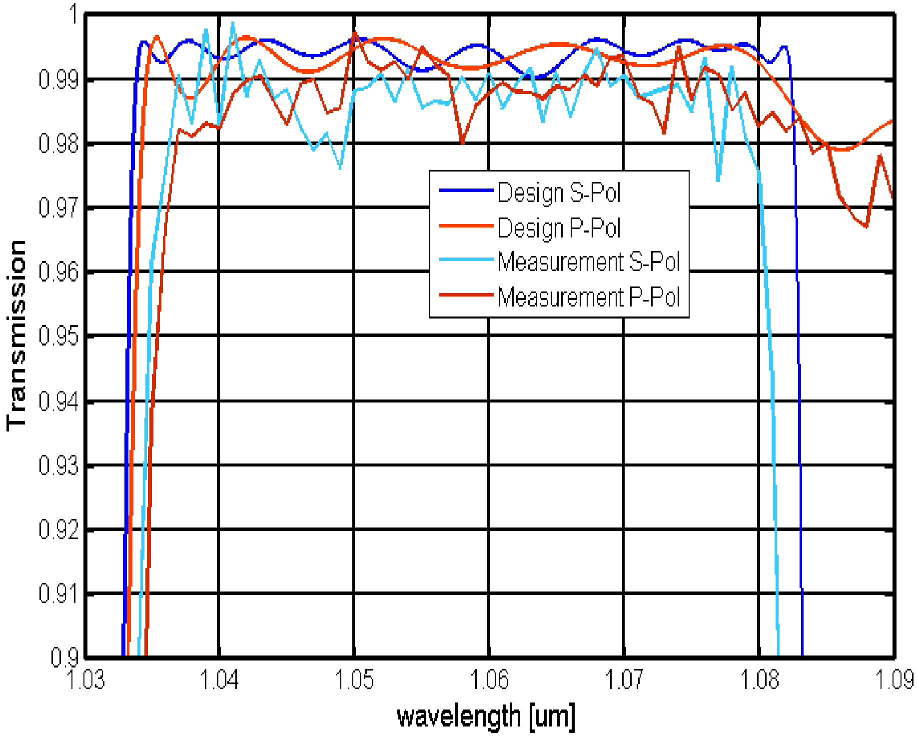
High Power Beam Combiner

Production result

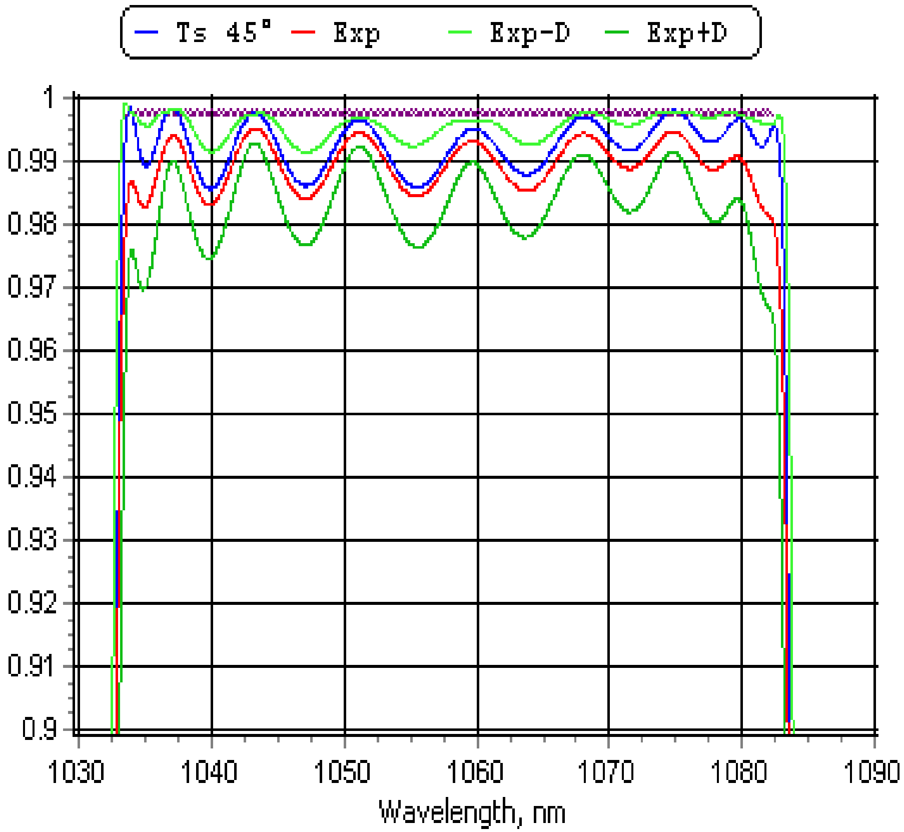


High Power Beam Combiner

Production Result Transmission Range



Measurement by Transmission Spectrometer



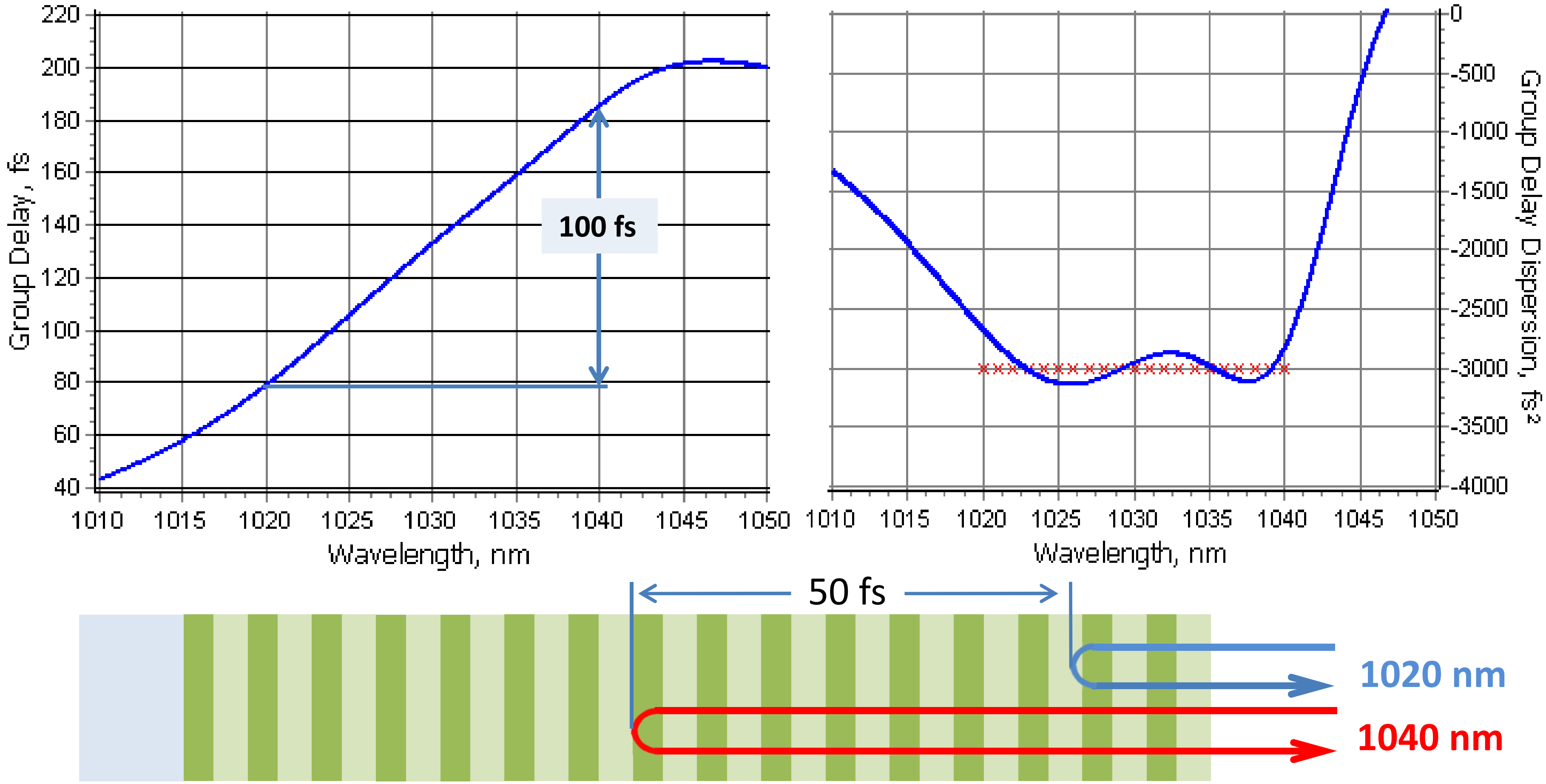
Statistical Error Calculation

Δn=0.0008, Δth=0.0008, N=200

Statistical Thickness and Dispersion Error << 0.08%

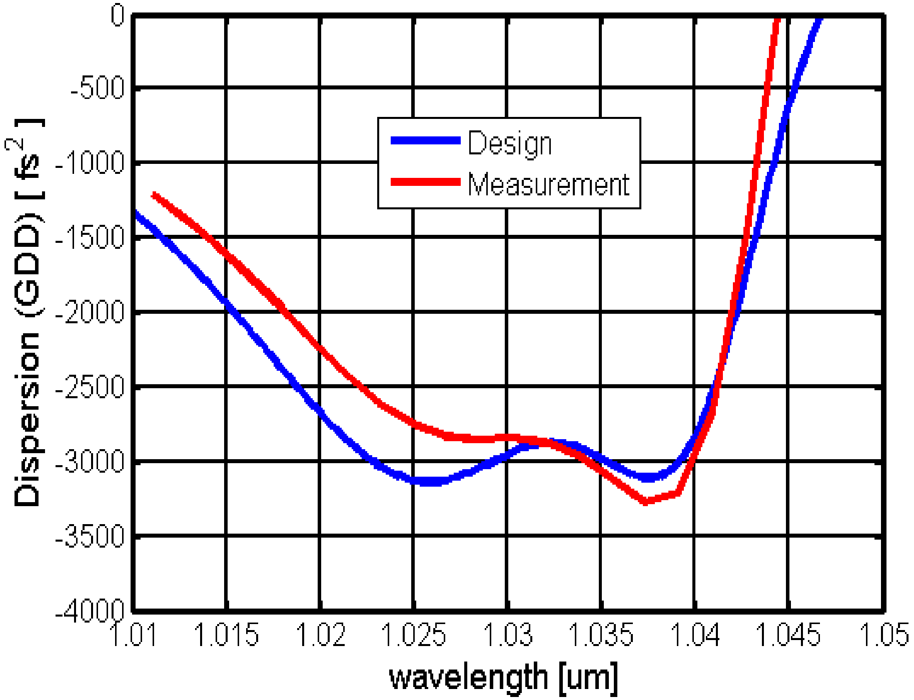
High Dispersion Mirror HDM @ 1030 nm with -3000 fs^2

Compensation of positive dispersion on beam path

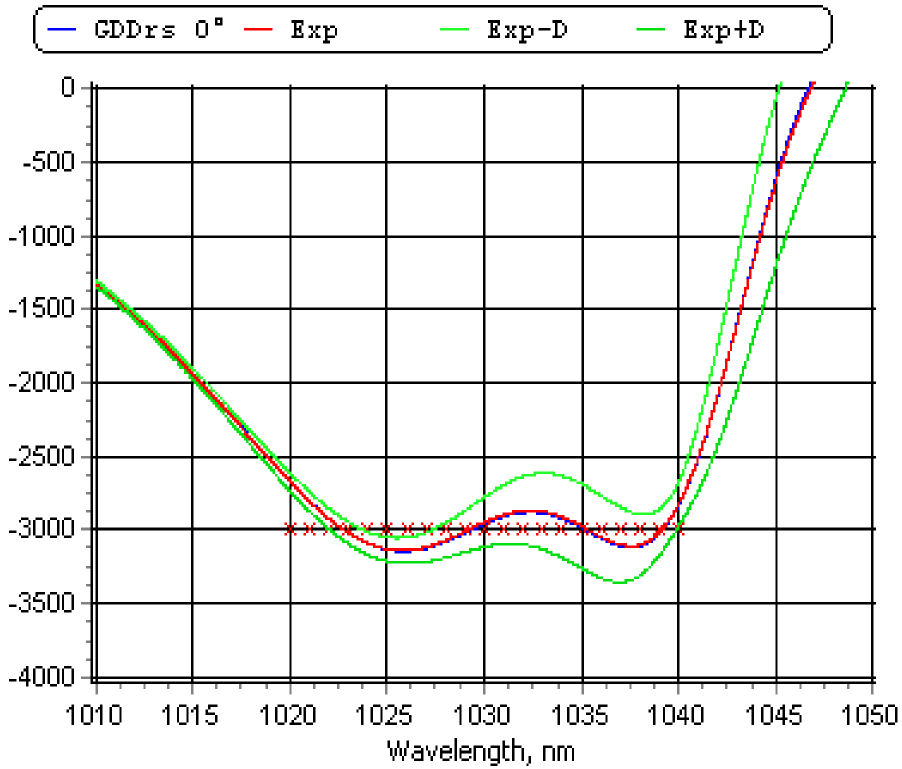


System data: no layers: 67 - total thickness: 9263 nm

Production Precision



Measurement by white light interferometer



Statistical Error Calculation

Δn=0.0005, Δth=0.0005, N=200

Production result within statistical error region Exp +/-D

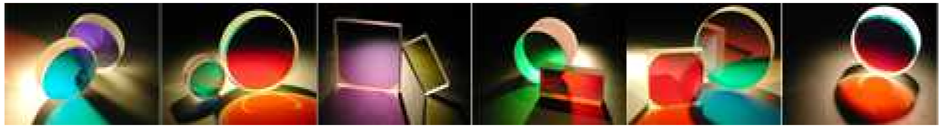
Production error in layer thickness < 0.05 %   <==>   Δth < 1 Angstrom

LIDT of Naneo Coatings

Coating System	LIDT Specification	LIDT Value [J/cm^2]
HR 1064 nm, R>99.98 Mat: Ta_2O_5, SiO_2 Substrate super polished	@ 1064 nm 20 ns 1 on 1, f_{rep}=20 Hz	90 / 140
HR 786 nm, R>99.9 Mat: Ta_2O_5, SiO_2 Standard QWOT Field Optimized	@ 786 nm 180 fs f_{rep}=1kHz n on one, 10^5	0.65 1.20
AR 786 nm, R<0.01 Mat: Ta_2O_5, SiO_2	@ 786 nm 180 fs f_{rep}=1kHz n on one, 10^5	1.20
Dichroic 390 nm, R 786 nm, R Mat: Al_2O_3, , SiO_2	@ 393 nm 180 fs f_{rep}=1kHz n on one, 10^5	0.39

Summary

- IBS is a very well controllable and stable production process
- Very high quality coatings can be produced in industrial scale
- Systems with very high spectral or phase broad band specifications can be produced routinely
- Coatings have very low scatter and absorption losses
- Coatings achieve high damage thresholds



Thank you for your attention