VIGO IR-Detector Program : Remarks to it‘s Structure

VIGO PHOTONICS

DoroTEK VIGO-Distributor since February 1991

The VIGO Infrared Detectors are based on the *internal photoelectric effect* in *semiconductors*. Absorption of photons excites electrons to higher levels, namely from the valence band to the conduction band.

Used Detector Materials

- HgCdTe (MCT, II-VI semiconductors)
- InAs / InAsSb (A3B5-compounds, containig the metal In and the non-metals As and Sb)

Basic Detector Structure and Options

- Standard : 3D Hetero Structures of the used semiconductor alloy
- SL = Super Lattic Structure
- M = Multiple p-n-Junctions
- I = Optical Immersion

Principle of Operation

- PV – Photovoltaic (photo diode)
- PC - Photo Conductor
- PEM – Photo Elektro Magnetic

Type of Cooling

- Uncooled (room temperature operation)
- TE = Thermoelectically cooled (2, 3 or 4 stages of Peltier coolers)

Number of Detector elements

- Single Element Detectors
- Quadrant Detectors
- Linear Arrays (up to 32 elements)

Detector Materials

$Hg_{1-x}Cd_xTe$ (MCT)

Material of choice for HOT photodetectors

Advantages:

- ► band gap tunability 0-1.4 eV → MWIR, LWIR
- ► large figure of merit α/g_{th} → high performance
- ► lattice constant independent on x → easy band gap engineering
- ► stable n- and p-type doping → complex 3D heterostructures

InAs / InAsSb

RoHS compatible alternative

Advantages:

- ► RoHS compliant → completely safe for the consumer market
- ► higher temperature resistance → improved reliability (even up to 300°C)
- ► InAs/InAsSb super lattice structures → parameter similar or even better than MCT achievable

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Detector types: PC, PV, PEM

Photoconductor	
Pros	Cons
Simple design	Bias required
High responsivity	1/f noise
Large areas	Long response time for MWIR

Photovoltaic	
Pros	Cons (for uncooled LWIR PV)
short response time	Low quantum efficiency
No bias	Very low resistance
No 1/f noise	Useless with conventional design
Convenient to use	

Photoelectromagnetic	
Pros	Cons
Very short response time (ps-range)	bulky
No bias	Modest performance
No 1/f noise	

Photoconductive Devices (PC)
Photoconductive Devices (PC) are detectors based on the photoconductive effect. Infrared radiation generates charge carriers in the semiconductor active region decreasing its resistance. The resistance change is sensed as a voltage change by applying a constant current bias.

Photovoltaic Devices (PV or PVM)
Photovoltaic devices (photodiodes) are semiconductor structures with one (PV) or multiple (PVM) homo- or heterojunctions. Absorbed photons produce electron-hole pairs, resulting in an internal photocurrent.

Photoelectromagnetic Devices (PEM)
PEM detectors are photovoltaic devices based on the photoelectromagnetic effect. It relies on a spatial separation of optically generated electrons and holes in a magnetic field applied to the semiconductor by a permanent magnet built in the detector housing.

Options:
I, TE, M

Optical Immersion
All detectors can be monolithically integrated with immersion microlens.

Hyperhemispherical immersion microlens is offered as a standard.

TE Cooling
VIGO PC, PV and PVM detectors are available as uncooled devices or equipped with multiple stage TE cooling.

“2TE”, “3TE” or “4TE” for two-, three-, or four stage TE cooled detectors respectively.

Multijunction
Use of multiple p-n-junctions in series for LWIR detectors (≥ 8 µm)

Resulting Standard Detector Types	
Photoconductor	PC, PCI, PC-nTE, PCI-nTE
Single junction photovoltaic detector	PV, PVA, PVI, PVIA PV-nTE, PVI-nTE PVA-nTE, PVIA-nTE
LWIR multiple junction photovoltaic detector	PVM, PVMI, PVM-nTE, PVMI-nTE
Photoelectromagnetic detector	PEM, PEMI

n = number of TE cooling stages, 2,3 or 4
A = detectors made from InAs or InAsSb

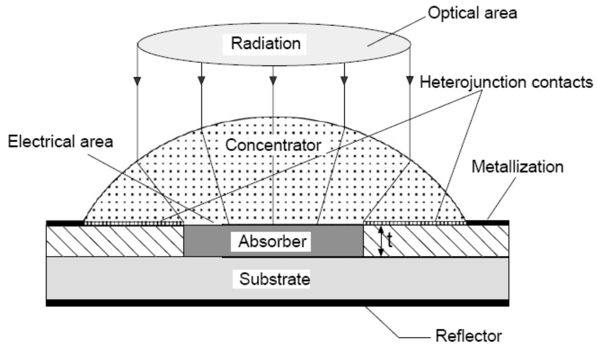
Monolithic Optical Immersion

The generation-recombination limited detectivity :

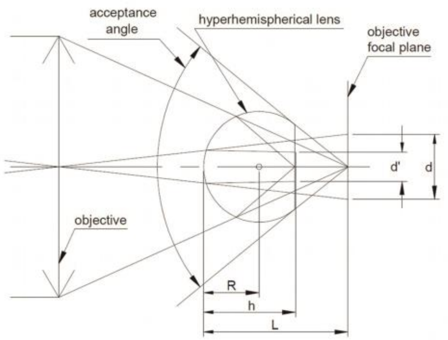
$$D^* = \frac{\lambda}{hc} \cdot \left(\frac{A_o}{A_e}\right)^{1/2} \cdot \frac{\eta}{t^{1/2}} \cdot \frac{1}{[2(G+R)]^{1/2}}$$

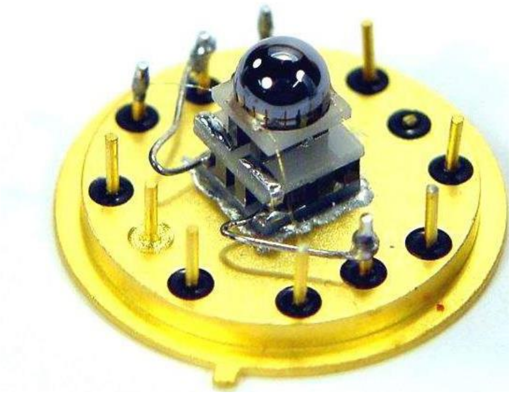
→ Increasing the ratio of optical detector area to the electrical active detector chip improve the D*

→ Lens directly shaped from the GaAs buffer, no reflectoion losses



Parameter	Symbol	Hyperhemisphere	
		Theory	GaAs
Distance	L	R (n+1)	4.3·R
Diameter ratio	d / d'	n^2	10,9
D* ratio	$D^*_{imm} / D^*_{non\text{-}imm}$	n^2	10,9
Acceptance angle	Φ	$2 \arcsin (1/n_{GaAs})$	35.3°
F-number	F/#	$1 / 2\, n_{air} \sin (\Phi /2)$	1.65





Attention : Influence to the Range of Linearity

Type of Immersion	Range of Linearity*
Hyper-hemispherical	app. 0.1 mW
Hemispherical	app. 0.4 mW
Without immersion, flat detector	app. 1 mW

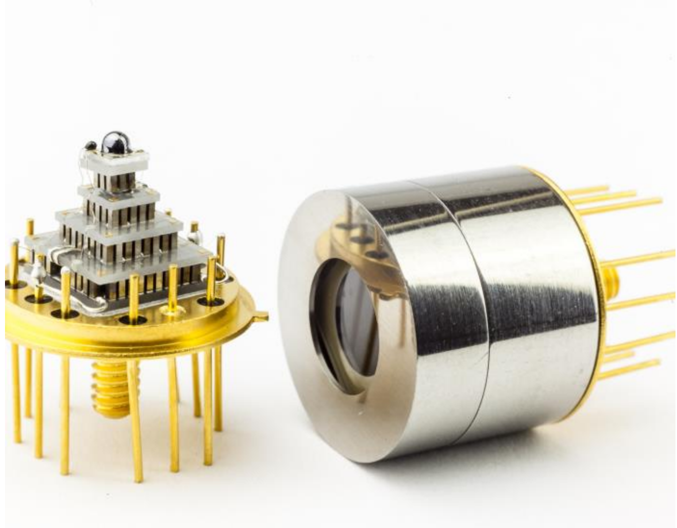
*less than 90 % deviation from linear response

n – refractive index of lens material, ~3,3 for GaAs
d – optical (apparent) detector size
d' – physical detector size
R – lens radius
L – lens face to objective focal plane distance
h = R+R/n – lens thickness

TE Cooling

$$D^* = \frac{\lambda}{hc} \cdot \left(\frac{A_o}{A_e}\right)^{1/2} \cdot \frac{\eta}{t^{1/2}} \cdot \frac{1}{[2(G+R)]^{1/2}}$$

- → Detector cooling reduces noise, increases responsivity and, in some devices, improves high frequency response.
- → Two-, three- and four-stage TE coolers are available.
- → TEC is biased with DC power.
- → All Specifications are given for 300 K heat sink temperature.



Parameter	Unit	2TE	3TE	4TE
Detector Temperature	K	~230	~210	~195
V (max)	V	1.3	3.6	8.3
I (max)	A	1.2	0.45	0.5
Q (max)	W	0.36	0.27	0.28
ΔT (max)	K	92	114	125

Maximum Temperature Difference

ΔT_{max} rated at Q=0, at other Q the ΔT should be estimated as $\Delta T = \Delta T_{max} \cdot (1\text{-}Q/Qmax)$
with Qmax = maximum heat pumping capacity

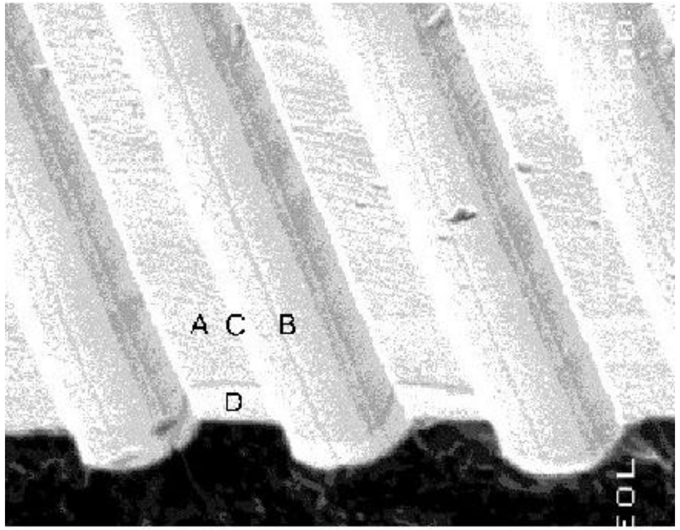
Multijunction udetectors

Large area and/or long wavelength HOT diodes have impractically low resistance and voltage responsivity:

Solution : **PVM - multiple cells in series along surface in fabrication since 1996**

Features

- Zero bias operation – no 1/f noise
- Very useful for large area devices
- Perdiodic fluctuation of responsivity
- Polarisation dependent response



SEM image of a multi-heterojunction photodetector:
A mesa structure, B – trenches, C – non-metallised wall
D – non-metallised region of the device

Packages

	Package type	Cooling	Window	Detector type
	BNC	uncooled	no	PC, PCI, PV, PVI, PVM, PVMI
	TO39	uncooled	no	PC, PCI, PV, PVI, PVA, PVIA, PVM, PVMI
	PEM-SMA	uncooled	yes	PEM, PEMI
	PEM-TO8	uncooled	yes	PEM, PEMI
	TO8	uncooled	no	PCQ, PVMQ
	TO8	TE cooled	yes	PC-2TE, PC-3TE, PC-4TE PCI-2TE, PCI-3TE, PCI-4TE PV-2TE, PVA-2TE, PV-3TE, PV-4TE PVI-2TE, PVIA-2TE, PVI-3TE, PVI-4TE PVM-2TE PVMI-2TE, PVMI-3TE, PVMI-4TE
	TO66	TE cooled	yes	PC-2TE, PC-3TE, PC-4TE PCI-2TE, PCI-3TE, PCI-4TE PV-2TE, PVA-2TE, PV-3TE, PV-4TE PVI-2TE, PVIA-2TE, PVI-3TE, PVI-4TE PVM-2TE PVMI-2TE, PVMI-3TE, PVMI-4TE

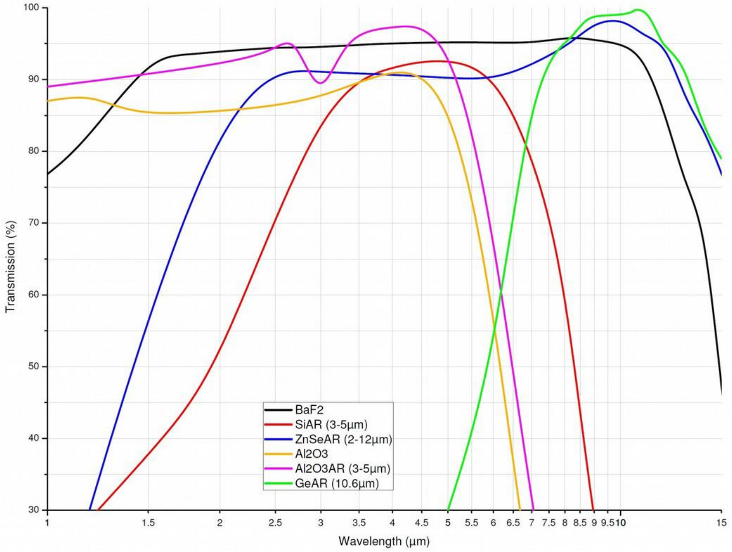
Remark
The packages of TE-cooled detectors are filled with dry, heavy noble (inert) gases for low thermal conductivity (Kr/Xe mixtures). Water vapor condensation is prevented by careful sealing and water absorbers applied inside the package.

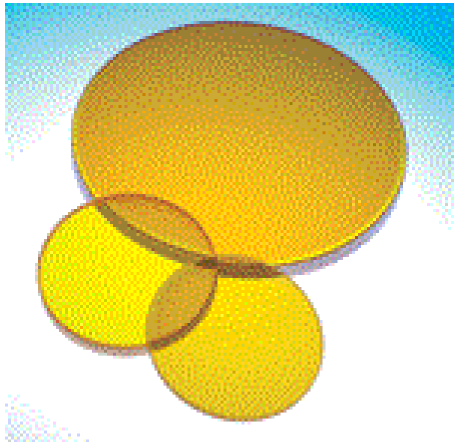
Windows

VIGO TE cooled detectors are typically provided with:

- 3° wedged Al_2O_3 windows (wAl_2O_3)
- 3° wedged ZnSe AR coated windows (wZnSeAR)

Uncooled detectors are supplied without window, but of course possible if harsh environment is requiring a detector protection

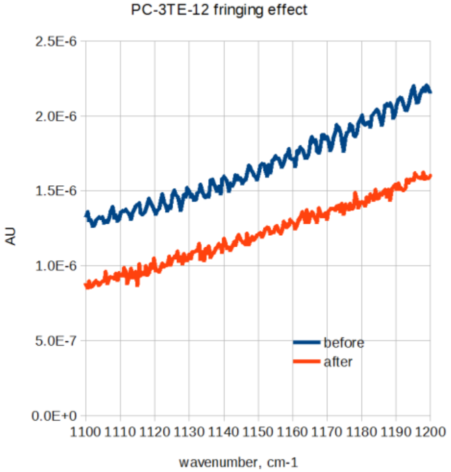




Fringing / Etalonging:

Cause: reflections and interferences at window, substrate or interfaces

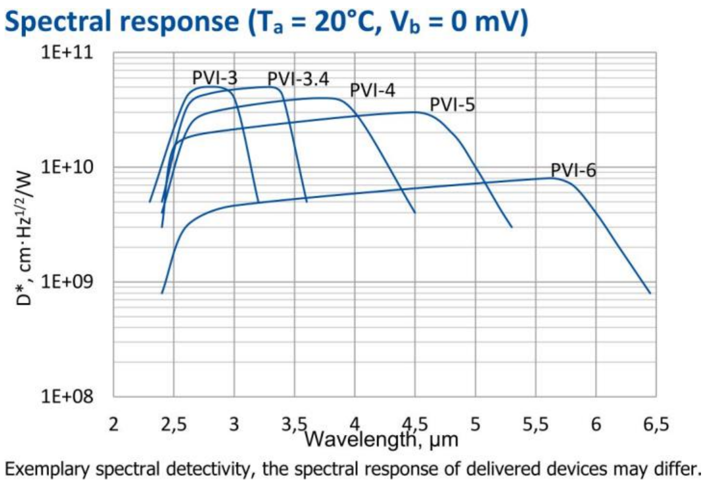
Material	Refractive index	Thickness, mm	Possible fringing. Delta k, cm^{-1}
Sapphire window	1,7	0,4	7,4
ZnSe window	2,4	0,8	2,6
Silicon window	3,4	1	1,5
BaF2 window	1,4	1	3,6
Germanium window	4	1	1,3
GaAs detector substrate	3,3	0,4	3,8
Xenon between window and detector	1	2	2,5



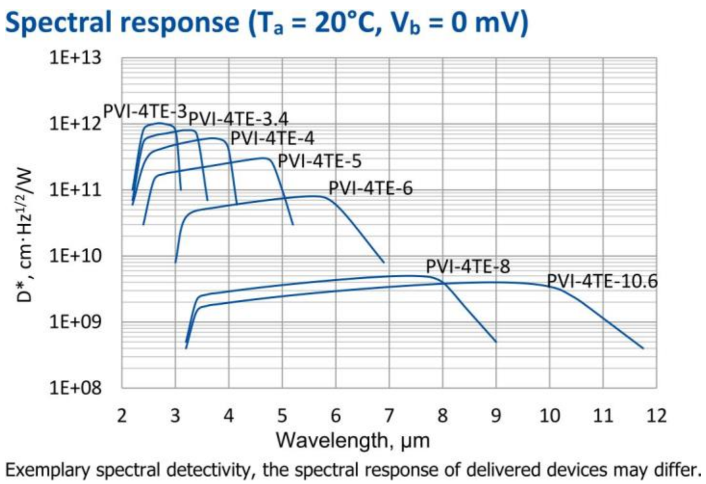
Optimum Wavelength Selection for II-VI (MCT) Detectors

Because the used detector materials Hg, Cd and Te are belonging to the main groups 2 and 6 of the periodic system, the groupname II-VI-detectors is used in the Infrared-World. For HgCdTe detectors it is possible to tune the band gap E_g by the ratio of Hg : Cd in the compound. Thus the detector can be optimized for a certain wavelength.

Detector type	Optimum Wavelenth [µm]										
PC, PCI				5	6		9	10.6			
PCQ, PVMQ								10.6			
PC-2TE, PCI-2TE				5	6		9	10.6	12	13	
PC-3TE, PCI-3TE							9	10.6	12	13	
PC-4TE, PCI-4TE							9	10.6	12	13	14
PV, PVI	3	3.4	4	5	6						
PV-nTE, PVI-nTE	3	3.4	4	5	6	8		10.6			
PVM, PVMI, PVM-nTE, PVMI-nTE						8		10.6			
PEM, PEMI								10.6			



Example : Uncooled Detector Series : PVI



Example : Cooled Detector Series : PVI-4TE

Optimum Wavelength Selection for III-V Detectors

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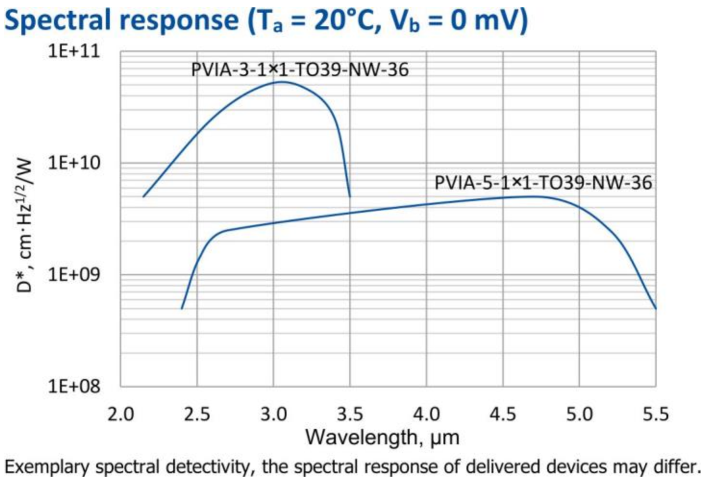
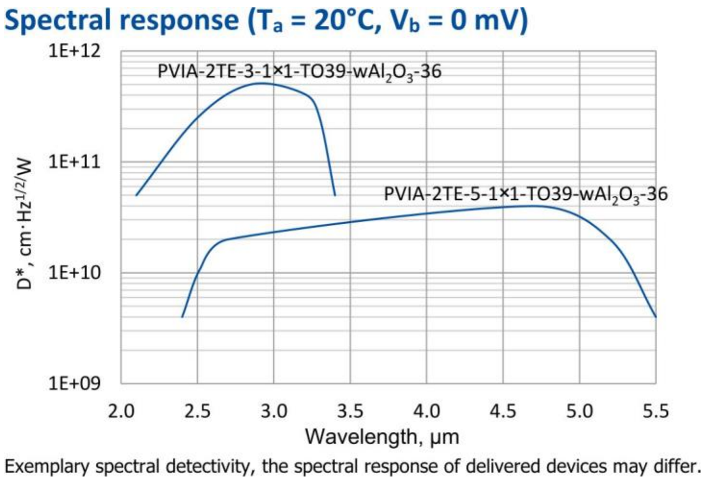
Because the used detector materials In, As and Sb are belonging to the main groups 3 and 5 of the periodic system, the groupname III-V-detectors is used in the Infrared-World. VIGO is producing two configurations : InAs and InAsSb.

Detector type	Optimum Wavelenth [µm]	
PVA, PVA-2TE PVIA, PVIA-2TE	3	5



Example : Uncooled Detector Series : PVIA



Example : Cooled Detector Series : PVIA-2TE

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Preamplifiers

From the IR-Detector to the IR-Detector-Module

The VIGO infrared detectors can be supplied as well as turn-key IR detector module. It include the preamplifier and for the TE-cooled detectors the cooler controller.

AIP	MIP	SIP	PIP
			
All-in-One-Solution	**Low-Noise-Solution**	**Miniaturized Solution**	**Programmable Solution**
Transimpedance Pre-amplifier with integrated cooler controller	Transimpedance Pre-amplifier with axial fan for flexible laboratory operation.	Transimp. Preamplifier for OEM applications	Programmable “SMART” preamplifier with axial fan for flexible laboratory operation
High cut-off frequency 250 MHz (AIP-INTIR : > 1 GHz)	High cut-off frequency 250 MHz	High cut-off fr. : 100 MHz	High cut-off frequency 200 MHz
For TE cooled detectors	For TE-cooled detectors	For uncooled and TE-cooled detectors, requires an external heat sink	For TE-cooled detectors

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Cooler Controller PTCC-01

From the IR-Detector to the IR-Detector-Module

The TE-cooled detectors need for their operation a controller for the cooling procedure and monitoring of the cooling status. PTCC-01 is a series of programmable, low-noise controllers. A temperature stability of ±0.01 K is achieved !

PTCC-01-ADV (advanced)	PTCC-01-BAS (basic)	PTCC-01-OEM (oem)
› TEC controller and preamplifier power supply encapsulated in a small size package. › Configurable by built-in function keys or PC software available on VIGO and DoroTEK website. › Status LCD indicator.	› TEC controller and preamplifier power supply encapsulated in a small size package. › Configurable by PC software available on VIGO and DoroTEK website. › Status LED indicator.	› TEC controller and preamplifier power supply without package. › Configurable by PC software available on VIGO and DoroTEK website. › Status LED indicator and status/ data connector.

Selected Line

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The VIGO detectors can be distinguished in different way, as described in this presentation.
Type (PC, PV, PVM, PEM), the used material, uncooled or cooled, with or without optical immersion. In addition the detectors are available with different optimum wavelength and active areas. In total the VIGO offer contains **more than 400 different detectors**. And we do not consider here the additional options of different packages and windows.
Parallel VIGO offers 6 preamplifiers types with choosable bandwidth. In total **more than 20 preamp options**. Not all detector – preamplifier are useful, nevertheless the 400 + 20 would result into 8000 possible combinations.

The VIGO conclusion : to chose useful and most ordered combinations and create a selected line. The advantages :

- ► lower price compared to the sum of the single components
- ► warrantied bandwidth for the IR-detector modules
- ► mostly delivery from stock

Type	Included Detector	Included Preamplifier	Spektral Range	Bandwidth
LaBM-I-4	PVI-4TE-4-1x1	PIP	2,4 – 4,3 µm	DC - > 5 MHz
LaBM-I-5	PVI-4TE-5-1x1	PIP	2,9 – 5,5 µm	DC - > 15 MHz
LaBM-I—6-01	PVI-4TE-6-1x1	PIP	2,5 – 7,0 µm	DC - > 3 MHz
LabM-I-10,6	PVMI-4TE10,6-1x1	PIP	2 – 12 µm	DC - > 100 MHz
microM-10,6	PVM-10,6-1x1	µIP	2 – 12 µm	DC - > 10 MHz
UM-I-10,6	PVMI-2TE-10,6-1x1	AIP	2 – 12 µm	DC - > 100 MHz
SM-I-12	PCI-3TE-12-1x1	SIP	2 – 14 µm	10 Hz - 1 MHz
UHSM-10,6	PV-4TE-10,6-0,05x0,05	AIP-INTIR	3 – 12 µm	300 Hz - > 1 GHz
UHSM-I-10,6	PVI-4TE-10,6-1x1	AIP-INTIR	3 – 12 µm	300 Hz - > 700 MHz

Thank you for your attention!

Do you have questions ?
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Or write us : info@dorotek.de