Linear Variable Filters for Applications in Spectroscopy and Fluorescence Diagnostics

By Henrik Fabricius and Oliver Pust

DELTA Optical Thin Film
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DELTA today

- Founded 1941
- 290 employees out of whom 50% are engineers
- Annual turnover 44 million Euro
- Headquarters in Hørsholm  Denmark
- Departments in Odense, Nordborg, Sønderborg, Västerås, Wales and Aarhus
Core Competences

Electronics
Microelectronics
Software technology
Light & Optics
Acoustics & vibration
Point of care systems
Sensor systems
Optical Thin Film Technology

DELTA Optical Thin Film milestones:

- Suggested use of interference filters for use in fluorescence microscopy in the late sixties
- Started volume manufacturing of fluorescence filters in the early seventies
- First computer controlled deposition implemented in the mid seventies
- Own synthesis and deposition control software allows us to offer coatings made with plasma assisted e-beam evaporation technology with a quality similar to that offered by IBS and similar technologies
- Obtainable batch sizes and coating speed allows us to offer volume products at very competitive prices
TopPride Filter-set FSTP 0003

Unglued filters without any coloured glass
Minimal auto fluorescence & Minimal lens effect

High transmission, Steep edges & Minimal ripple
Blocking better than OD5 to beyond 950 nm
TopPride Filter-set FSTP 0050

Unglued filters without any coloured glass
Stress compensation of the bending of the UHC dichroic
Durable and spectrally stable surface coatings
Suited for diamond tooling
Construction and Properties of DELTA's Filters

Standard filter

- Even thickness on the whole surface

Linear variable filter

- Layer thickness
- Length

Dielectric Multi Layers

Glass substrate

Example of a normal bandpass filter

Example of a linear variable BP filter

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Advantages of DELTA's Linear Variable Filters

- Robust and shift free surface coatings on unglued quartz substrates for minimal auto fluorescence and high Laser Damage Threshold
- The filters work well with the Super Continuum Light Source
- Transmission is mostly higher than 92%
- Blocking is OD3 or better
- Blocking to beyond OD5 by adding another Lin Var Filter
- SWP: Edge to be tuned from 340 nm – 850 nm
- LWP: Edge to be tuned from 300 nm – 850 nm
- Dichroic: Edge to be tuned from 320 nm – 750 nm
- BP: Centre wavelength from 400 nm to 700 nm

Helpful application notes available
Linear Variable LWP Filters

- Blocking of higher order contributions in grating based spectrometers
- Decreased background noise in large spectrometers and compact spectrometers

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Comparison with Existing LVLWP Filters

LEFT  Strong ripples, ~80% transmission, not very steep edges, OD2

RIGHT DELTA's filter: very low ripple, >90% transmission, very steep edge, better than OD3 blocking
New steeper version reaches OD4 level much faster.

- Helps collecting more emission light in fluorescence systems
- Helps forming narrow bandpass filters
Linear Variable SWP Filters

- The SWP filter is able to block the whole visual range
- Blocking is mostly better than OD3
- It is possible to increase blocking to beyond OD5 by putting two filters in series
Comparison with Existing LVSWP Filters

LEFT  Strong ripples, <80% transmission, far from steep edges, OD2

RIGHT DELTA's filter: low ripple, mostly >90% transmission, very steep edge, better than OD3 blocking
Fluorescence Spectrometer with LVF

Schematic drawing of a single Monochromator system for fluorescence measurements as proposed and tested by Edinburgh Instruments

M: Mirror
L: Lens
S: Slit
DG: Diffraction gratting
F: Variable filter stage
Figure 6: Raman spectrum of cyclohexane measured at an excitation wavelength of 500 nm. The red curve (upper) denotes a spectrum taken at 1 nm spectral resolution without the use of variable filters. The green spectrum (middle) is taken with the variable filters in place. For comparison, the same measurement was repeated on a double-monochromator spectrometer (blue – lower). The signal is severely reduced.
Linear Variable Dichroic for AOI = 45°

Minimal polarisation splitting for AOI = 45°
Wide blocking range (helps blocking excitation light)
Typical blocking > OD3
Dependence on the Width of the Light Spot

**Predicted transmission of un-polarized and parallel light at AOI = 45 Degrees.**

- **Black curve:** Width = 0.5 mm
- **Violet curve:** Width = 1.0 mm
- **Blue curve:** Width = 1.5 mm
- **Green curve:** Width = 2.0 mm
- **Red curve:** Width = 2.5 mm
- **Brown curve:** Width = 3.0 mm

The steepness of the edge decreases somewhat with increasing width of the light spot. Depending on the actual application, it may be acceptable to work with a width of a couple of mms or more.
**Dependence on the Angle of Incidence**

- $T$ (un-pol) shifts towards shorter wavelength as AOI increases.

- However the shape of the edge is quite stable.

- AOI increases from $37^\circ$ to $53^\circ$ in steps of 2 Degrees.

- Width of the light spot is 1.5 mm

Assuming an even angular energy distribution, in a non-parallel light bundle with an opening angle of OA the averaged transmission is predicted to be as shown.

- Opening angle (half cone angle) is increasing from $0^\circ$ to $8^\circ$ in steps of 1°
Linear Variable Narrow Band Filter

**Measured transmission for LVVISBP [400 - 700] nm**

**Measured blocking for LVVISBP [400 - 700] nm**

Centre wavelength
400 nm – 700 nm

Guaranteed blocking-range
UV – 850 nm

FWHM: 8 nm – 20 nm

No metal layers
No glue
No coloured glass
Comparison with Existing Narrow Band Filters

**LEFT**  Most Linear Variable BP filters contain thin metal layers limiting the peak transmission and the durability.

**RIGHT**  DELTA's filter is a durable all dielectric filter. The peak transmission is higher at all wavelengths from 400 nm to 700 nm.
Comparison of Blocking of Lin Var BP Filters

Competitor’s blocking

Typical leak

DELTA’s blocking

No leaks

Edges are not steep

Edges are steep

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Predicted Performance with Increasing Opening Angle

OA = ± 12.7º
(N.A. = 0.22)

OA = ± 20º
(N.A. = 0.34)
Influence of Slit Width on the Band

Opening angle = ±12.7° (N.A.=0.22)

Wedge: 6.8 nm per mm
Centred rectangular aperture (height 10 mm)

- Black: width = 0 mm
- Red: width = 0.5 mm
- Green: width = 1.0 mm
- Grey: width = 1.5 mm

FWHM stays nearly constant – but the band gets less box shaped as the slit-width increases.
Filters Directly Mounted or Glued to Sensor

- LVF covering complete wavelength range
- LVF segments covering wavelength sub-ranges
- Line scan CCD/CMOS
- Area scan CCD/CMOS

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Filters Directly Mounted or Glued to Sensor
Comparison Segmented vs. Unsegmented Filter

- Bandwidth variation along filter is smaller
  - Higher wavelength resolution
  - Total wavelength range can be larger
  - Smaller out-of-band blocking range necessary

- Covered field of view is larger
  - Higher frame rate possible
  - Required filter volume smaller
Filter and Sensor Coupled with Relay Lens

- Reduces chance of inter-reflections sensor/filter
- Resulting instrument is less compact
Future Products

- Narrower Linear Variable BP filters
  Expected FWHM: 3 nm – 7 nm

- Linear variable LWP and SWP filters for VIS + NIR
  Expected wavelength range: 300 nm – 1000 nm, 400 nm – 1100 nm

- Linear variable BP filters for food analysis
  Expected wavelength range: 800 nm – 1850 nm

The needed amount of coating material increases proportionally to wavelength. It would be necessary to modify the applied coating machine in order to produce advanced linear variable filters for food analysis.
Conclusion

- DELTA has lifted the quality of variable filters and beam-splitters to a new level
- The filters are coated on single quartz substrates for minimal auto-fluorescence and high laser damage threshold – and transmission mostly is higher than 90%. Wavelength goes down to 300 nm
- Simulations of the impact of spot size and angle of incidence of light have been discussed in detail for laser based systems
- A range of filters and dichroics are on stock and available in quantities

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Thank you very much for your attention!

Questions?

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