World's Largest Inventory of Optical Components

WHAT'S NEW IN OPTICAL COATINGS

AN IN-DEPTH LOOK AT COATING TECHNOLOGY, SPECIFICATIONS, AND APPLICATIONS

Stephan Briggs

January 2016

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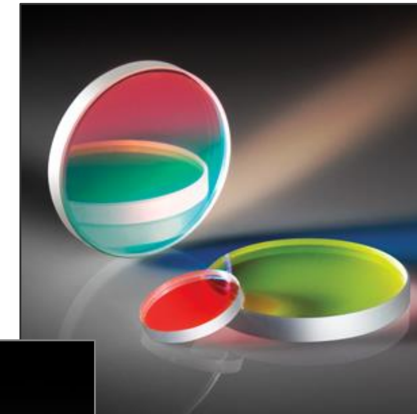
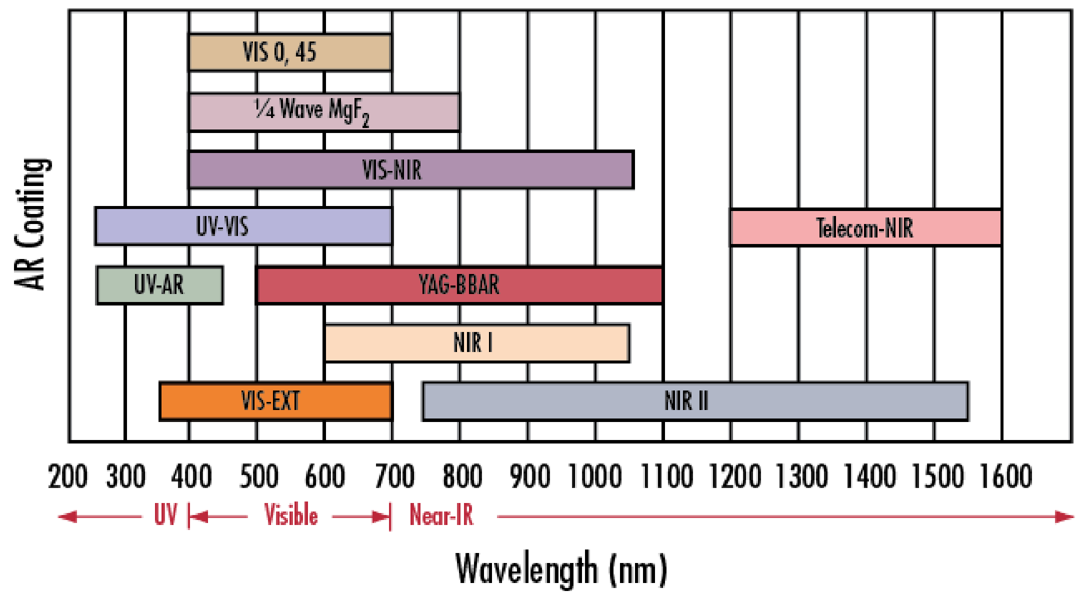
OVERVIEW

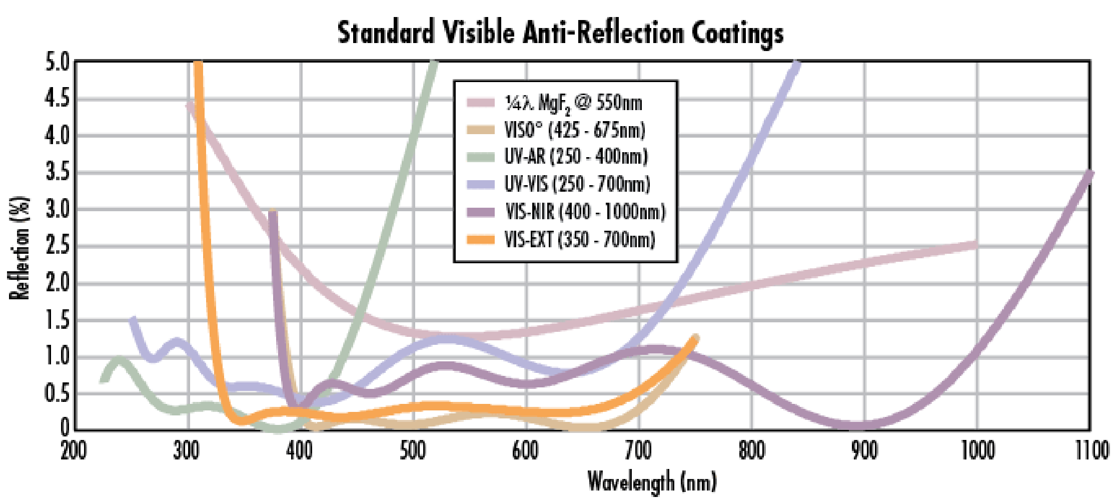
- Key Terminology
- Anti-Reflection vs. Filter Coatings
- Coating Technology
- Communicating Requirements
- Cost Drivers
- Prototype Qualification & Budgetary Considerations
- Verifying Performance
- Application Examples



AR COATINGS

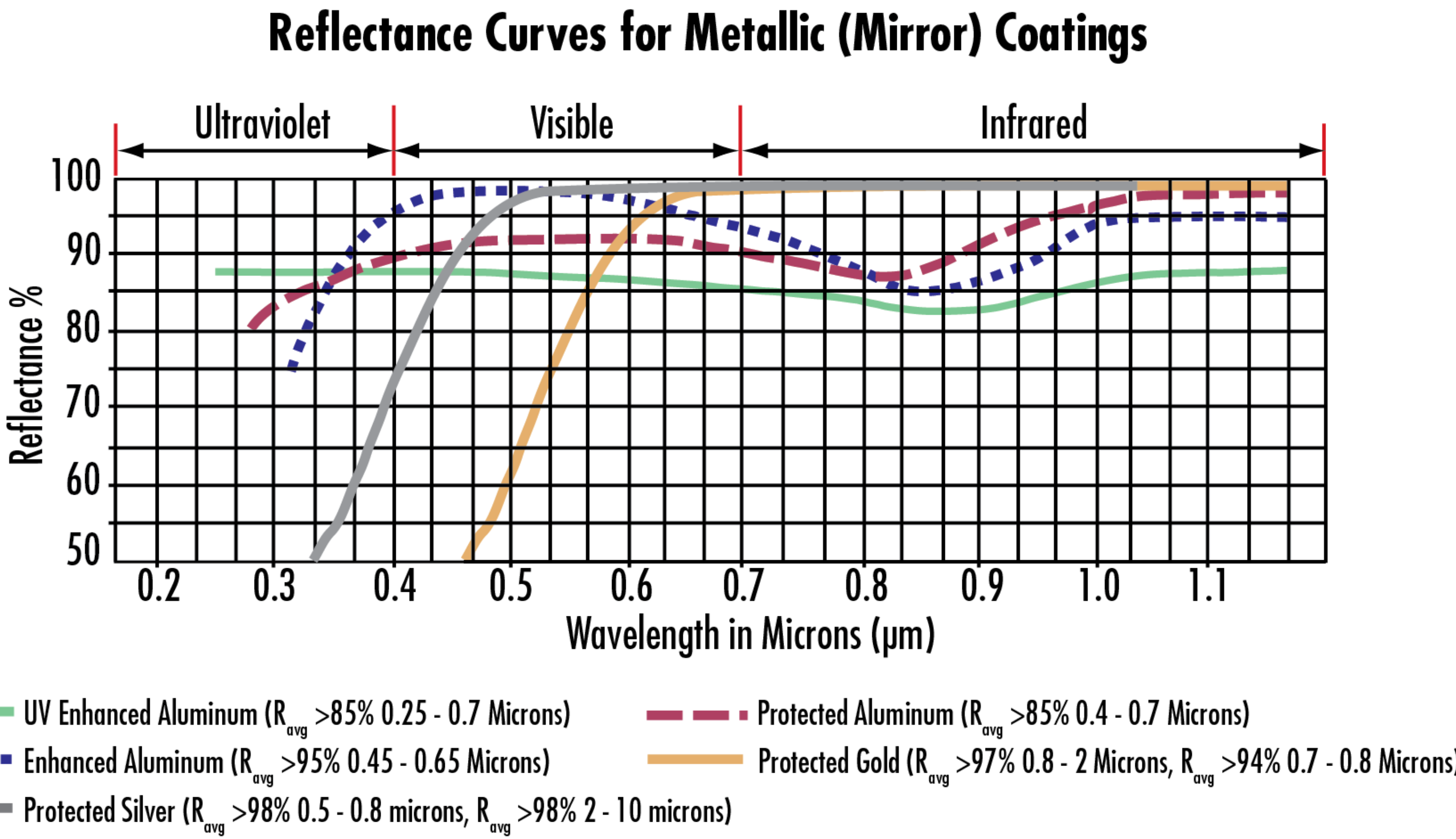


AR Coating
VIS 0, 45
¼ Wave MgF2
VIS-NIR
UV-VIS
Telecom-NIR
UV-AR
YAG-BBAR
NIR I
VIS-EXT
NIR II
200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600
UV
Visible
Near-IR
Wavelength (nm)

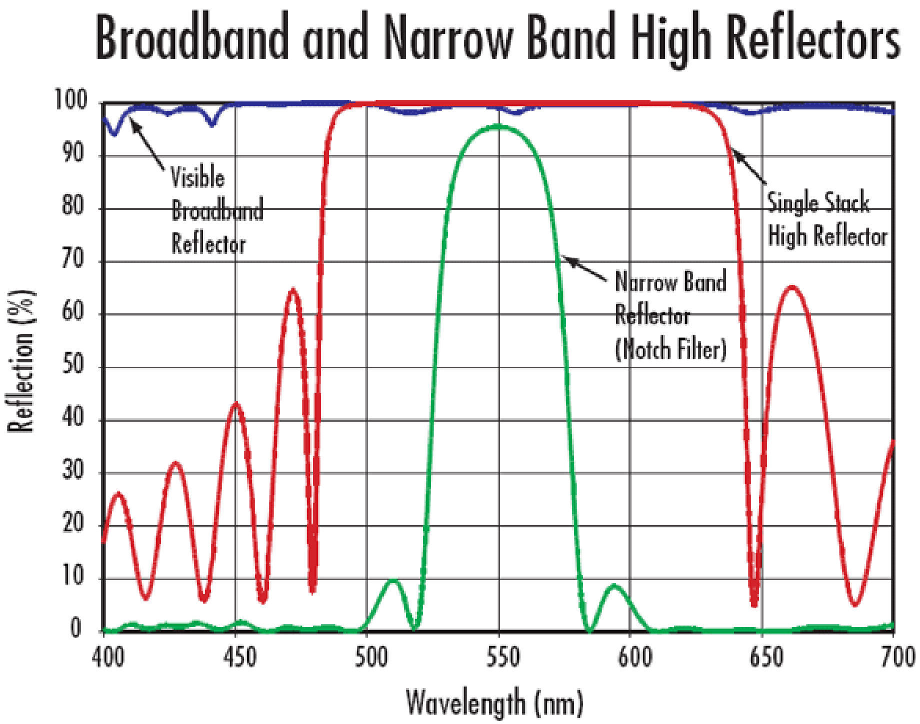


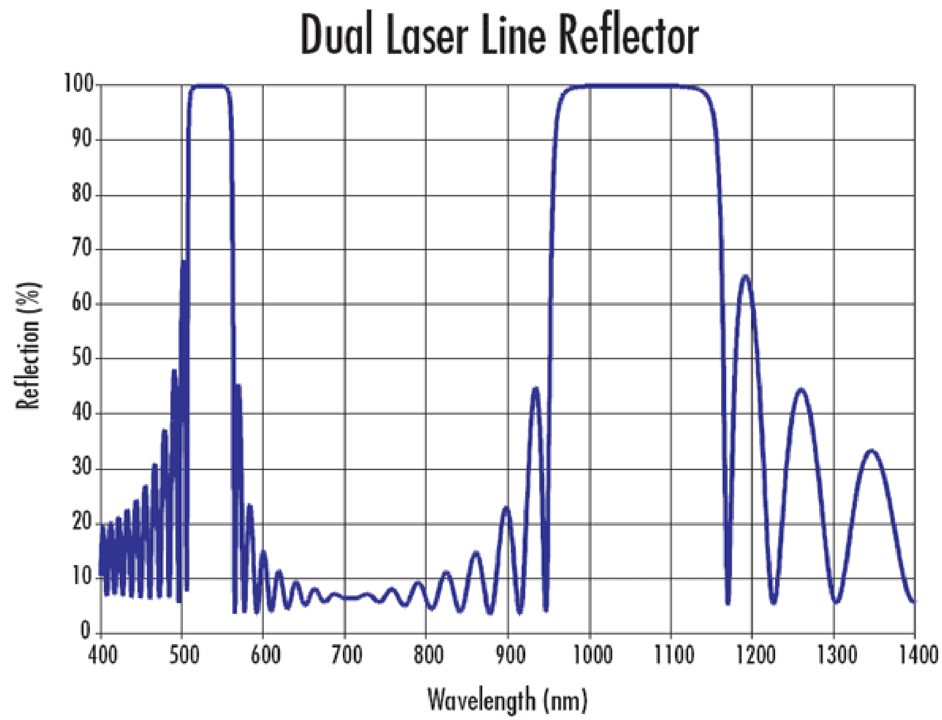
Standard Visible Anti-Reflection Coatings
Reflection (%)
5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0
¼λ MgF2 @ 550nm
VIS0° (425 - 675nm)
UV-AR (250 - 400nm)
UV-VIS (250 - 700nm)
VIS-NIR (400 - 1000nm)
VIS-EXT (350 - 700nm)
200 300 400 500 600 700 800 900 1000 1100
Wavelength (nm)

METALLIC MIRRORS



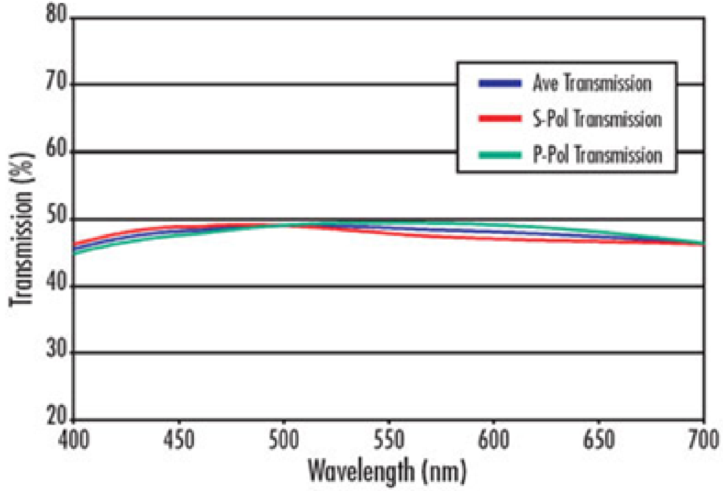
DIELECTRIC MIRRORS



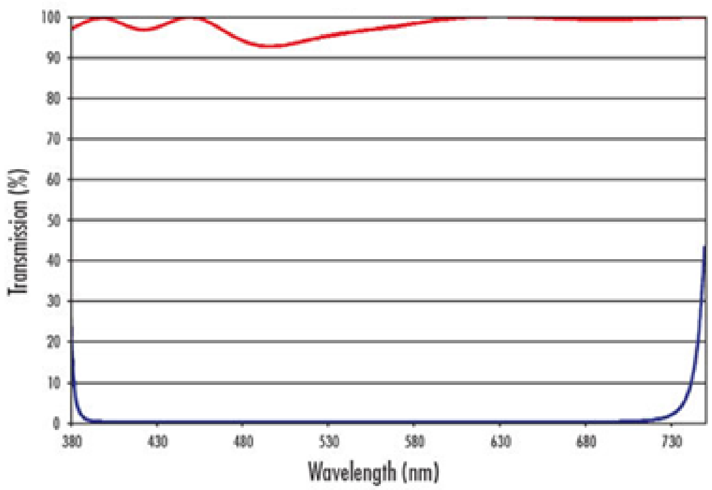


BEAMSPLITTER FILTERS

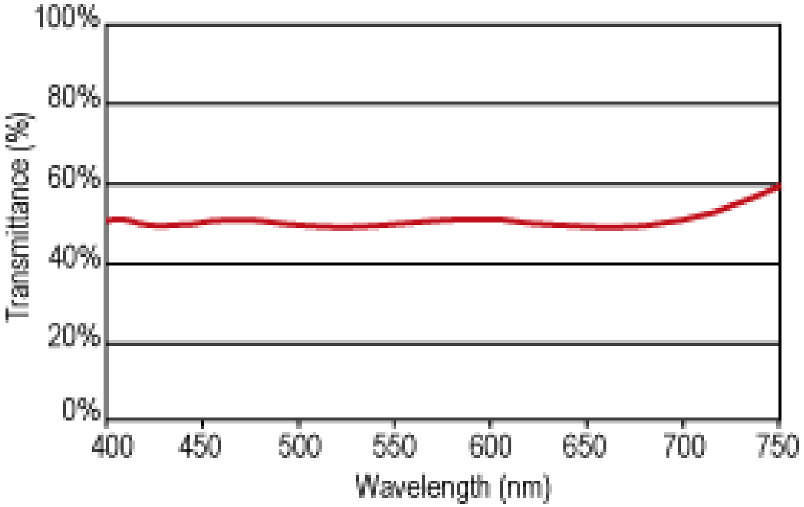
Non-Polarizing Cube Beamsplitter



Polarizing Cube Beamsplitter



50/50 Plate Beamsplitter



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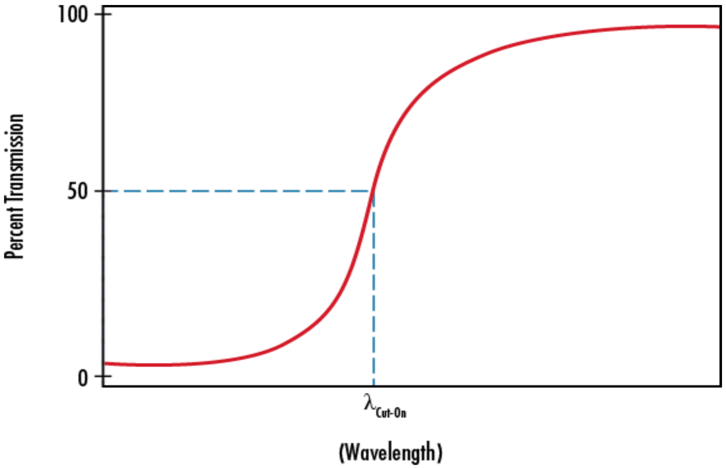
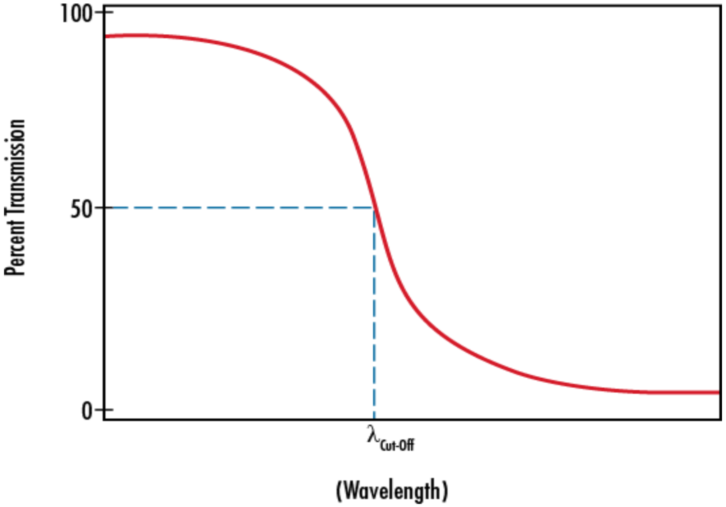
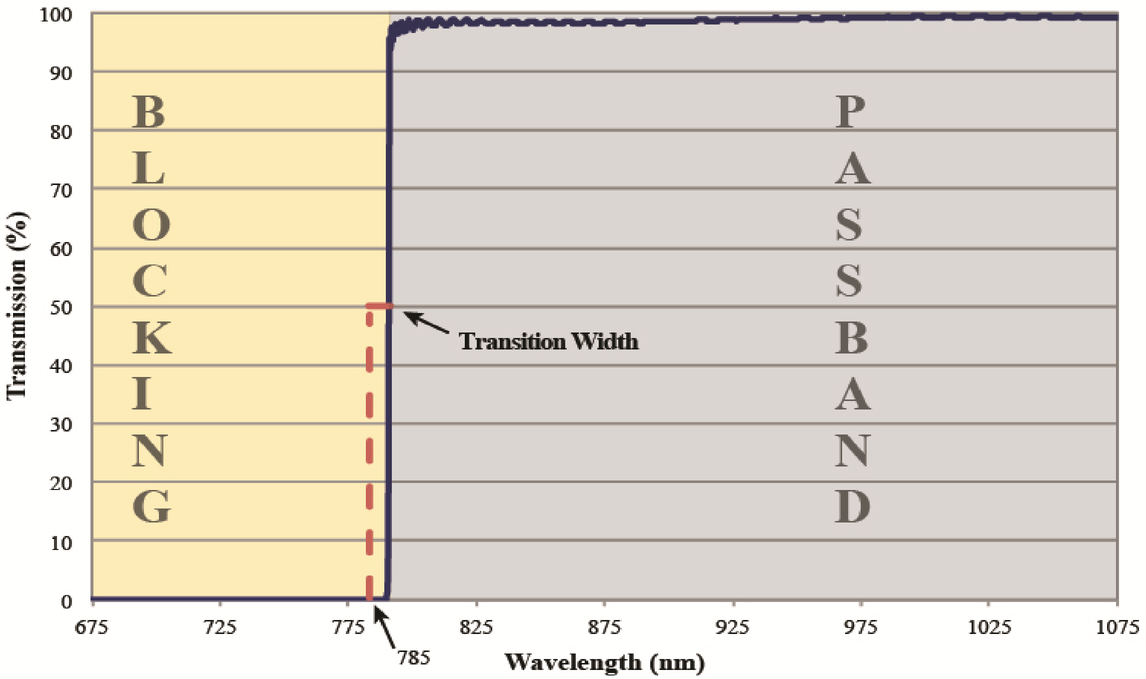
EDGE FILTER PARAMETERS

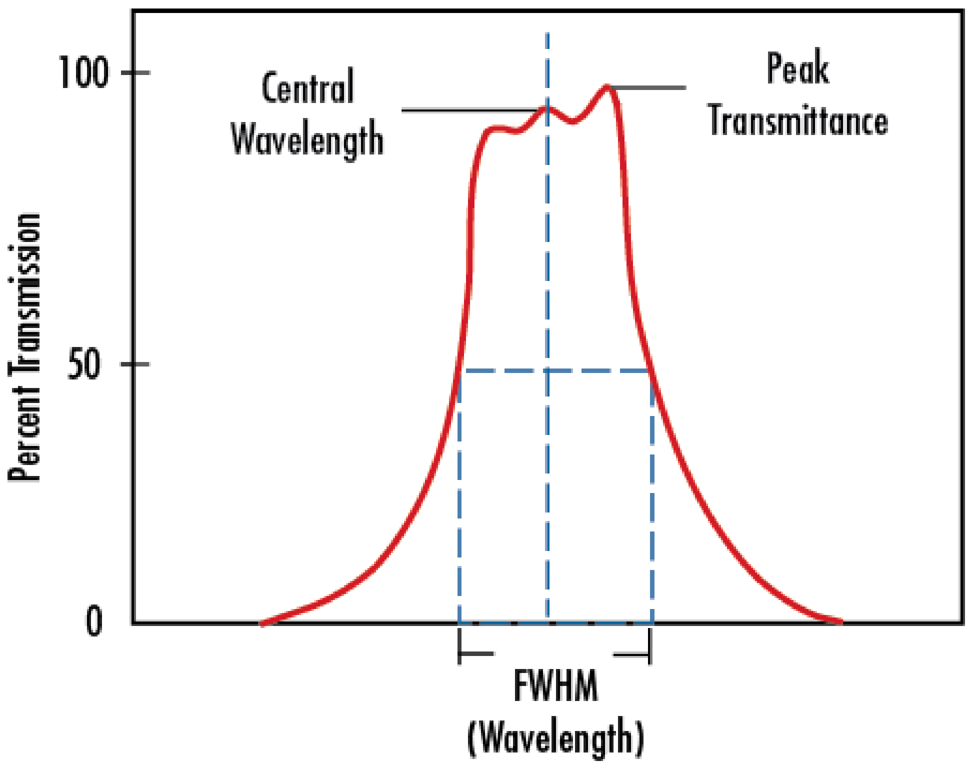


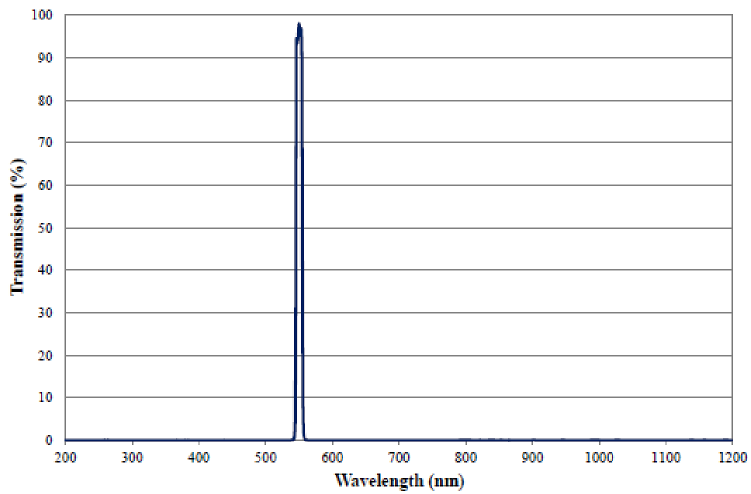


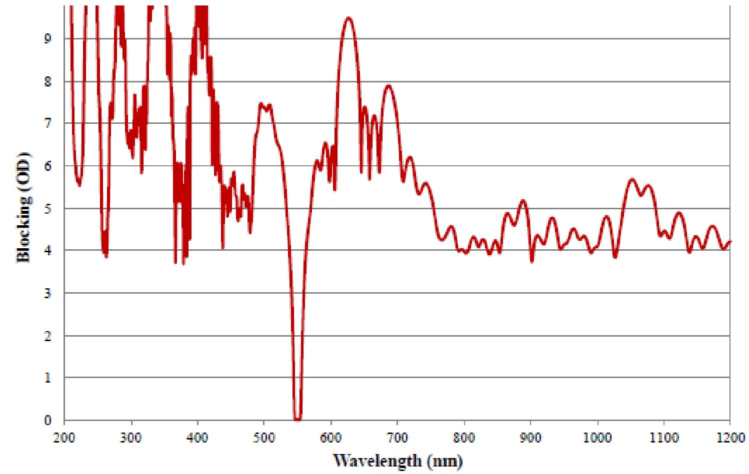


785nm Raman Longpass Edge Filter OD ≥ 6

BANDPASS FILTER PARAMETERS







$$T\ (Percent\ Transmission) = 10^{-OD}\ x\ 100$$

RATIONALE FOR COATINGS

- Almost all optical systems require Anti-Reflection coatings – they optimize the transmission through multi-element systems. **Example:** for a standard BK7 glass substrate, ~4% of visible light is lost per surface. AR coat can reduce this to <0.5%.

- Filters are integral components in most photonics applications, particularly biophotonics systems in medicine – filters allow us to control and manipulate certain wavelengths of light for the most sensitive detection and imaging systems.

- Regardless of the type of coating, the manner in which it is specified can dictate whether it's "commercial" or "precision."

TOP-LEVEL COMPARISON

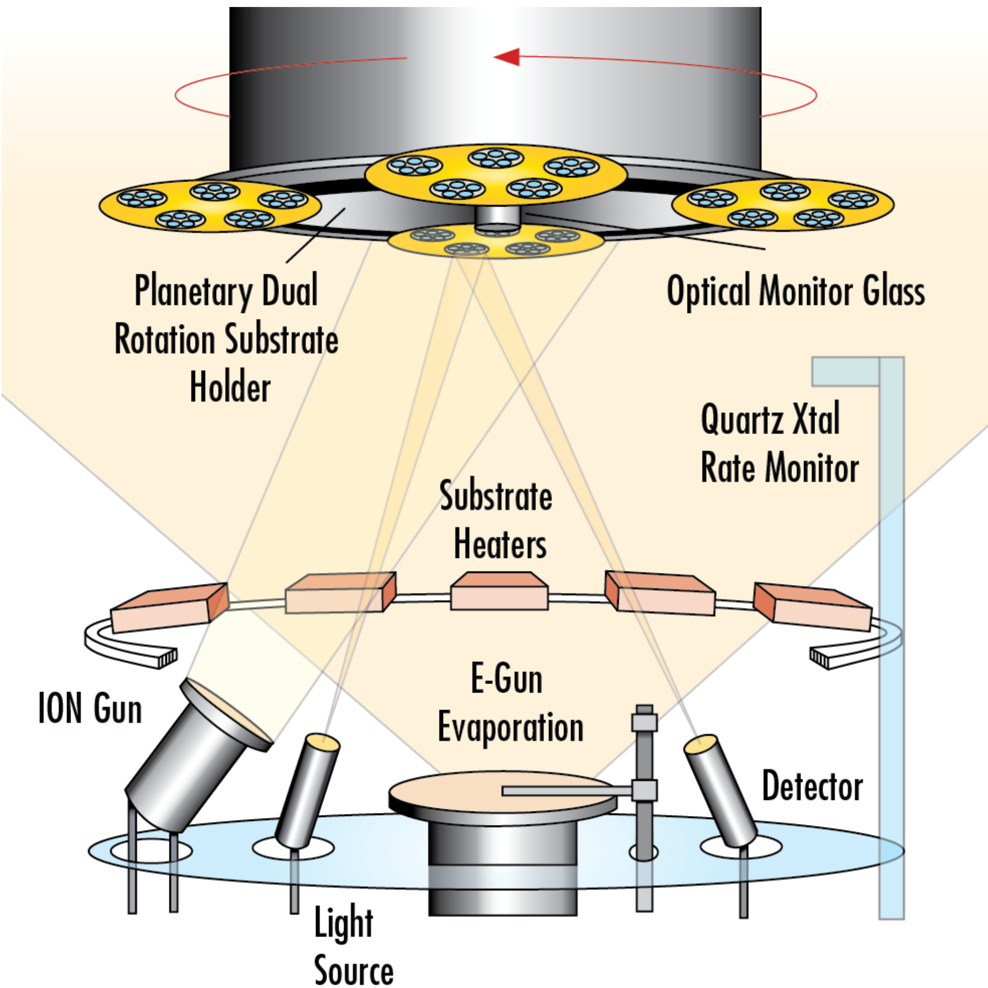
Anti – Reflection

- Typically < 10 layers
- Quartz X-tal Monitor is sufficient
- More tolerance relief due to extended range
- Less sensitive to chamber geometry/uniformity
- Array of manufacturing options available

Filter

- > 10 Layers , More Coating time
- Better achieved with OMS
- Tighter tolerance for critical transitions
- Requires good understanding of chamber distribution
- Manufacturing method is largely tolerance driven

COATING TECHNOLOGY



Schematic of a PVD Optical Coating Machine equipped with:

- Ion Assisted Deposition (IAD)
- Optical Monitoring
- Planetary work holders
- Process temperature typically 200 -300C

COATING TECHNOLOGY

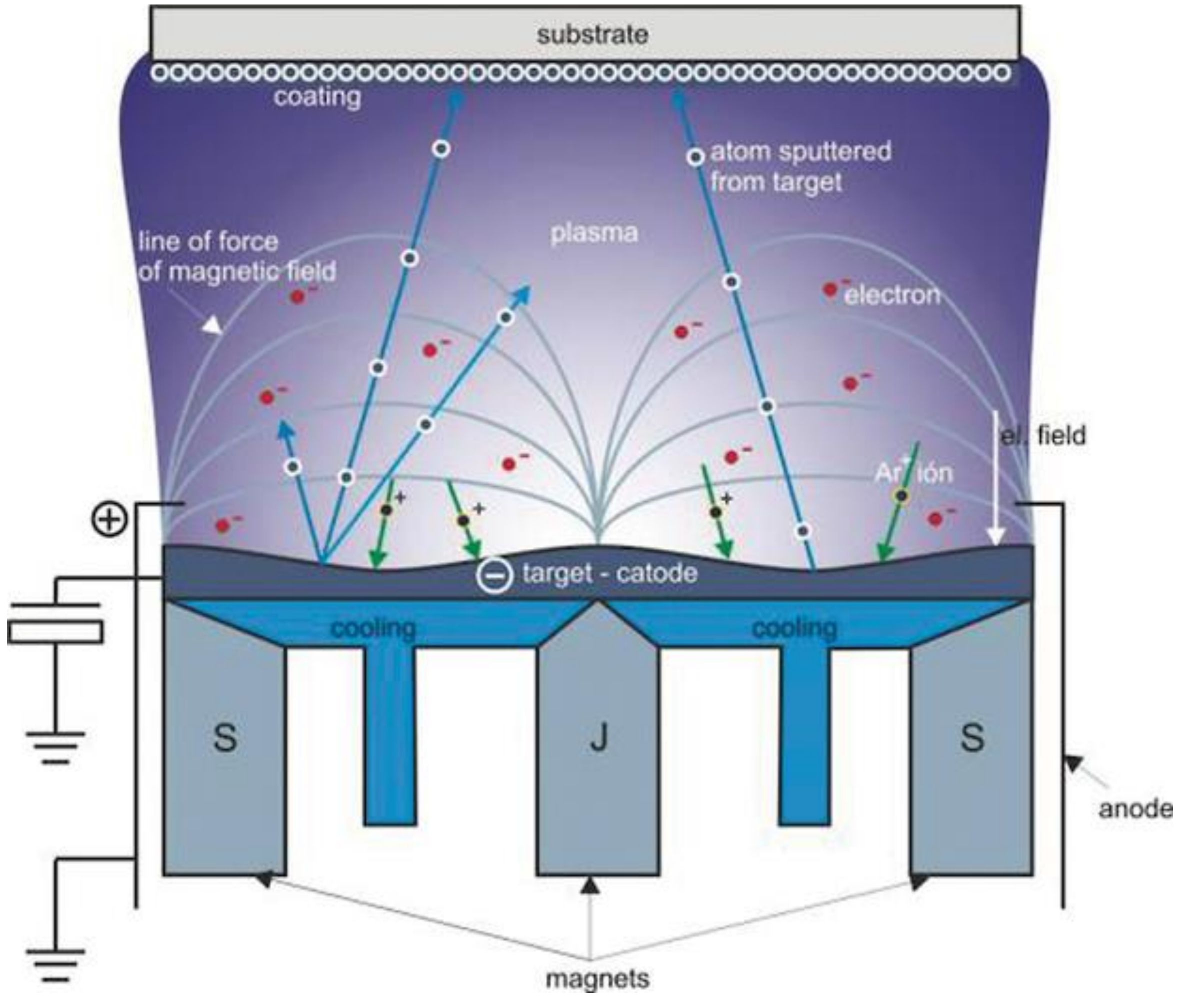


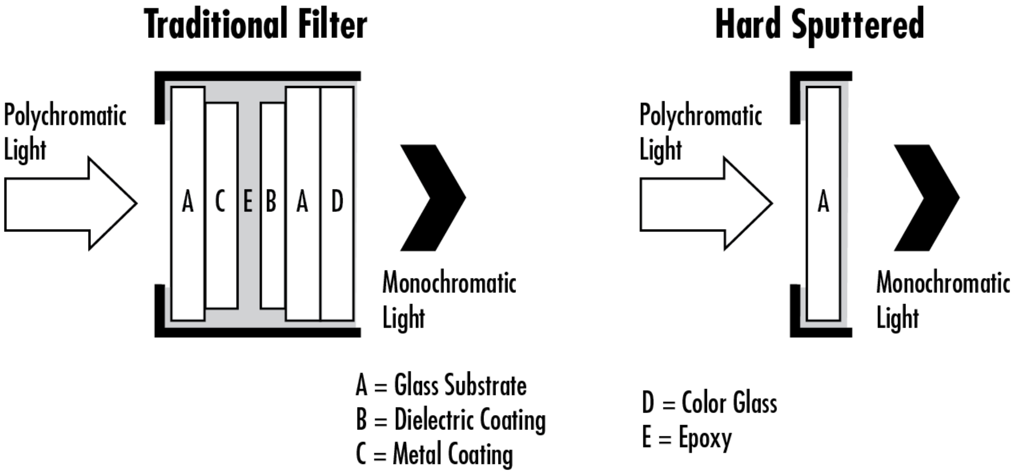
Image source: Slovak Academy of Science.

FILTER EVOLUTION

- Telecom boom of the late 1990's drove innovation to fabricate DWDM filters with superior performance

- In traditional-coated bandpass filters, layers of varying index materials are deposited onto multiple substrates which are then sandwiched together.

- Conversely, in hard-sputtered bandpass filters, materials of varying indices are deposited onto only a single substrate. This technique leads to thin filters with high transmission.



COMMUNICATING REQUIREMENTS

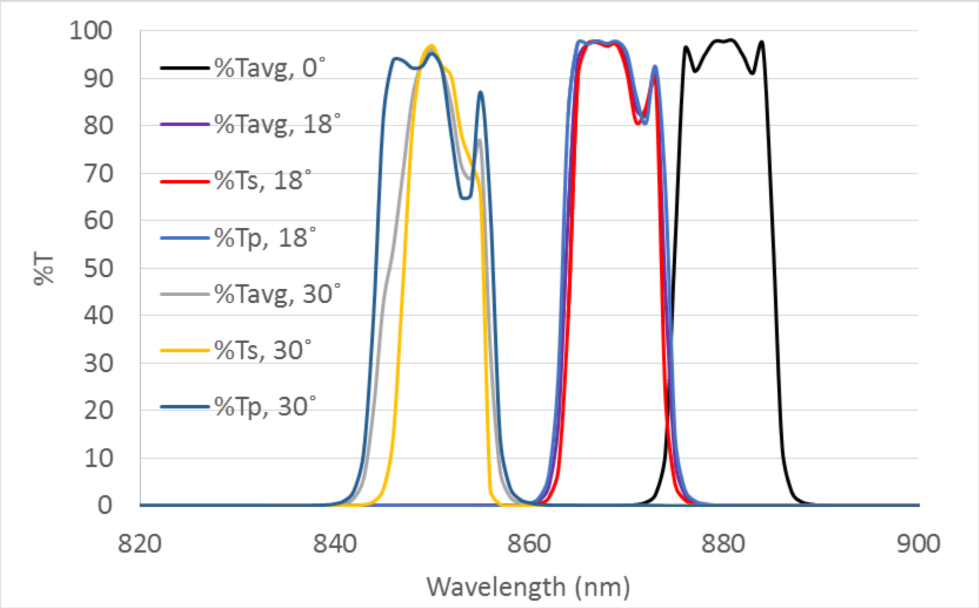
Critical system requirements to communicate:

- Angle of Incidence (AOI)– nominal angle, cone/half-cone angle
- Substrate – glass material, grade, flatness, surface quality
- Size/Shape – dimension, thickness, tolerances
- Environmental – robustness, where will the coating be used
- Spectral – wavelength range, blocking, transitions

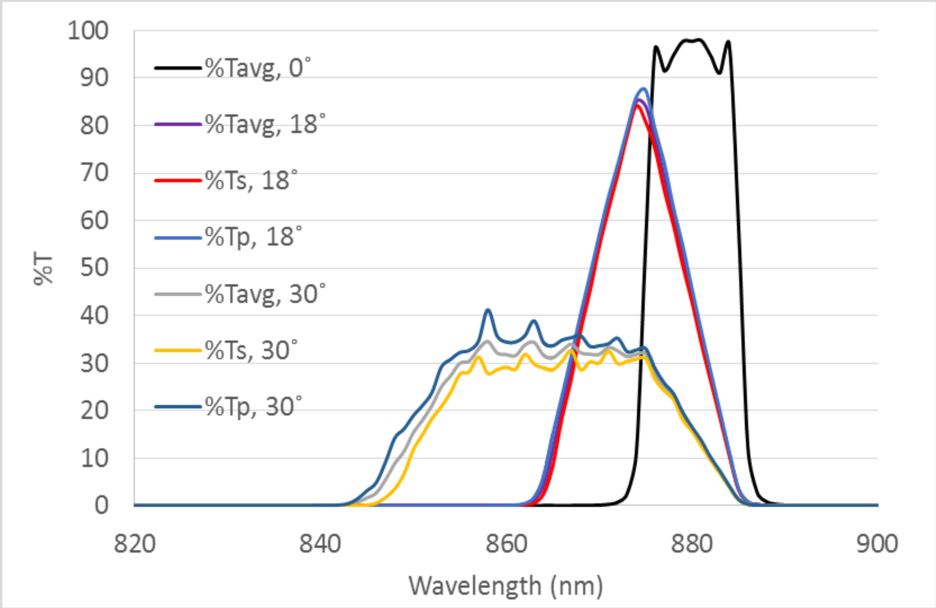
If these requirements can be kept broad, it increases likelihood that the manufacturer has something close in stock for prototypes and initial design

ANGULAR PERFORMANCE EFFECTS

Bandpass 880-10 with
Collimated Illumination

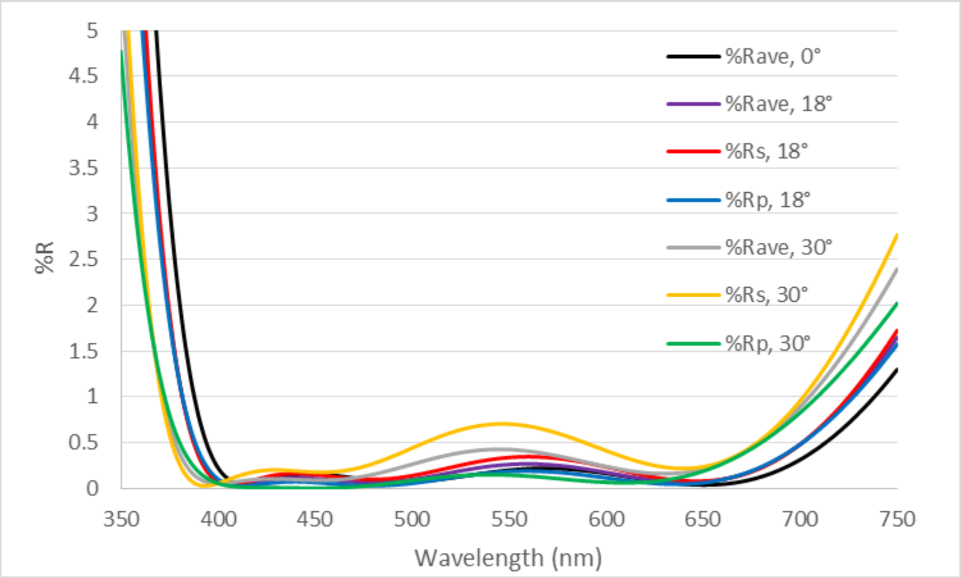


Bandpass 880-10 with
Cone-Angle Illumination

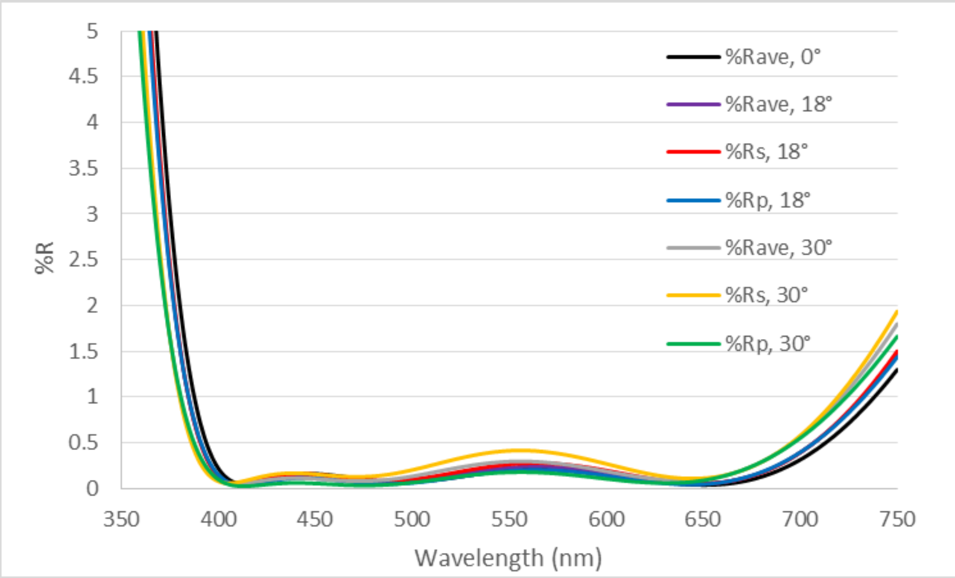


ANGULAR PERFORMANCE EFFECTS

VIS0° Coating with
Collimated Illumination



VIS0° Coating with
Cone-Angle Illumination



WAYS TO SAVE…

Manufacturers have a wide range of materials and processes at their command — but every specification comes at a cost.

- **Environmental requirements:** Don't specify extreme environmental conditions, unless your application requires it. Obscure tests add cost.
- **Substrate material:** If you can leave this choice to your vendor, they may be able to significantly reduce raw material costs.

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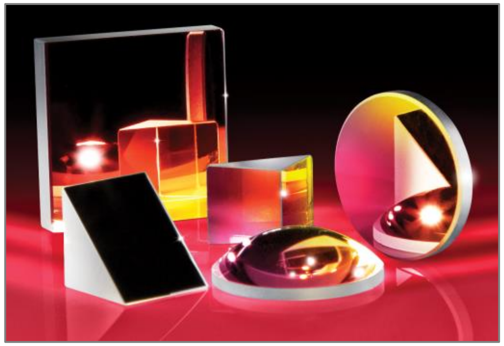
WAYS TO SAVE…

Scratch/Dig: Cosmetic imperfections do not always hinder optical performance. Tight requirements here can reduce production yields, ultimately increasing the price per part.

Size and Shape: If you can base your requirements on the physical envelope of an existing product, the vendor can easily source the material and minimize lead-times by using readily available manufacturing tooling.

Surface Figure/Flatness: an unnecessarily tight requirement here will drive up costs for both the substrate and the coating process.



COATING COST DRIVERS

	PARAMETER	COMMERCIAL	PRECISION	HIGH PRECISION	CONSTRAINT
SUBSTRATE	Glass Type *(Grade)*	Borofloat	N-BK7 Sapphire	UV/IR Grade Fused Silica Silicon	Lead-Time
SUBSTRATE	Dimension Tolerance	±0.2mm	±0.05 - 0.1mm	≤ ±0.05mm	Yield
SUBSTRATE	Thickness	≥ 2mm	0.5 - 1mm	≤ 0.5mm	Yield Lead-Time
SUBSTRATE	Size/Shape	1/2" - 1"	< 5mm and > 50mm	Irregular Edges Wedge or High Curvature	Yield Lead-Time
SUBSTRATE	Surface Quality *(Scratch/Dig)*	80-50	60-40 40-20	20-10 10-5	Yield
SUBSTRATE	Surface Figure *(TWE/RWE)*	λ - λ/2	λ/4 - λ/8	λ/10 - λ/20	Yield
SPECTRAL	Slope* *(Transition from %T to OD)*	≥ 2%	1%	< 0.5%	Design/MFG Time
SPECTRAL	Spectral Tolerance* *(CWL, FWHM, Cut-On/Off)*	2%	1%	< 1%	Design/MFG Time Uniformity/Run Size
SPECTRAL	Blocking*	OD2 - OD3	OD4 - OD5	≥ OD6	Design/MFG Time
	Laser Damage*	≤ 1 J/cm^2	5 J/cm^2	≥ 10 J/cm^2	Process/MFG Time

*Relative to Wavlength Range

INCREASING COST

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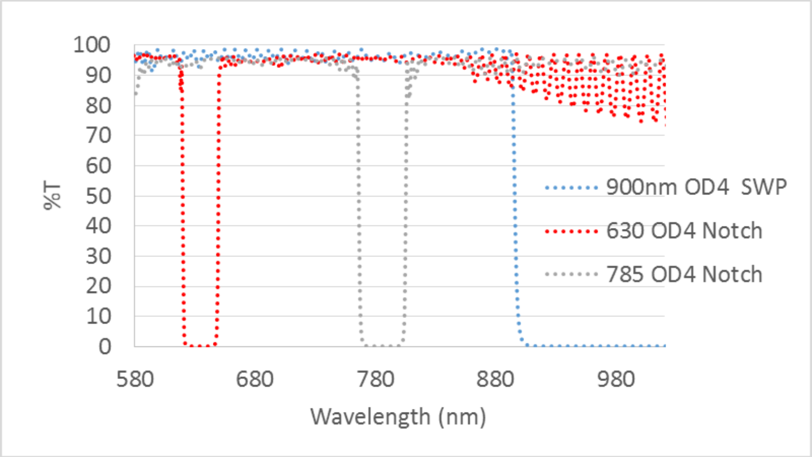
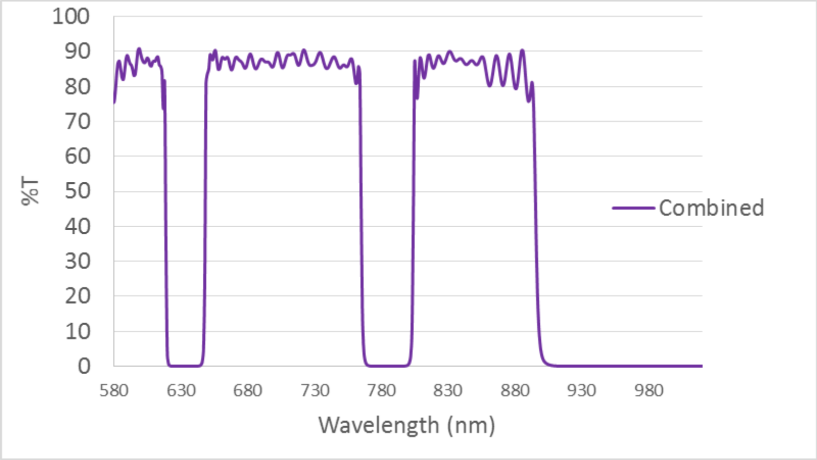
PROTOTYPE QUALIFICATION

- Qualifying a filter can be expensive
  - Demand is typically only 1 – 5pcs
  - Minimum lot charges for a custom run can be in excess of $3k



- Off-the-Shelf is the most cost-effective approach and can help to further refine & fine-tune spectral requirements



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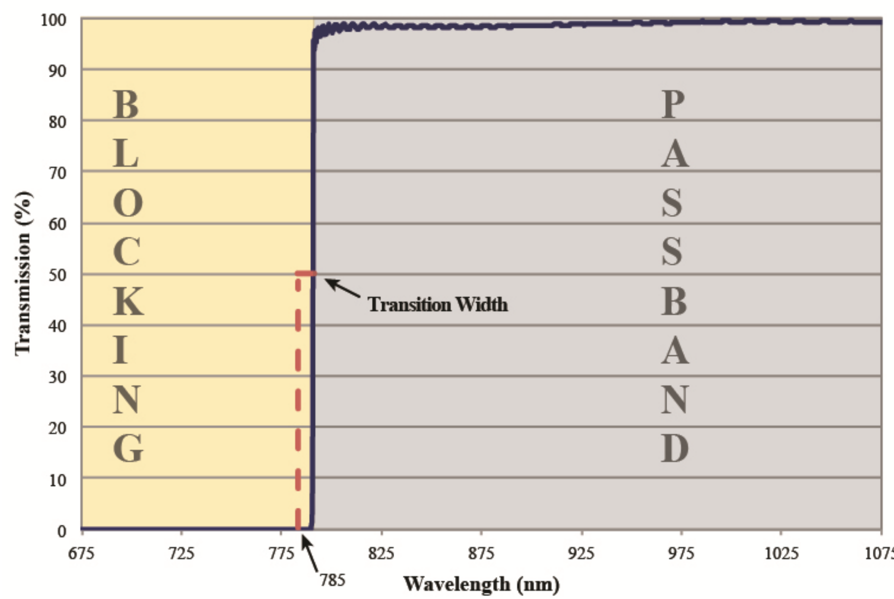
VERIFYING PERFORMANCE

Given that the technology exists to design & manufacture *almost any* optical filter, how do you confirm it meets spec?

To extract the most out of your spectrophotometer, you need properly trained technicians to work through issues such as…



1. Blocking > OD6 (detector sensitivity & noise limitations)
2. Steep Edge Transitions < 1% (resolution & spectral BW)
3. Spectral ranges beyond the limits of detection (below 200nm, beyond 2-3um)

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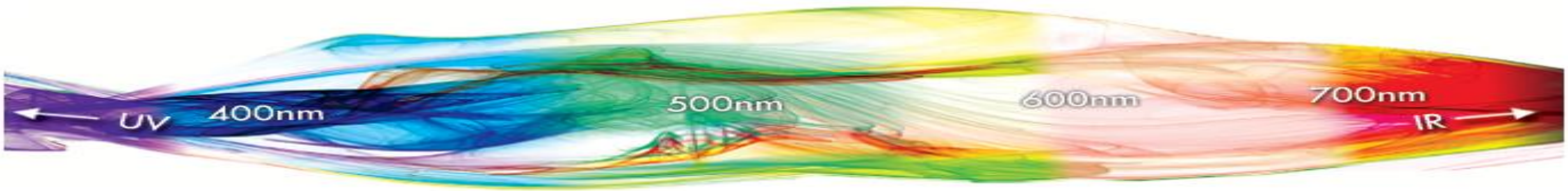
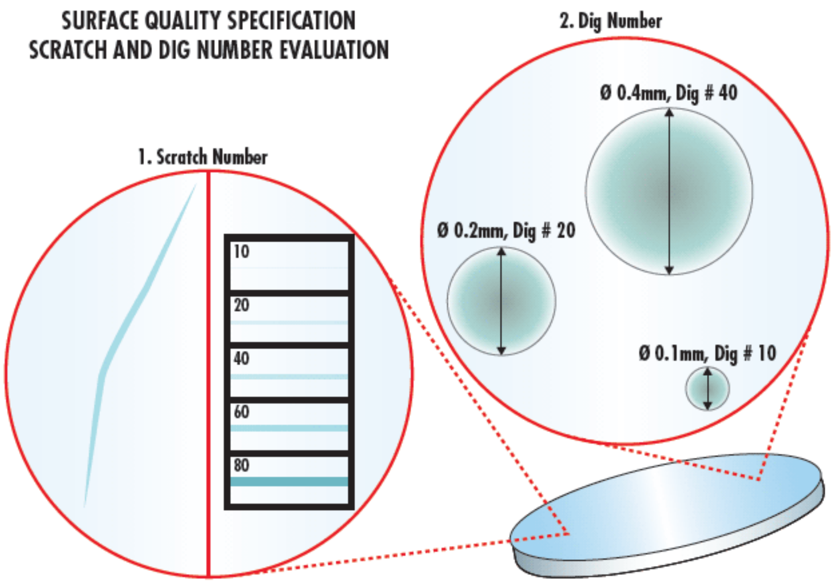
VERIFYING QUALITY



Tools Available:

- Supplied measurement data
- Industry accepted standards for surface quality inspection
  - OP1.002
  - ISO 10110-7



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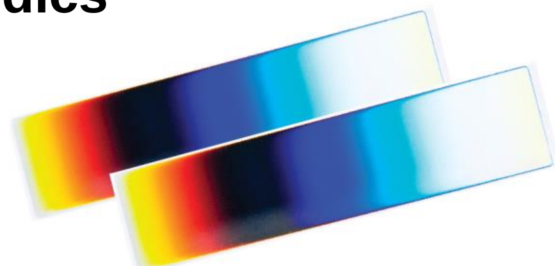
NOVEL BIOMEDICAL APPLICATIONS

1. **Microscopy**
   – Fluorescence, Confocal, and Multiphoton systems
   – "Sedat" vs "Pinkel"
2. **Flow Analysis & Fluidics**
   – Flow Cytometry
   – Cell Sorting
3. **Optogenetics**
   – Genetically modified neurons
   – Rhodopsins
   – Activation & Suppression

Raman Edge Filters

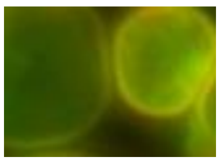

Linearly Variable Filters

Multi Band Fluorescence Filters

MICROSCOPY

Fluorophores, microscopy, and filters are synonymous with one another

In Fluorescence microscopy, for a 3 Fluorophore study, 7 filters can be replaced by 3!

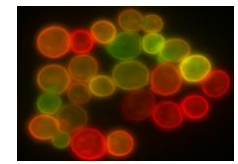


Single-band Fluorescence Filters

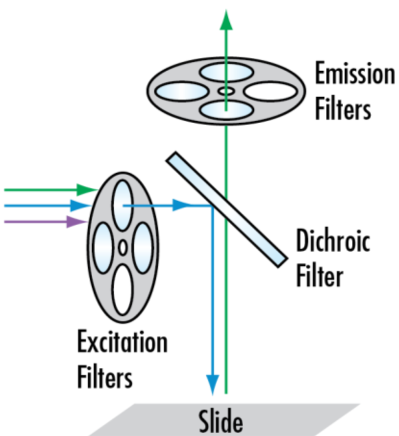
~$225 - $300 off the shelf

Tri-band Fluorescence Filters

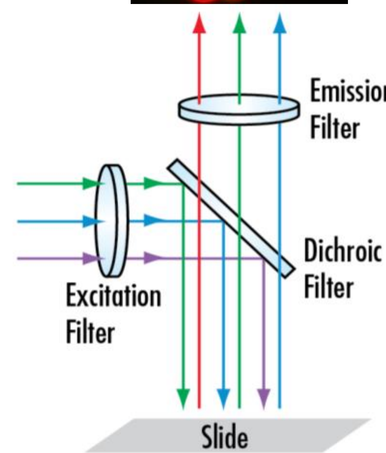
~$375 - $450 for equivalent size



$2100 vs $1350



A "Sedat" Configuration uses a filter wheel to house single-band Exciters/Emitters and a multi band dichroic



A "Pinkel" Configuration uses a multiband exciter or multiband emitter with a multiband dichroic

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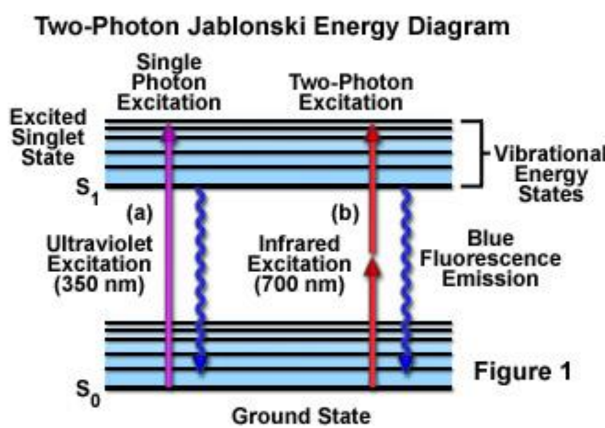
MICROSCOPY

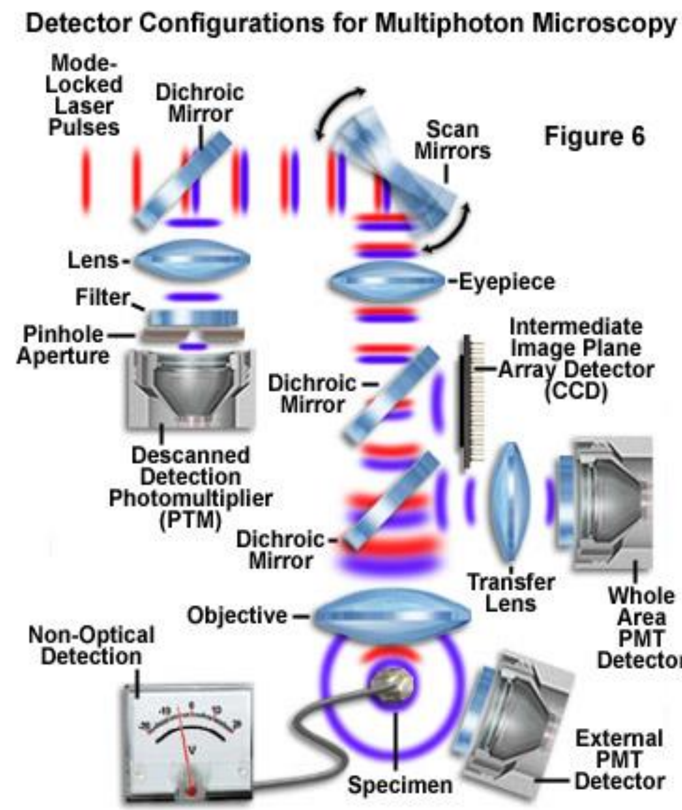
Confocal and Multiphoton microscopy is the advancement of fluorescence microscopy, utilizing thin depth sections and unique wavelength ranges

UV and IR precision filters become important !!!

- Two photons are absorbed simultaneously
- Sources with fast pulse rates are required, as the two photons must arrive within an attosecond of one another (10^{-18} s)
  - Ti:Sapphire
  - Er:Doped



Nikon MicroscopyU



Olympus Micro

FLOW CYTOMETRY

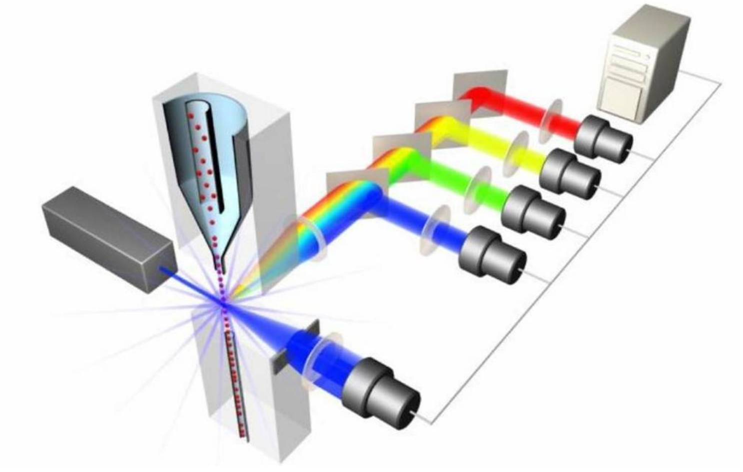
Flow Cytometry is a demanding biomedical application that requires many high quality precision optics, specifically filters

Flow rates that result in 1000+ cells and particles being analyzed a second!

Systems can demand upwards of 20 filters for precise 3-4 channel analysis and acquisition

<u>Specifics on filter requirements for flow systems..</u>

- OD6, or greater
- Extended blocking ranges 200 – 1600nm
- Cut-on and cut-off transitions ~1%
- Transmission > 98%
- Ripple < 1%



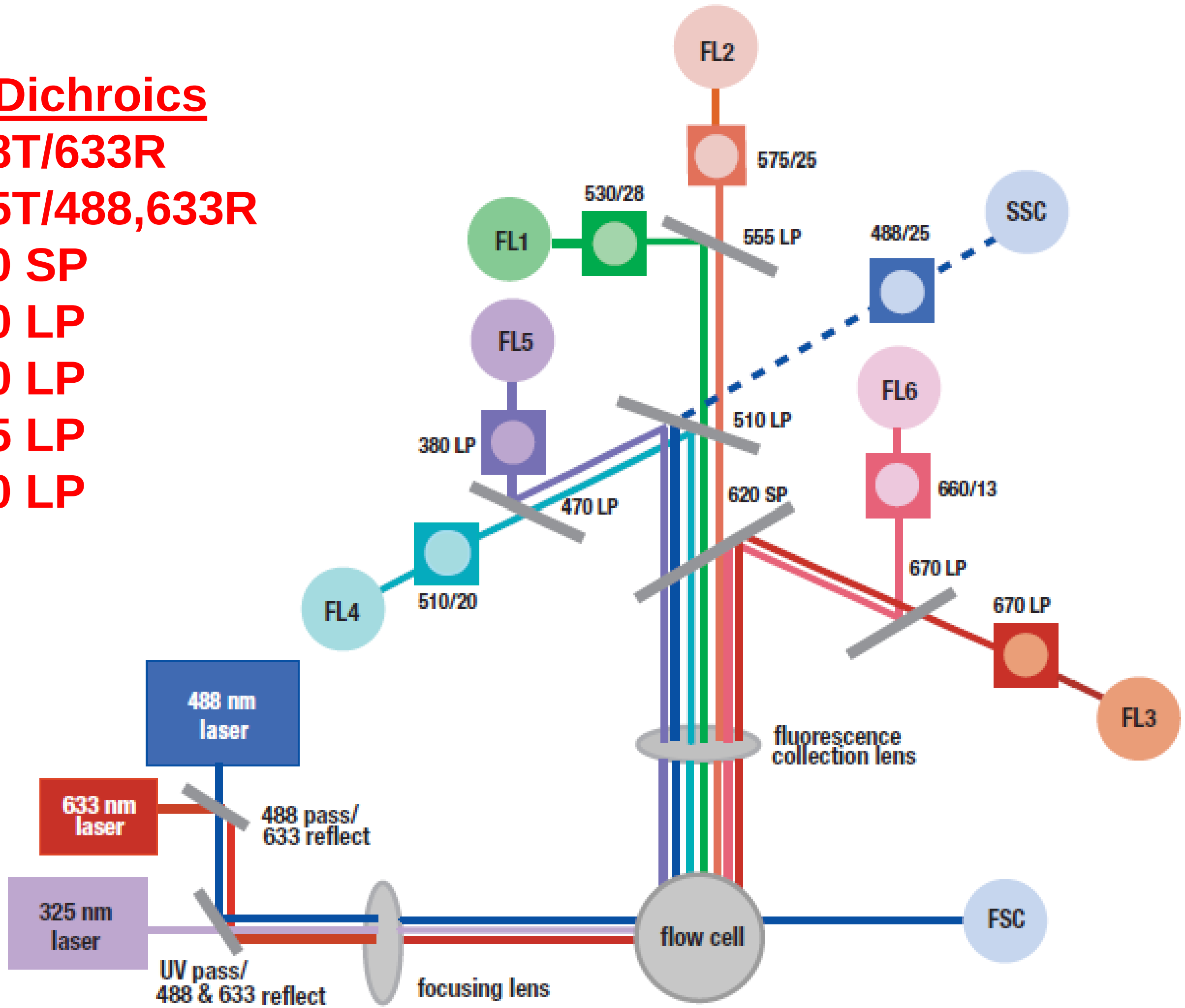
http://regmed.musc.edu/flowcytometry/flowcytometry.html

BD LSR FLOW CYTOMETER

3 Sources
- 325nm
- 488nm
- 633nm

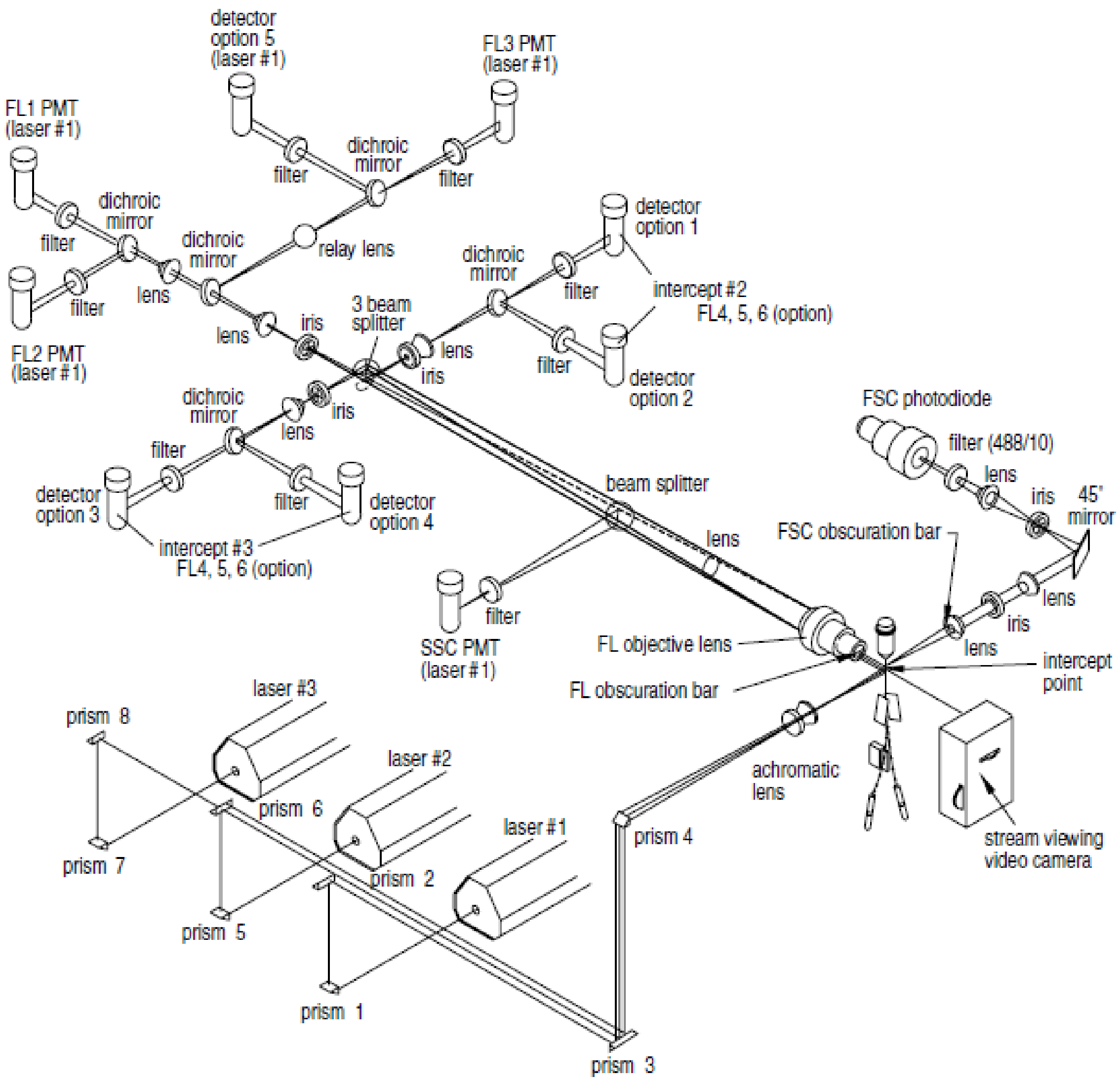
7 Channels
- 488/25nm
- 530/28nm
- 575/25nm
- 670nm LP
- 510/20nm
- 380nm LP
- 660/13nm

7 BS/Dichroics
- 488T/633R
- 325T/488,633R
- 620 SP
- 670 LP
- 510 LP
- 555 LP
- 470 LP



Becton Dickinson – Intro to Flow Cytometry

BD FACS-VANTAGE SE FLOW CYTO



Becton Dickinson – Intro to Flow Cytometry

- 10 Filters
- 8 BS/ Dichroics
- 3 Lasers
- 8 Prisms
- 11 Lenses
- 1 Photodiode
- 1 Camera
- 9 PMTs
- Miscellaneous mechanics / apertures

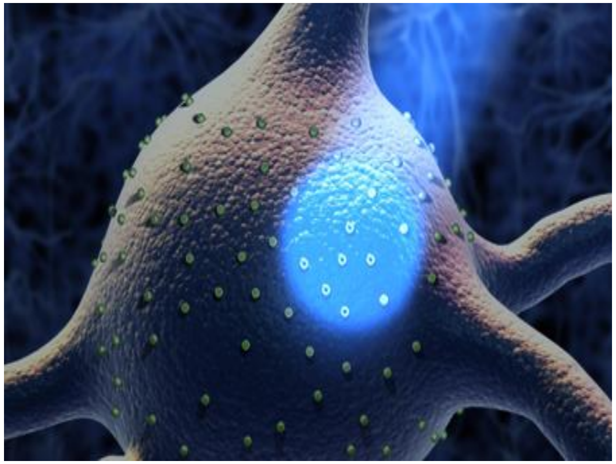
OPTOGENETICS

Field that utilizes light to specifically control genetically modified neurons with sensitivity to light

Light sensitive proteins known as **rhodopsins**

Due to extreme sensitivity to inactivation or photobleaching, highly specific control of photon activation is required.

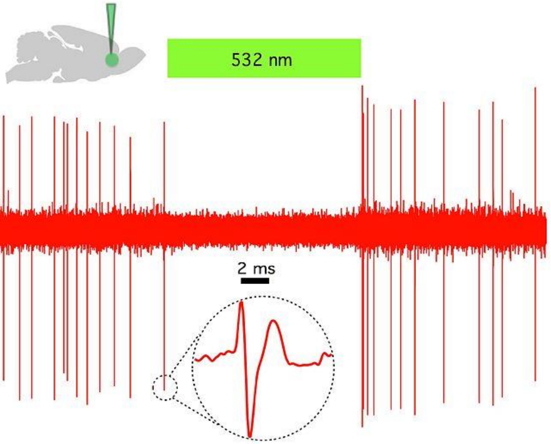
High quality filters can alleviate much of this concern



MIT Media Lab

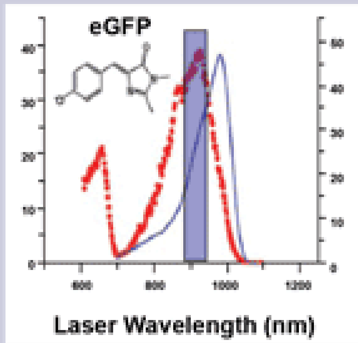
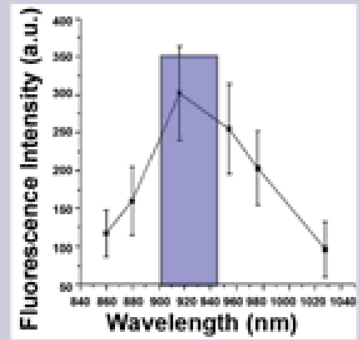
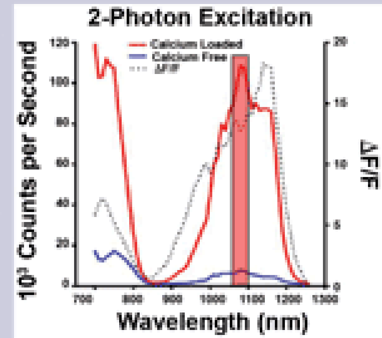
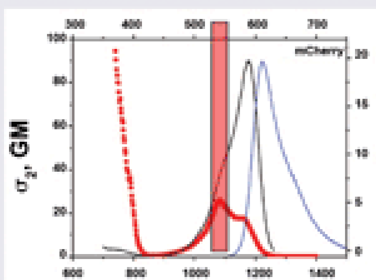
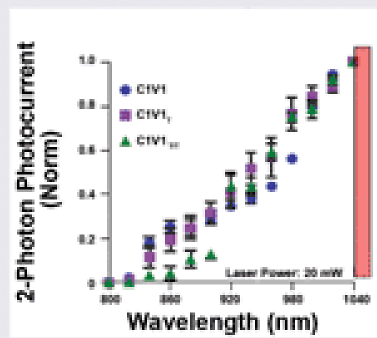
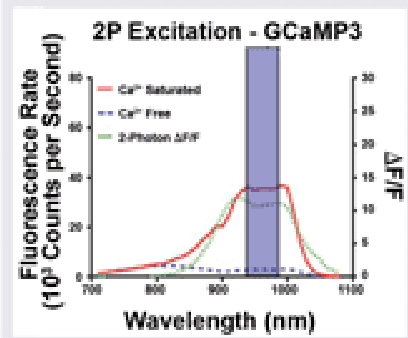
Example…

- Channelrhodopsin-2 (ChR2) → blue light driven activation in prefrontal cortex neuron bundles in rats
  - 473nm fiber coupled, filter ensured delivery
- Halorhodopsin (NpHR) → green light driven suppression in prefrontal cortex
  - 532nm illumination, silences expression of single unit cells



http://en.wikipedia.org/wiki/Optogenetics

OPTOGENETIC SIGNALS

	Imaging	Activation	Ca Detection
Example 1	eGFP (~920 nm) 	ChR2 (940 nm) 	RCaMP (1100 nm) 
Example 2	mCherry (1100 nm) 	C1V1 (>1060 nm) 	GCaMP (940 nm) 

http://www.photonics.com/Article.aspx?PID=1&VID=118&IID=780&Tag=Features&AID=56784

HOW CAN WE HELP YOU?

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Stephan Briggs is responsible for researching innovative optical techniques in microscopy and medical imaging systems to noninvasively diagnose and treat.