

Advanced Optics by Aspherical Elements

Engelberg
7. March 2007

Rüdiger Hentschel

Actual Impacts on Optics

- Modern Optics faces new challenges e.g.
 - Analogue vs. digital data/image acquisition
 - Special products vs. high volumes manufacturing
- Increasing requirements from application e. g.
 - Shorter wavelength, higher resolution, increased transmission (microlithography)
 - Smaller, weight reduced, telecentric, zoom lenses instead of fixed lenses (digital photography)

Economical solution ?

Consequence: Impact on complete value added chain

- Spheres → Aspheres → Free form surface
- Impact on each process step (design, materials, processing, metrology, coating, assembly)
- Modification of existing technologies vs. development of new technologies

Goal of the Day

- Show structure of optical modern technologies
- Short and compressed information on management level
- Basic understanding of technologies
(tool: optical technology reference book)

New Publication coming soon

Optical Technology Reference Book:

Advanced Optics by Aspherical Elements

Edited by: B. Braunecker, R. Hentschel, H.J.Tiziani
(to appear at SPIE June 2007)

Content:

- Whole workflow in a short and compressed form
- Information provided on management level
- Detailed technology descriptions by experts' contributions
- Links for further readings
- Template structure allows to compare alternative methods

Contributions of almost 60 experts:

J. Alkemper	B. Dörband	C. Gunkel	J. Korth	H. Pulker	B. Szyszka
S. Bauer	A. Dubarrè	M. Haag-Pichel	D. Kura	B. Reiss	H. Tafelmeier
K. Beckstette	H. Ebbesmeier	H. Hagedorn	E. Langenbach	D. Ristau	U. Tippner
A. Bell	M. Eisner	P. Hartmann	A. Laschitsch	S. Ritter	W. Ulrich
T. Bergs	O. Fähnle	B. Hladik	R. Litschel	U. Schallenberg	R.Völkel
M. Biber	M. Falz	C. Horneber	H. Mann	B. Schreder	A. Wälti
R. Börret	H. Feldmann	A. Jacobsen	R. Mayer	A. Schwarzhans	K. Weible
U. Brauneck	M. Forrer	N. Kaiser	M. Meeder	K. Seneschal-Merz	A. Würsch
B. Bresseler	E. Fischer	P. Karbe	R. Müller	L. Stauffer	J. Zimmer
H. Buchenauer	S. Gold	C. Klein	U. Peuchert	T. Sure	



News Release

January 26, 2004

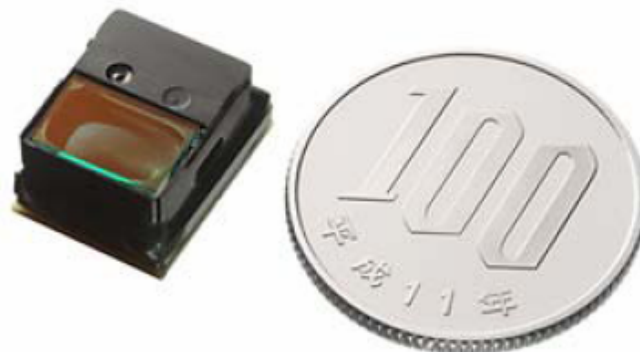
Advantages of new development:

...
In the current prototype, two free-shaped prisms provide performance equivalent to a conventional coaxial lens that has three to five lens elements, and can achieve theoretical resolutions of 250 line-pairs per millimeter at the center, and 200 line-pairs per millimeter at the periphery

...
light rays strike the surface of the image sensor at a perpendicular angle

...

Olympus Develops New Free-Shaped Prism Type Thin Lens Unit and Announces Plans to Enter Cellphone Camera Module Market



Free-Shaped Prism Type Lens Unit

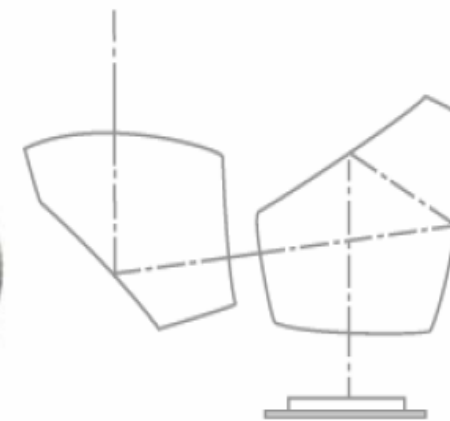
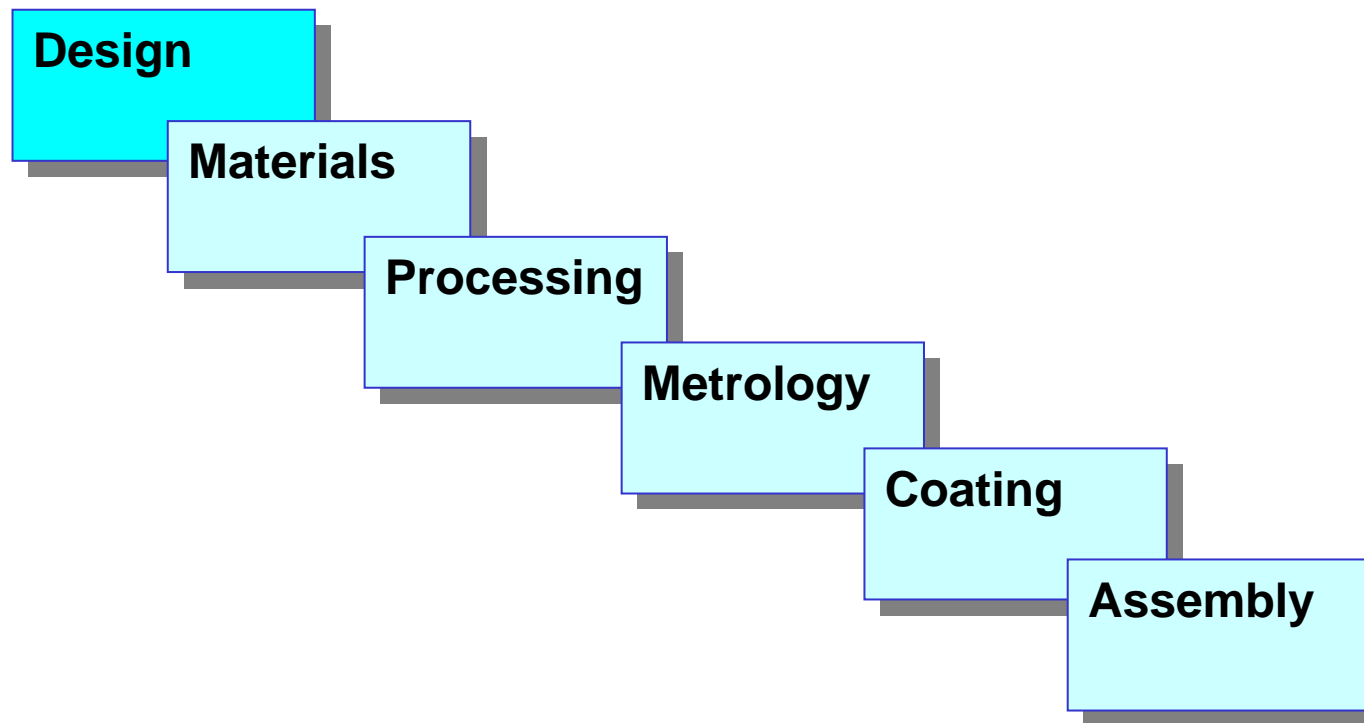


Fig. 1 - Free-Shaped Prism Type Lens Structure & Light Path

Summary

Olympus Corporation (President: Tsuyoshi Kikukawa) is pleased to announce the development of a new, Free-Shaped Prism Type Lens Unit for use in camera-equipped cellular telephones. A prototype camera module with a thickness of 8.5 millimeters has been produced using the new lens unit, and has been demonstrated to support 1.3-megapixel resolutions. It is the thinnest such unit yet developed, and is notable for its potential to meet the performance demands of image sensors with a resolution in excess of two megapixels. A fully functional camera module incorporating the new lens unit and an image sensor is scheduled to be available in the fall of 2004.

Value Added Chain for Aspherical Lenses



Design Drivers

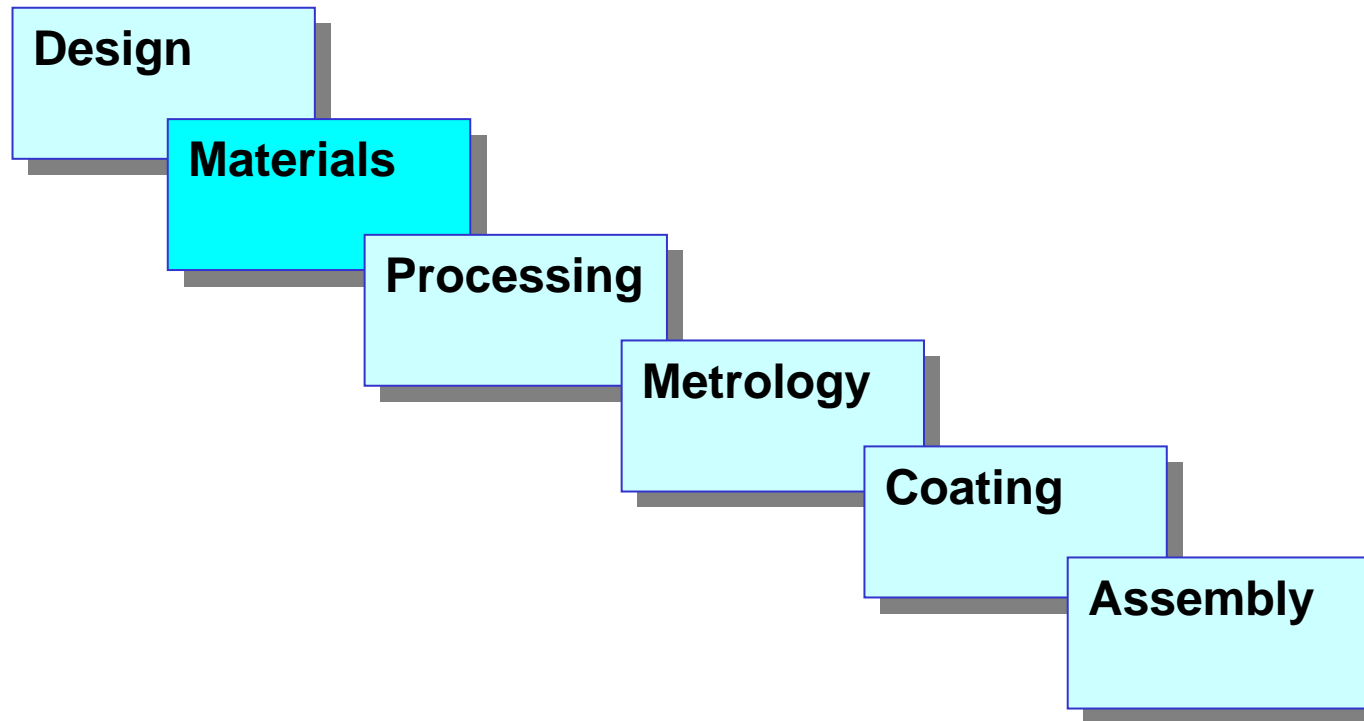
The reduction of the number of optical components is only one reason to insert aspheres into optical systems. Other important design drivers are

- to increase the imaging quality (resolution; distortion), which can't be achieved by a pure spherical design. Example: Deep-UV-Lithography.
- to reduce the construction size. Example: Photographic zoom lenses.
- to save weight, since one asphere is perhaps lighter than several spherical components yielding the same optical performance. Example: IR-Optics at 1-5 μm and 8-12 μm , made of 'heavy' Germanium- or Silicon material.
- to improve the total light transmission by reducing the number of optical elements. Example: Fluorescence microscopes with high transmission demands in the blue and UV spectral range.
- to simplify the assembly process

Status of Aspherisation

Application fields	Advantages and drivers	Status
<u>Large quantities</u>		
Illuminations	Better imaging quality with one element; cost reduction	Production
Laser Collimator	Better imaging quality with one element; cost reduction; beam stability	Production
Photo Optics	Necessary for zoom systems; cost reduction; better imaging quality; smaller construction length	Production
Large Format Film Lenses	Necessary for zoom systems; cost reduction; better imaging quality; smaller construction length	Production
<u>Small quantities</u>		
UV-Lithography	Better imaging quality; higher transmission at UV wavelengths	Production
Aerial Survey	Better correction of distortion and telecentricity; cost, weight and size reduction	in Preparation
Space Communication	Light weight; compact layout; radiation resistance	Prototype
Correction Plate for Mirror Telescope	ditto; better imaging quality	in Study

Value Added Chain for Aspherical Lenses



Material Classification

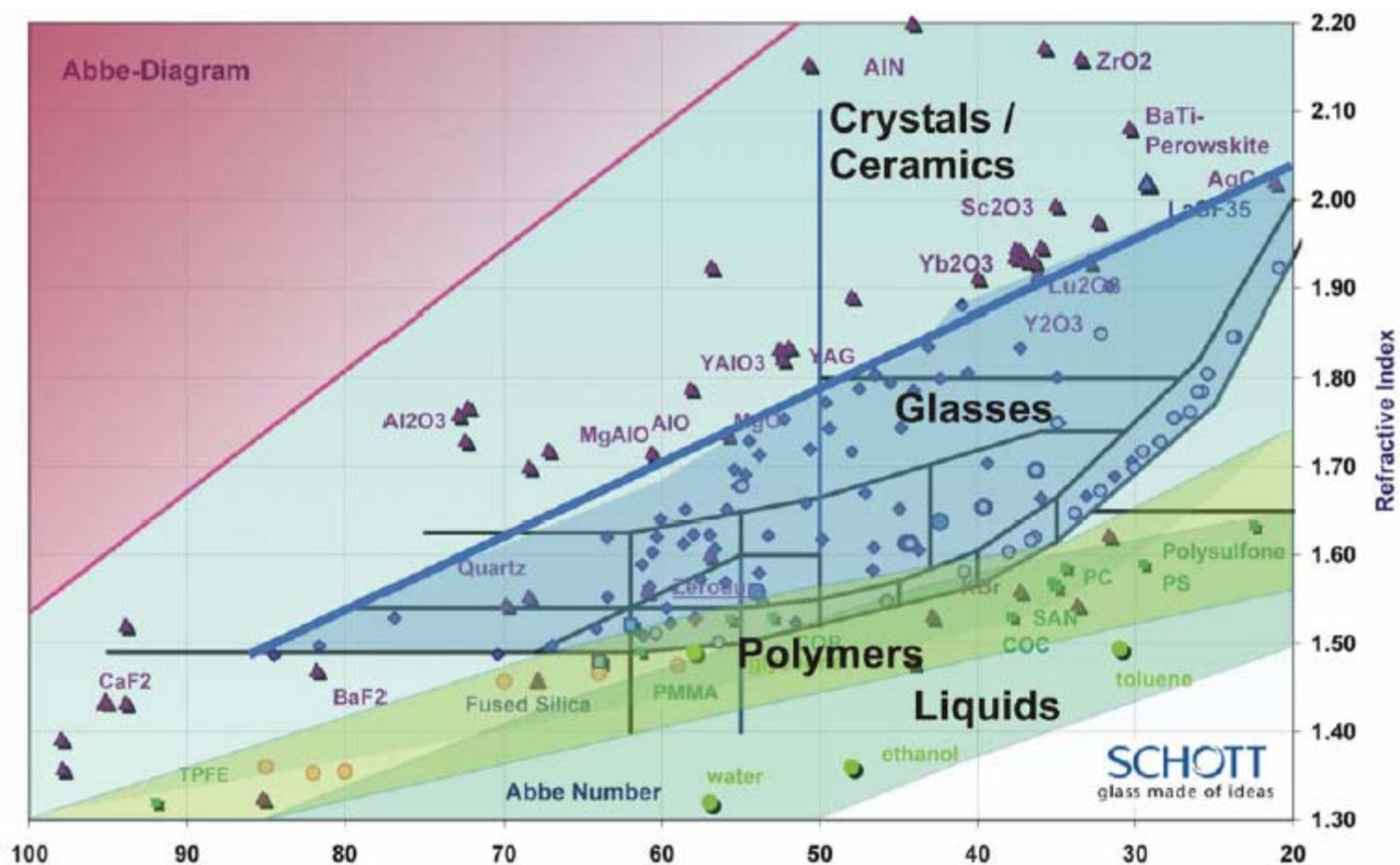


Figure 14: Abbe-Diagram of Optical Materials (Fluids, Polymers, Glasses, Crystals)

Optical Designers need additional Information

Optical designers need information beyond n_d and v_d :

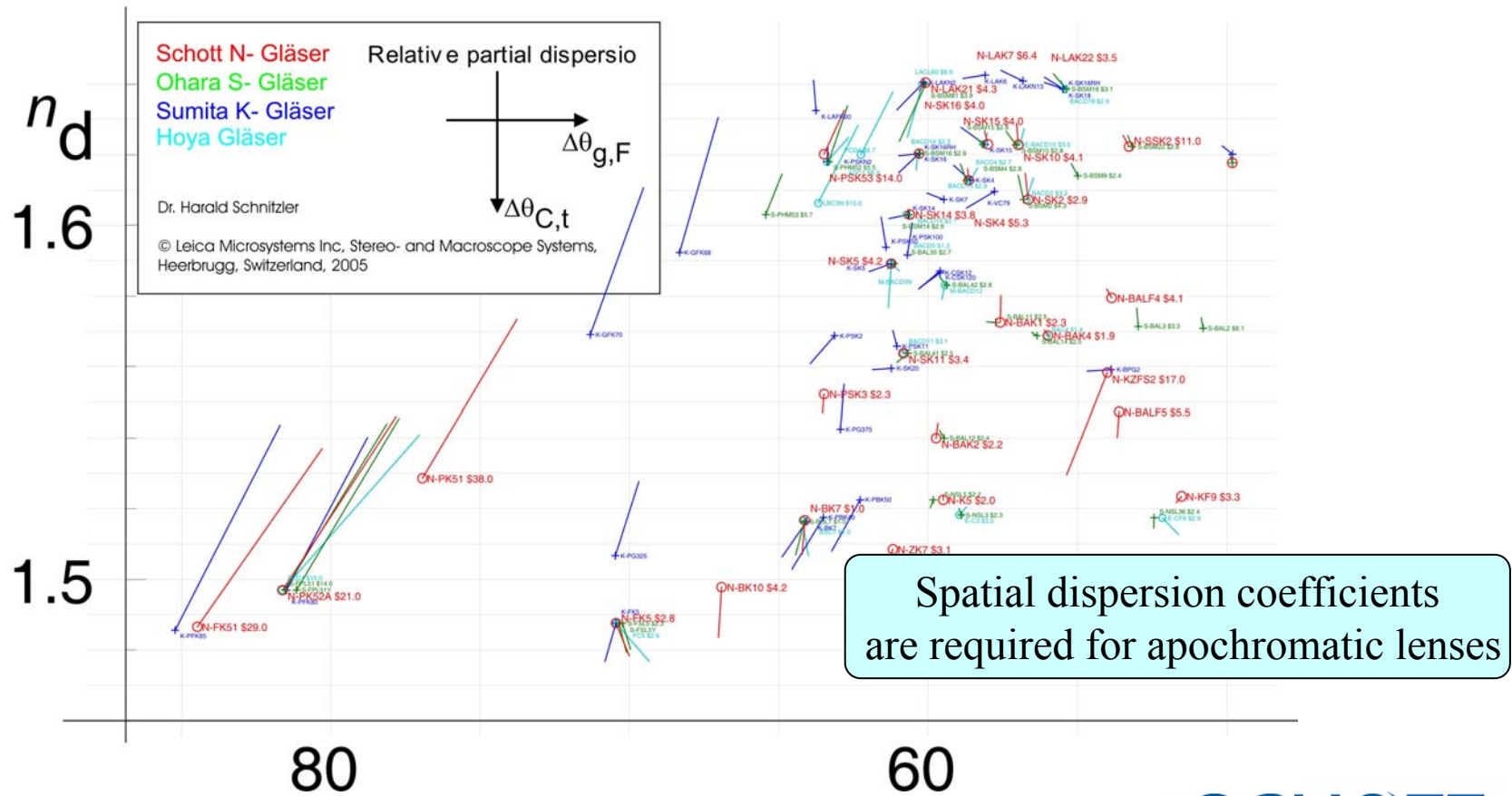
- partial dispersion values P
- transmission values T
- stress optical coefficients K and birefringence
- Chemical resistance against water, acids, and bases
- Mechanical properties like hardness (Knoop HK) and Young's modulus E
- Thermal parameters like the thermal expansion coefficient α , thermal capacity Cp, thermal conductivity λ , heat resistance, and the thermal shift of optical properties

Sometimes it is convenient to use deduced coefficients which describe the Material/system in real situations:

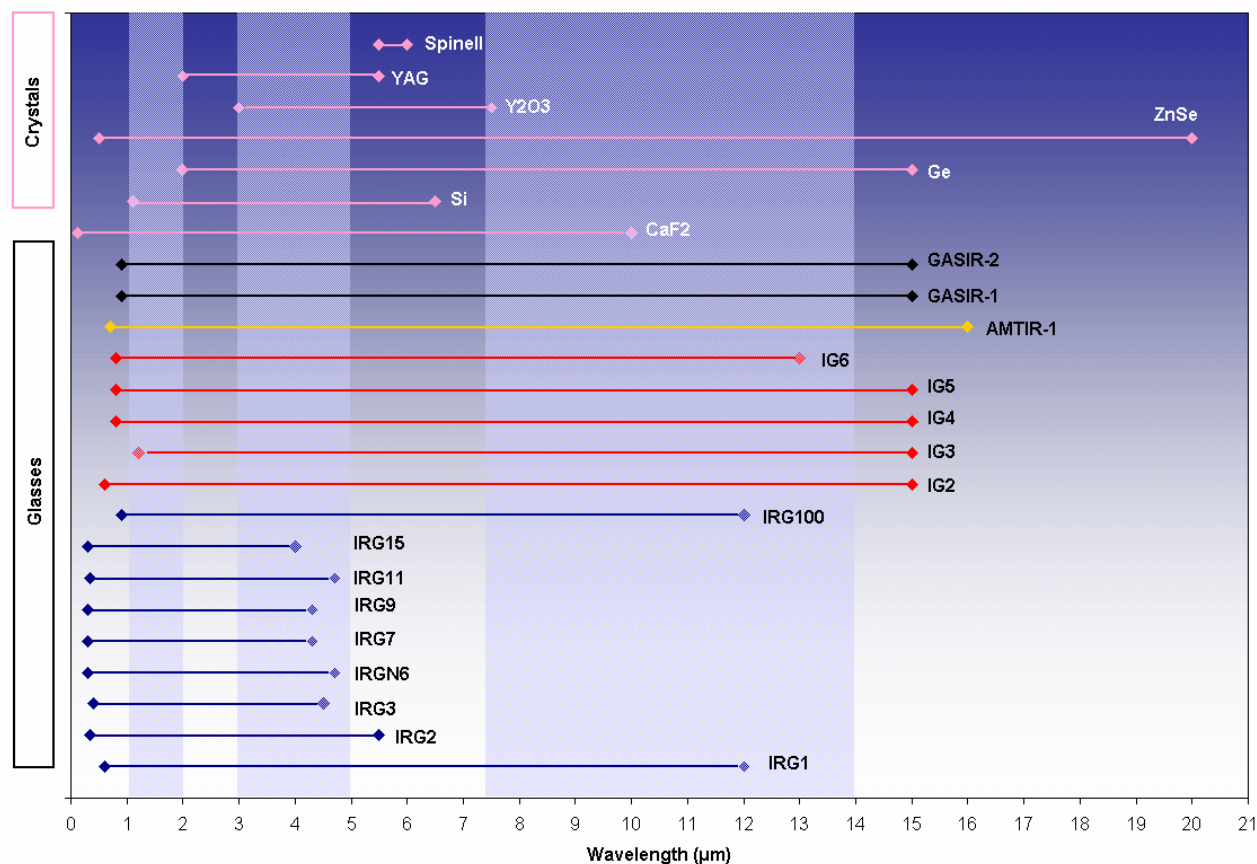
- specific thermal stress $\varphi_w = \frac{\alpha \cdot E}{1 - \mu}$ for the maximal expected stress in glass for a spatial local temperature difference of 1 K
- The specific heat conductivity $\kappa = \frac{\lambda}{c_p \cdot \rho}$ describes the heat diffusion in materials

How to get an Overview on Material Properties

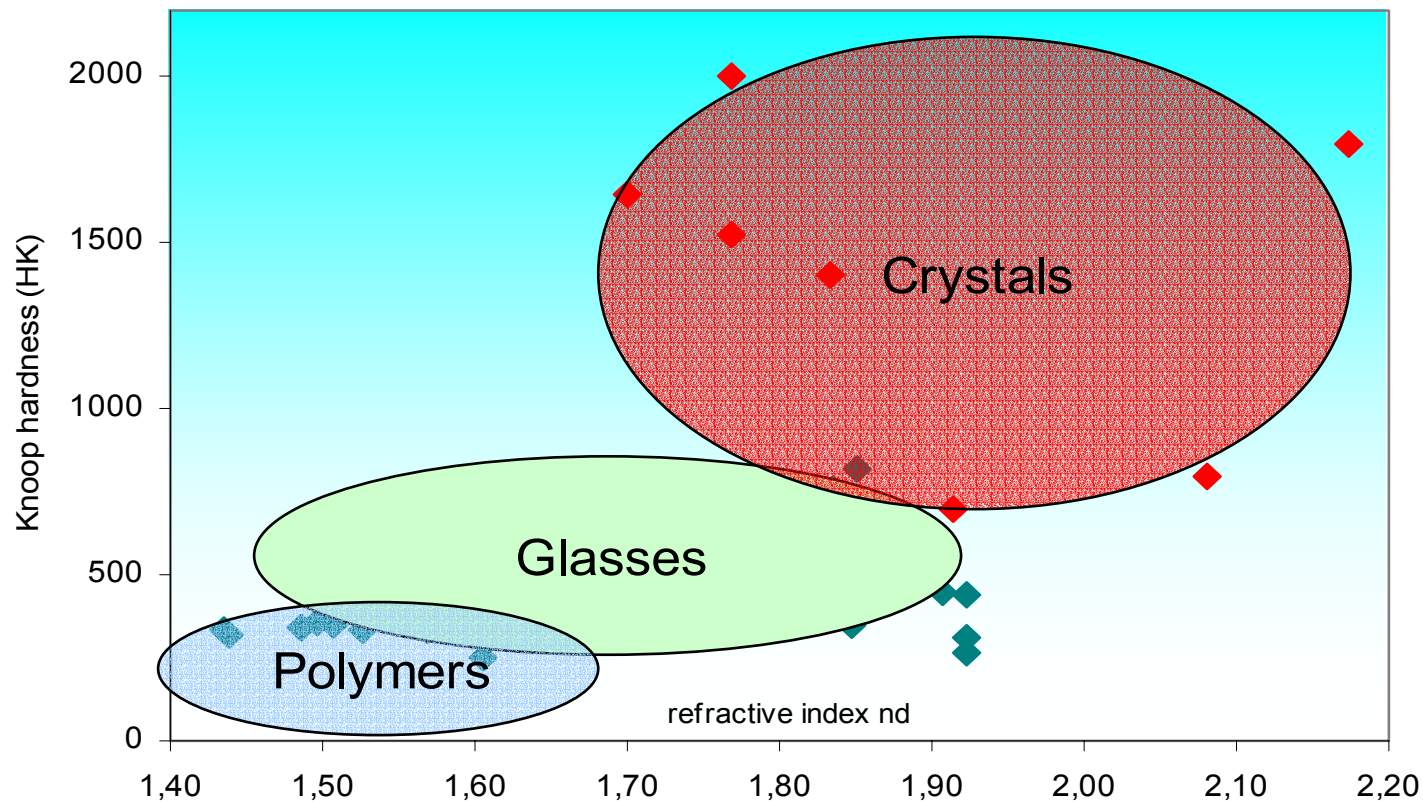
Example: n_d - v_d - P_g F- P_{Ct} -diagram (courtesy H. Schnitzler, Leica Microsystems AG)



How to get an Overview on Material Properties



How to get an Overview on Material Properties



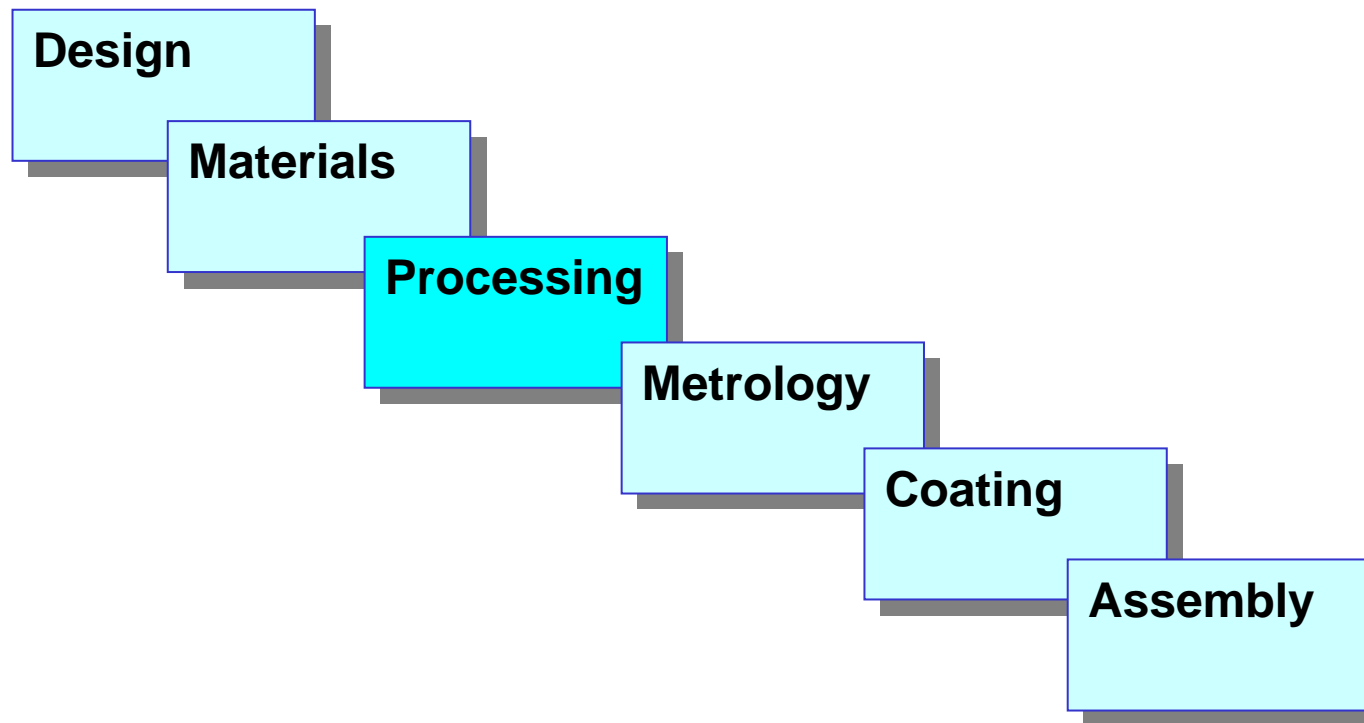
Drivers for Material Development

A few examples of material development drivers:

- Overall drivers:
 - Environmental requirements e. g. Pb-free glass types
- Technology drivers:
 - PGM (Precision Glass Moulding) requirements e. g. Low T_g glass types
- Application drivers:
 - Design drivers e. g. high index optical ceramics
 - User driven requirements e. g. low weight of optical components

**Driven by use of
aspherical lenses**

Value Added Chain for Aspherical Lenses



Historical Approach

The idea of polishing aspherical lenses is very old
– but considerable results are obtained only within the last 100 years

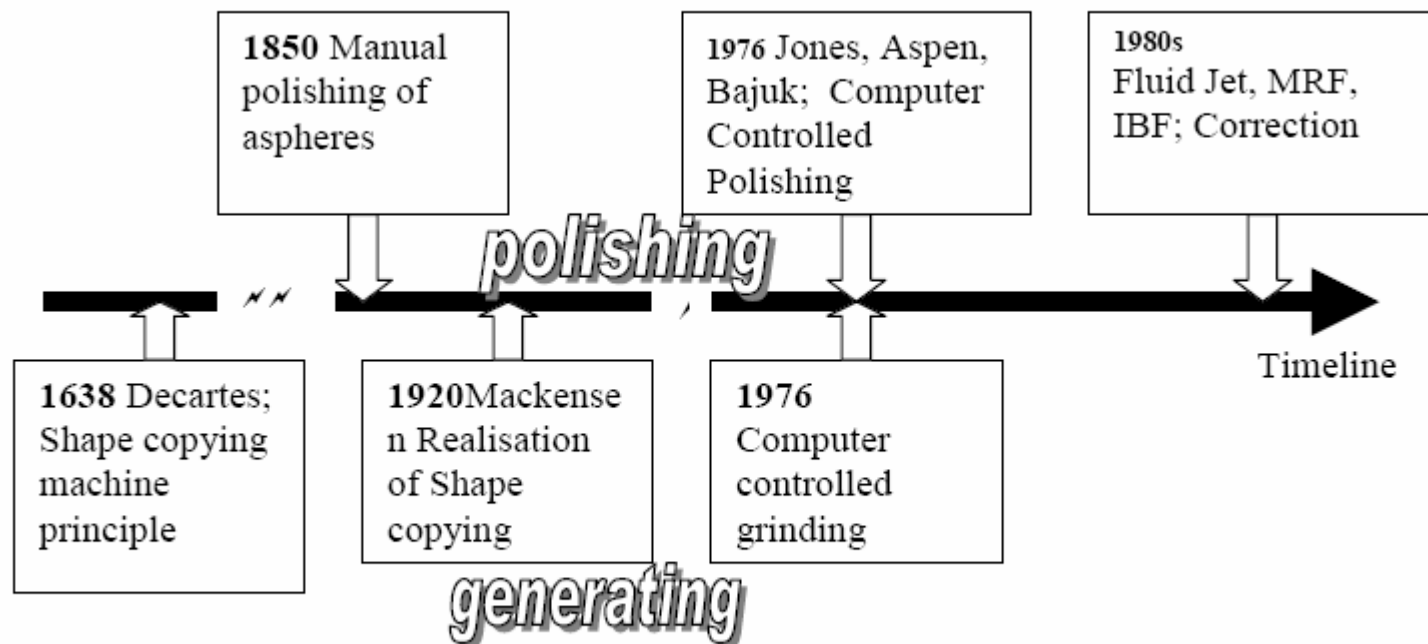


Figure 22: Historical progress in generating and polishing processes

Functional Approach

There are 3 main processing technology lines:

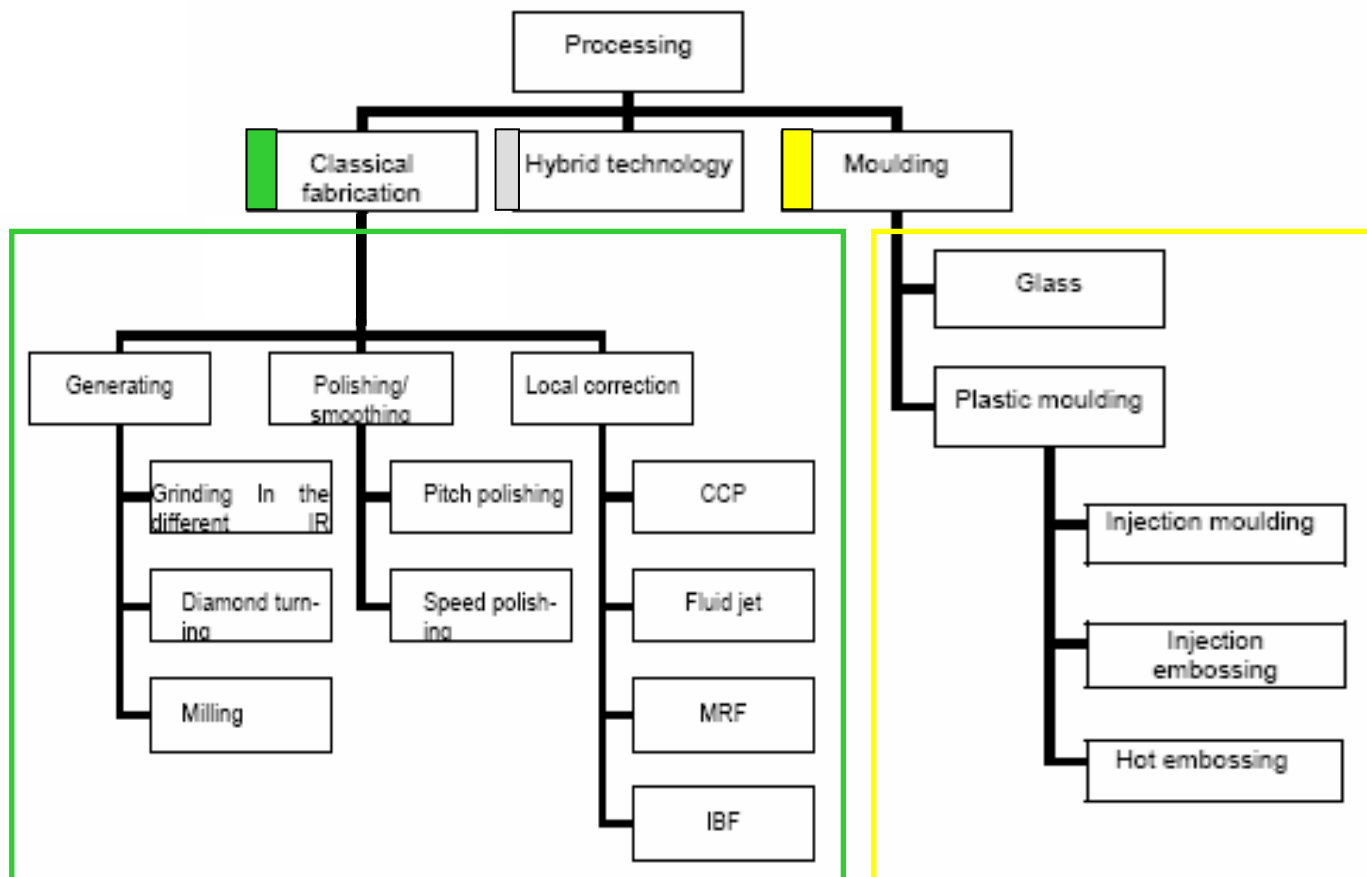


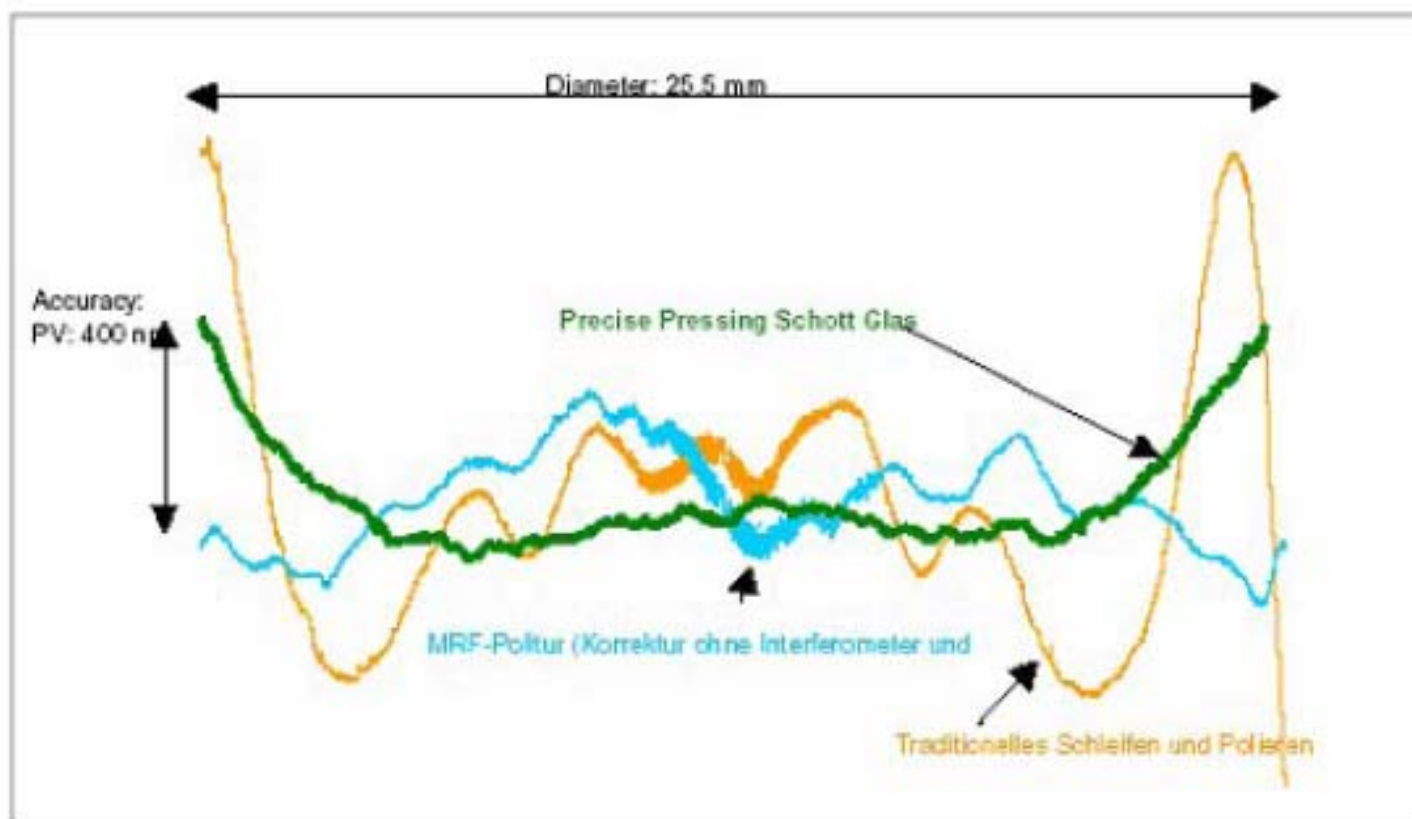
Figure 29: Overview over different kind of process technologies.

Overview on Processing Technologies

Overview specifications and characteristics of the different processes (typical values in production)

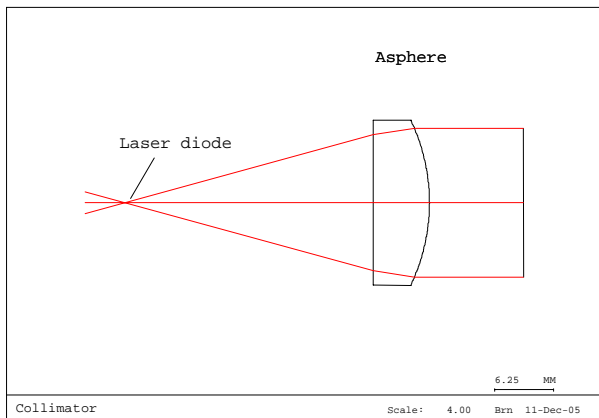
Process	Batch size	Dia.	Shape deviation	Surface roughness	Advantages	Limits	Main cost driver
		[mm]	[nm] PV	[nm] rms			
Grinding	< 10 ⁴	2 - 400	1000	50 - 1000	Fast generating process	Subsurface damage	size, accuracy
Diamond turning	< 10 ³	2 - 400	100	5 - 20	No subsurface damage, for IR sufficient roughness	Surface roughness	size, accuracy
Speed / pitch polishing	< 10 ⁴	10 - 300	300	0.2 - 0.5	Very low surface roughness, fast polishing process	Correction of local surface deviations	size
CCP	< 10 ³	5 - 8000	30	0.5	30 years experience	Tool wear, edge roll-off	size
MRF	< 10 ³	5 - 500	10	0.3	no edge roll-off, no tool wear, low damaged surface layer	Center artefact for r-φ tool path	size, fluid
Fluid Jet	< 10 ³	5 - 240	30	0.5	no edge roll-off	Stability of foot print	size
IBF	< 10 ³		5	0.2	no edge roll-off	Low removal rate	vacuum
Precision glass moulding	10 ⁴ to >10 ⁶	0.5 - 35	1-5	2	High volume	Size, accuracy	Cycle time, accuracy
Injection moulding	10 ⁴ to >10 ⁶	0.5 - 200	1 - 10	5	High volume, complicated shapes possible	Birefringence, micro structures	accuracy
Injection/ hot embossing	10 ⁴ to >10 ⁶	0.5 - 200	1- 10	5	Low birefringence, optics including mounting	thickness	Cycle time, accuracy

Surface Structure for different Processing Technologies



Measured surface deformations for different manufacturing processes

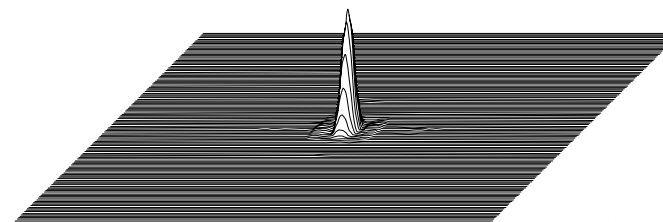
Example: Beam Rider for Line Marking



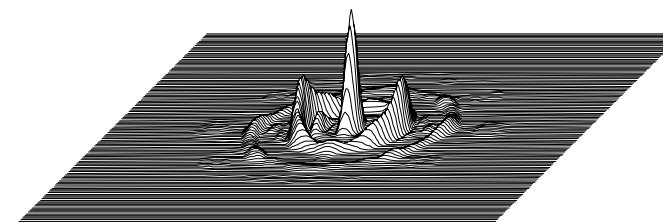
Laser collimator with aspheric lens



Laserspot at 100 m



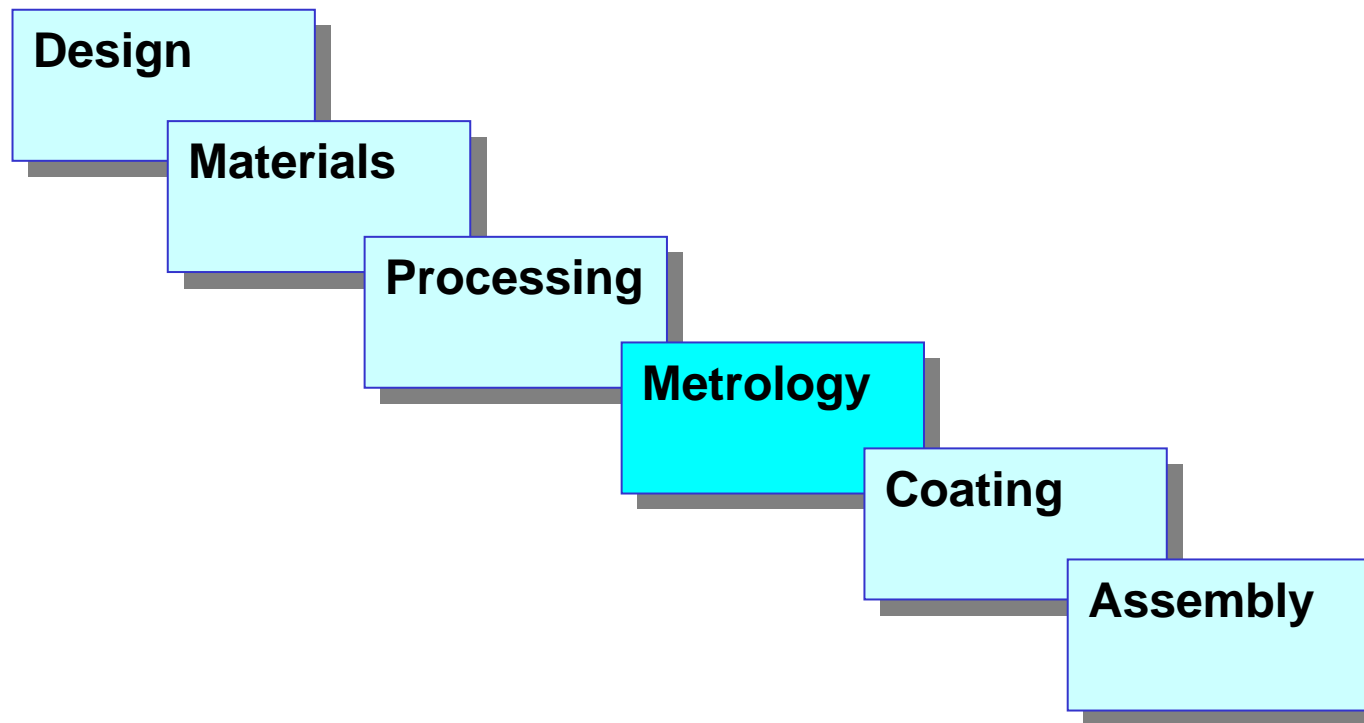
Ideal lens



Lens with surface deformation
(Amplitude +/- 300 nm; spatial frequency 4 mm)

Courtesy Leica Geosystems

Value Added Chain for Aspherical Lenses



Classification of Surface Topography

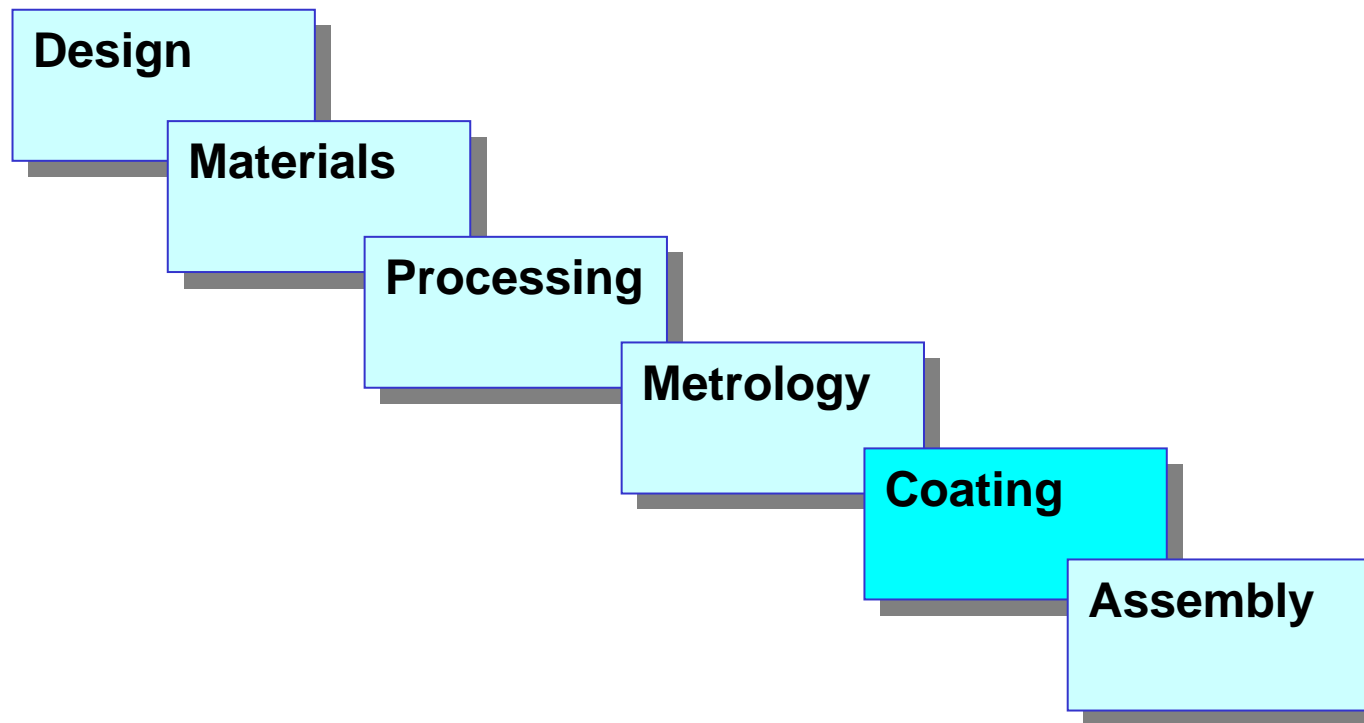
Roughness (high spatial frequencies)	Waviness (mid spatial frequencies)	Form (low spatial frequencies)
$\Lambda \leq 20 \mu m$	$20 \mu m \leq \Lambda \leq 1 mm$	$\Lambda \geq 1 mm$

Measuring Principle and Resolution

			Roughness			Waviness			Form						
			0.01nm	0.1nm	1nm	10nm	100nm	1µm	10µm	100µm	1mm	10mm	100mm	1m	10m
Interferometry	Spatial Resol. / meas. Spatial Range	1µm-1000mm													
	Height Resol. / Microroughness range, RMS	0.2nm-200nm													
Macroscopic Fringe projection	Spatial Resol. / meas. Spatial Range	10µm-2m													
	Height Resol. / Height Range	10µm-1mm													
Microscopic Fringe Projection	Spatial Resol. / meas. Spatial Range	1µm-30mm													
	Height Resol. / Height Range	0.1µm-10µm													
Confocal Principle	Spatial Resol. / meas. Spatial Range	0.5µm-30mm													
	Height Resol. / Height Range	10nm-10µm													
White light Interferometry	Spatial Resol. / meas. Spatial Range	0.7µm-5mm													
	Height Resol. / Height Range	1nm-10µm													
Stylus Instrument	Spatial Resol. / meas. Spatial Range	100nm-100mm													
	Height Resol. / Height Range	0.5nm-10µm													
Scattering (λ=633nm)	Spatial Resol. / meas. Spatial Range	100µm-100mm													
	Height Resol. / Height Range	0.5nm-10nm													
AFM	Spatial Resol. / meas. Spatial Range	5nm-100µm													
	Height Resol. / Height Range	0.05nm-10µm													

Spatial resolutions, the practical range of the field and the rms height resolution together with the practical height range of potential techniques used for the measurement of optical surfaces (λ = 633 nm).

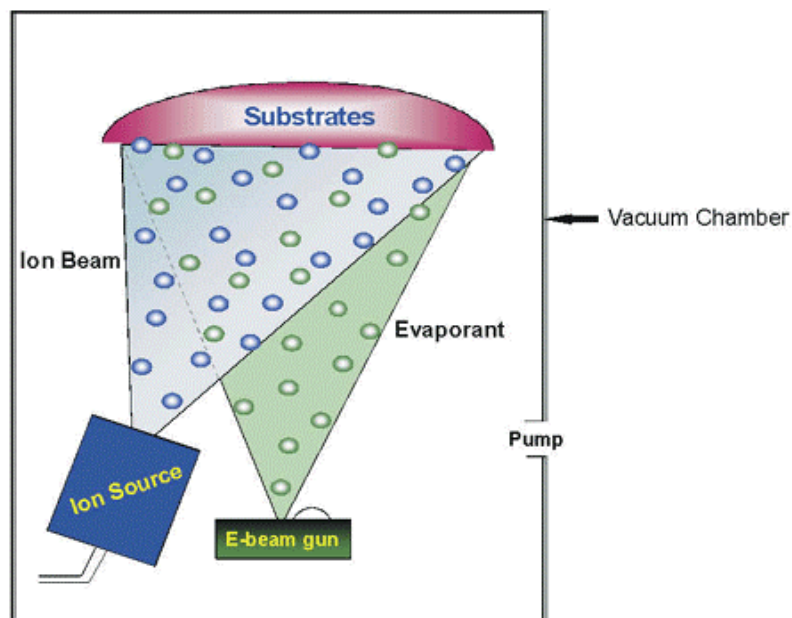
Value Added Chain for Aspherical Lenses



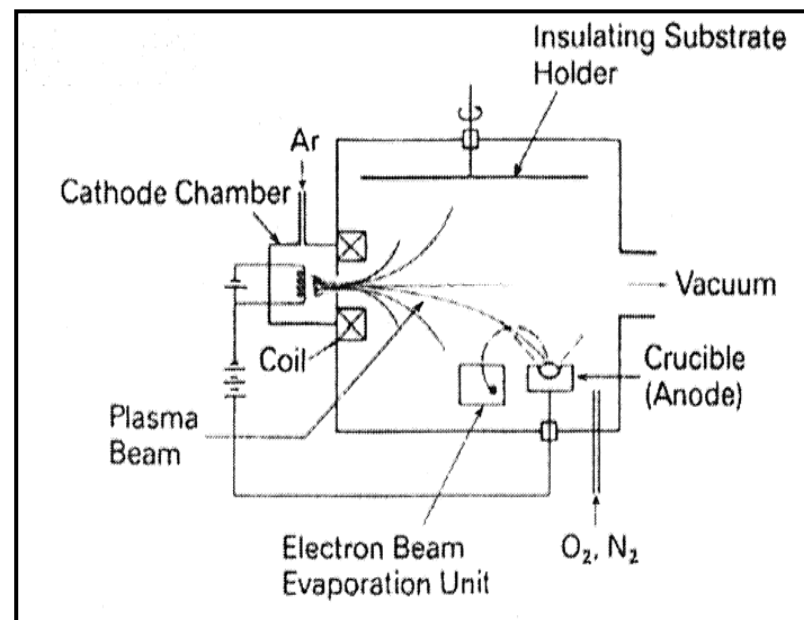
What is the difference of coating technologies (1)

	Generation	Transport	Condensation	Advantages
BOAT	Coating material is heated resistively or by e-beam	Thermal transport to substrate through high vacuum (some 1/10 eV)	Film growth; polycrystalline structures by resistive heating	
IAD	Coating material is heated resistively or by e-beam	Thermal transport to substrate through high vacuum and ion beam (some 1/10 eV)	Compressed film growth by bombardment with energetic ions accelerated by an ion gun (some 100 eV)	Dense coatings result in improved mechanical and optical properties
IP	Coating material is heated resistively or by e-beam and ionised by a plasma beam accelerated from a low-voltage high-current electron source (working gas Ar und reaction gas e. g. O ₂)	Coating material is accelerated by 2 effects: 1) Impact of ions 2) e-ionisation and accelation	Film growth in a reactive gaseous environment and bombardment by energetic ions accelerated from ionised vapour source; polycrystalline structures by plasma	dense, amorphous, abrasion, resistant and environmental stable films with excellent optical and functional properties; best temperature stability

What is the difference of coating technologies (2)



IAD (ion-assisted deposition)
courtesy of

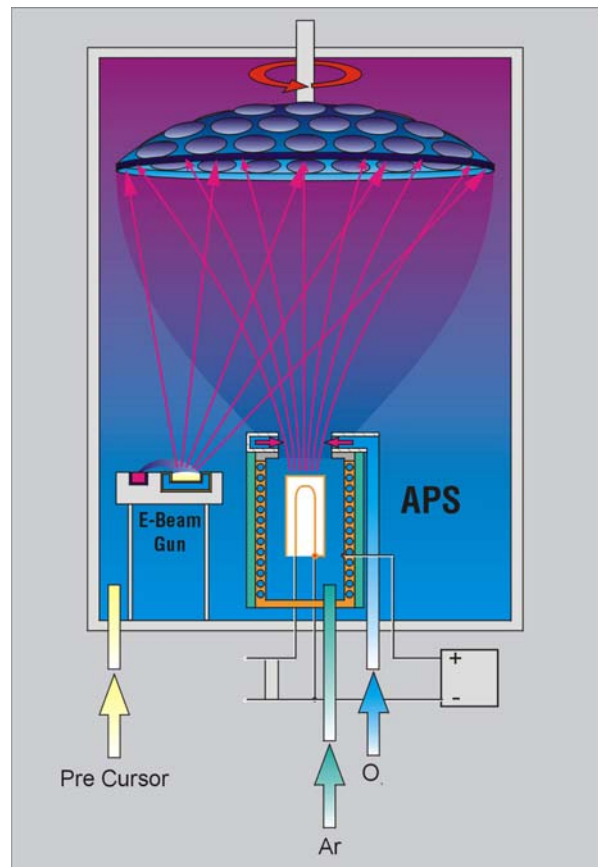


IP (ion plating)
courtesy of

What is the difference of coating technologies (3)

	Generation	Transport	Condensation	Advantages
APS	Coating material is heated resistively or by e-beam	Thermal transport to substrate through a low-pressure plasma environment (some 1/10 eV)	Film growth in a reactive gaseous environment and concurrent bombardment with energetic ions accelerated from an Advanced Plasma Source	Dense, shift-free coatings with superb layer qualities for optical and functional coatings

What is the difference of coating technologies (4)

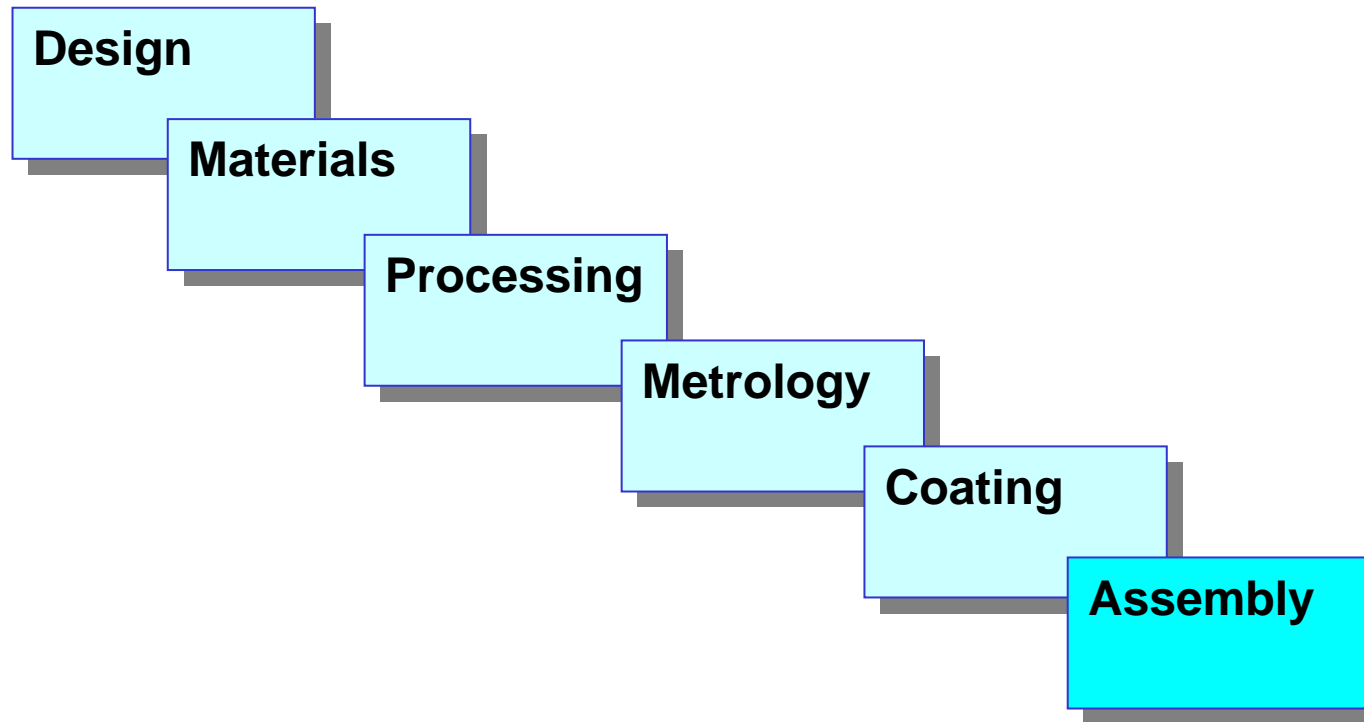


APS (advanced plasma source)
courtesy of

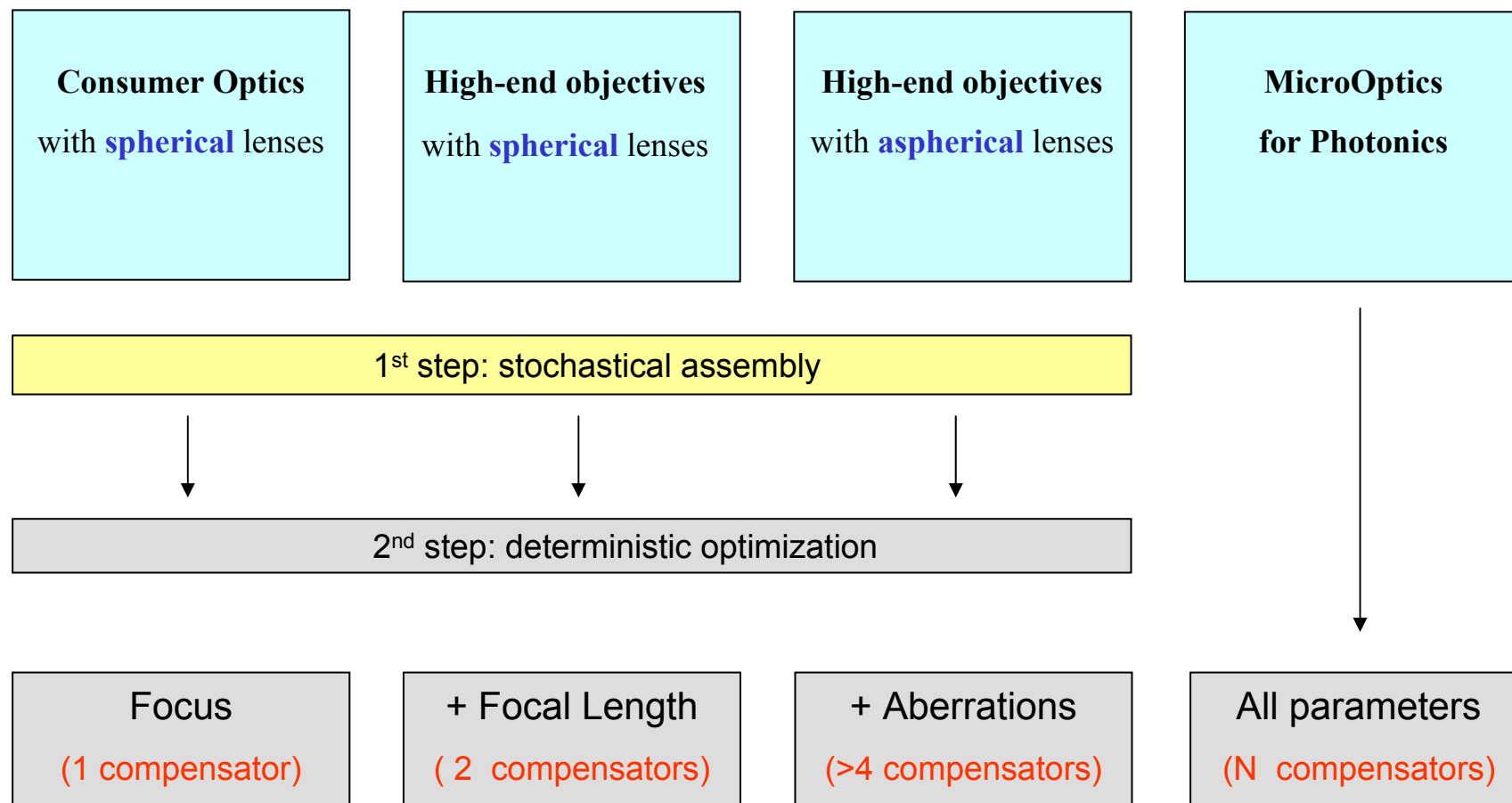
In general Aspherical Lenses require no specific Coating Technologies

- Coating technologies got a big impact by telecom business
- Optical elements typically require an AR-coating (simple single layer MgF₂ or 4-layer broadband coating)
- Coating technologies are not specific for aspherical lenses

Value Added Chain for Aspherical Lenses



Assembly process and compensators



Active Compensation (Micro-Optics)

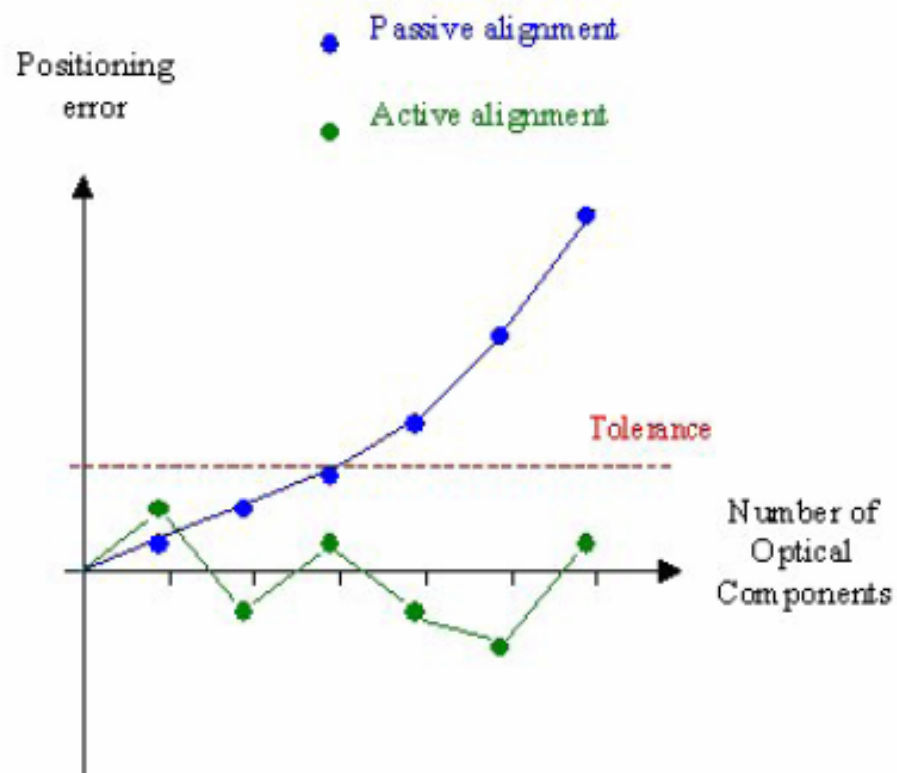
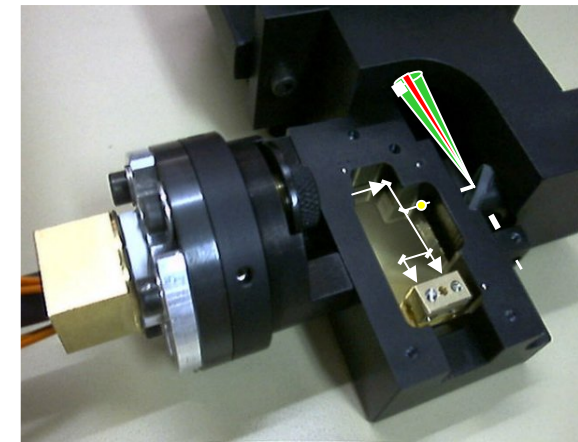
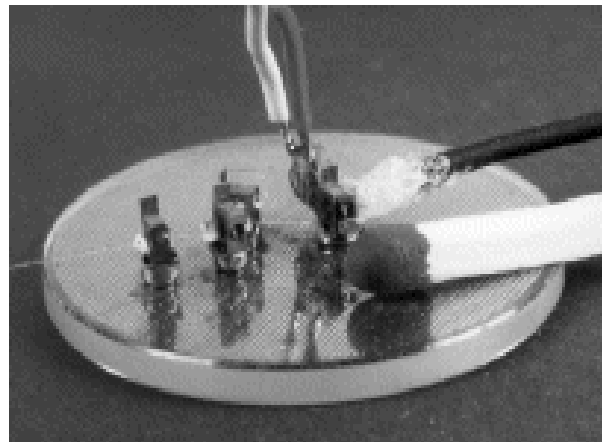
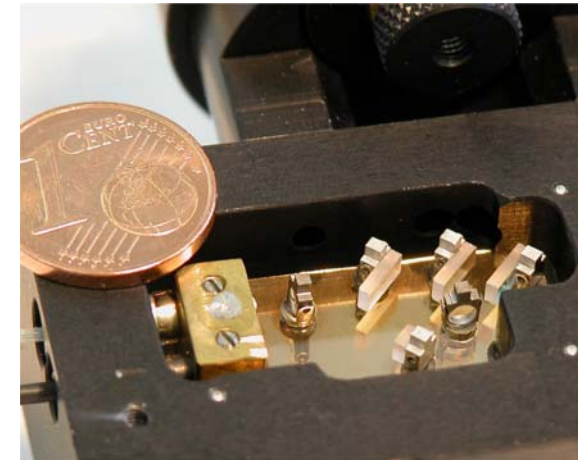
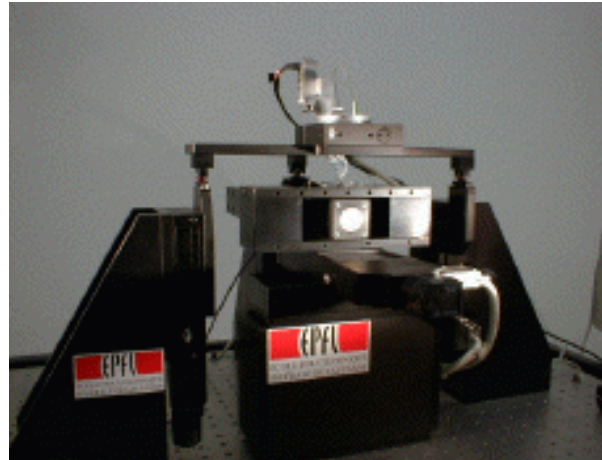
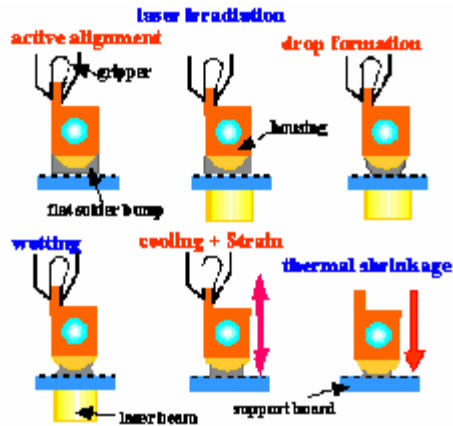


Figure 46: Active compensating avoids the pile up of residual positioning tolerances

Active Compensation (Micro-Optics)



Courtesy Leica Geosystems

Component Tolerances

Component tolerances	Consumer Optics (spherical lenses)	HQ-Optics (spherical lenses)	HQ-Optics (aspherical lenses)	MicroOptics for photonics
Refractive index	< 10 ⁻⁴	< 10 ⁻⁵	< 10 ⁻⁵	< 10 ⁻⁴
Abbe-number	< 0.8%	< 0.1%	< 0.1%	< 0.8%
Melt data	no	yes	yes	no
Radius-deviation	< 2λ	< 0.2λ	0.2λ...2λ	< 2λ
Surface form error	< λ/5 rms	< λ/20 rms	< λ/20 rms	< λ/5 rms
Centre thickness accuracy	± 40 μm	± 20 μm	± 20 μm	± 60 μm
Surface Roughness	< 10 Å rms	< 5 Å rms	< 5 Å rms	< 5 Å rms
Lens wedge error	< ± 5 arcmin	< ± 20 arcsec	< ± 10 arcsec (?)	< ± 1 arcmin

Assembly Tolerances

Assembly tolerances	Consumer Optics (spherical lenses)	HQ-Optics (spherical lenses)	HQ-Optics (aspheric. lenses)	MicroOptics for photonics
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Single lens				
Tilt error $\Delta\alpha$	< ± 5 arcmin	< ± 30 arcsec	< ± 10 arcsec	< ± 30 arcsec
Lateral decenter Δr	< ± 50 μm	< ± 10 μm	± 10 μm	< ± 1 μm
Axial displacement Δz	< ± 50 μm	< ± 10 μm	± 10 μm	< ± 1 μm

Lens group				
Tilt error $\Delta\alpha$	< ± 30 arcsec	< ± 30 arcsec	< ± 10 arcsec	< ± 30 arcsec
Lateral decenter Δr	< ± 50 μm	< ± 2 μm	± 10 μm	< ± 1 μm
Axial displacement Δz	< ± 50 μm	< ± 1 μm	± 10 μm	< ± 1 μm

Compensators				
Lateral position accuracy	NA	$\pm 0,2$ μm	$\pm 0,2$ μm	NA
Axial positioning accuracy	NA	$\pm 0,2$ μm	± 1 μm	NA

Operating temperature	0°C/+40°C	23°C \pm 1°C or -10°C/50°C		-10°C/+40°C
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Future Trends I

- Looking into the Abbe diagram, there are trends to extend the different material regions.
- Efforts are undertaken to generate glasses within the crystal nd-vd-area.
- Optoceramics will try to offer optical positions in the crystal field at lower costs.
- The economical fabrication of aspheres for high and medium quality, also in future, will be the main technology driver.
- The classical fabrication process of generating and polishing will be used for batch sizes smaller than 10^4 .

Future Trends II

- The general trend will be to use the computer power for simulation the process within the machine
- Integration of processing and metrology
- Closed loop systems with wave front sensors adjust the flexible mirror surface to compensate the measured wave front aberrations
- Less expensive computer generated holograms (CGH)
- Hybrid techniques gain on importance
- Improvement on assembly technologies
 - Clueing and cementing materials
 - Micro-optics assembly by monolithic technologies will come up
- Cost reduction for aspherical elements down to 20 to 40% of actual manufacturing costs