Photon Detection Products
ALV-CorrTector

DESCRIPTION

The ALV-CorrTector offers a combination of a Multiple Tau Digital Correlator and an Avalanche Photo Diode based Single Photon Detector in one unit to best suit the specific requirements of photon correlation experiments.

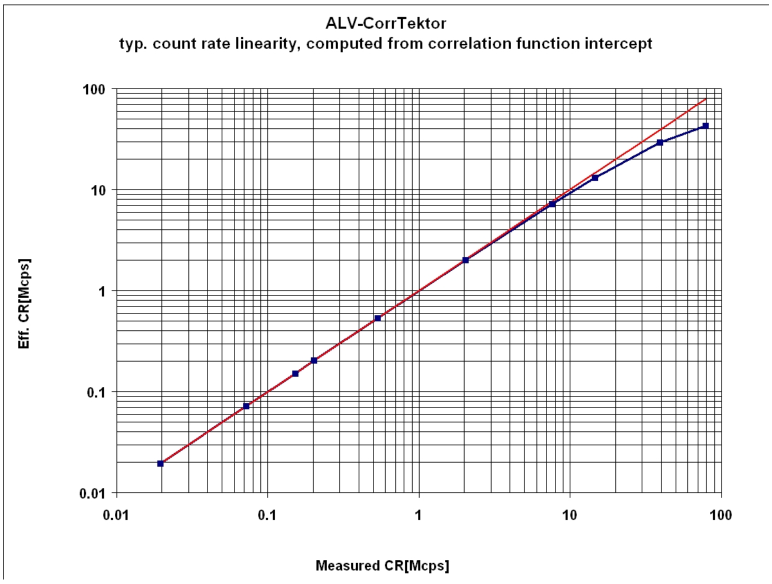
Combining the well known ALV-700X/USB digital correlator series with an ALV-developed special silicon avalanche photo diode, it not only allows simple and straightforward experimental setups (light in / correlation function out), but offers these at outstanding count rate linearity and extremely low detector self correlation contribution, the two most important parameters for a detector in almost every photon correlation experiment.

Offering Photon Detection Efficiencies of up to 20% (connectorized) at 532 nm wavelength, the ALV-CorrTector not only shows very low dark count contribution, but is an inherently safe design in the specific way it is operated, ensuring even strongest and sustaining overexposure conditions will not lead to any damage to the APD-detector.

Highly efficient optical coupling of single mode fiber output via a standard FC/PC fiber socket completes this product, which strictly follows the idea of 'light in - correlation function out'.

APPLICATION

- **DLS/SLS**
- **DWS**
- **FCS**
- **Particle Sizing**
- **General Photon Correlation**
- **OEMs**



KEY FEATURES

- **Single Photon Detector and adopted ALV-7004/USB MultipleTau Correlator plus ALV-Correlator Software for WIN-7/8 (32/64 bit)**
- **Optimized optical input for Single Mode Fibres via FC/PC socket**
- **High quantum efficiency with a PDE of up to 20% (connectorized) at 532 nm wavelength**
- **Very high count rate linearity with a limiting count rate exceeding 80 Mcps**
- **Low self-correlation contribution allows sub-µs lagtime access even at low count rates**
- **Low dark count contribution of typ. 300 cps (smaller values are possible by selection and against surcharge)**
- **Inherently safe design, no detector damage even for strongest and sustained over-exposure**
- **Very compact (38 x 58 x 115 mm) and lightweight design (~250g)**
- **Simple Mini-USB connection to PC**
- **Very low power consumption of ~1.2 W (passive control version), resp. ~1.8W (TEC, active control version), single +5V power supply (fed via USB connector or proprietary IF)**

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ALV-CorrTector, Technical Data

Parameter	min.	typ.	max.
All APD Tile PDE [1] @ 532 nm @ 633 nm	- -	20% 14%	- -
Single APD Tile PDE [2] @ 532 nm @ 633 nm	- -	25% 18%	- -
Detector Dark Counts, All APD Tiles [3]			
Passive thermal control, DC selection grade - 1 (standard) Passive thermal control, DC selection - 2	- -	300 cps 150 cps	600 cps 300 cps
TEC thermal control, DC selection grade - 3 (standard) TEC thermal control, DC selection grade - 4	- -	200 cps 100 cps	400 cps 200 cps
Maximum Light Count [4]			
All APD tiles illuminated	80 Mcps	100 Mcps	-
Single APD tile illuminated	20 Mcps	25 Mcps	-
Afterpulsing Probability [5]			
Total Afterpulse 50 ... 500 ns lag time, 25 ns STC Peak Afterpulsing @ 50 ns lag time, 25 ns STC	- -	0.2% 0.02%	1% 0.2%
Amplifier Bandwidth (- 3dB)	> 120 MHz		
Amplifier DC Voltage Gain	49 dB		
Pulse Discriminator Bandwidth (-3 dB)	> 300 MHz		
Pulse Discriminator Min. Pulse Width	4.5 ns		
ALV-CorrTector Current Requirement at +5 V or USB [6]			
Passive thermal control TEC thermal control	- -	240 mA 350 mA	300 mA 500 mA
ALV-CorrTector Correlator In-Built	ALV-7004/USB Compatible Type		
Correlator Initial Sampling Time	25 ns		
Dimensions (H x W x L) incl. FC/PC fibre socket	38 mm x 58 mm x 115 mm		
Total Weight w/o Optical Fibre and Cables	~ 250 g		
Allowed Temperature Range for Operation [7]	10°C ... 50°C, non-condensing		

Footnotes:

[1] Using an appropriate Single Mode Fibre at the wavelength stated and with the internal transfer optics set such that all four APD tiles are illuminated equally and ideally (optimum linearity mode).

[2] Single APD tile PDE using an appropriate Single Mode Fibre at the wavelength stated and with the internal transfer optics set such that the light is focussed on one of the four APD tiles (optimum PDE mode). Note that in this configuration the maximum light count obtainable is reduced compared to the optimum linearity mode, see above table for details.

[3] Detector dark counts at ~21°C environmental temperature summed for all four tiles for passive thermal control. Detector dark counts at ~18°C internal APD temperature summed for all four tiles for TEC thermal control. Dark counts of a single tile can be approximated to be not larger than the dark counts stated divided by four in either case. Lower dark count selection is available as option and depending on the actual availability of APDs which such low dark count contribution.

[4] Maximum light count is guaranteed for the minimum value stated only. However, as option and at surcharge, special selection can be requested for higher guaranteed maximum light count.

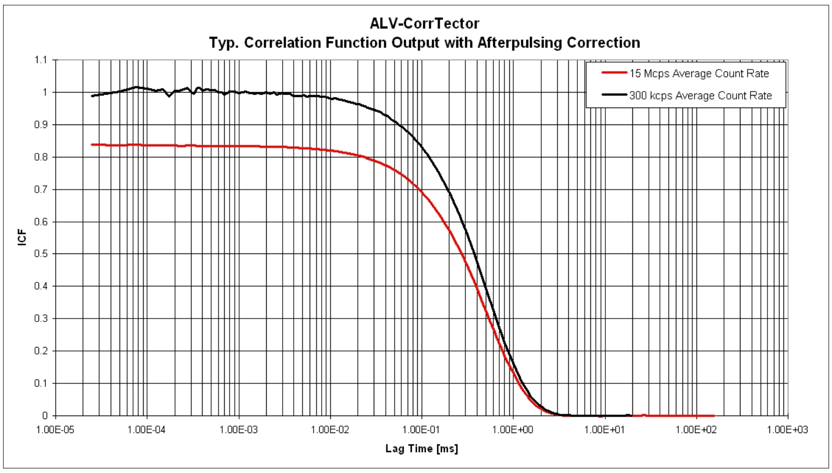
[5] Afterpulsing (including crosstalk) probability for all four APD tiles used (optimum linearity mode, cross-correlation). No further corrections applied, raw APD data. Applying additional corrections greatly enhances the detector's afterpulsing performance with typ. a factor of ten lower contribution after correction over the entire lag time range from 50 ns lag time on.

[6] Max. current requirement at maximum light count using all four APD tiles and with correlator and USB-interface active. Typ. value for TEC thermal control presumes environmental temperature to be less or equal 25°C, max. value ist to be expected for 30°C or above environmental temperature. Please also note the max./min. environmental temperature range allowed.

[7] Allowed temperature range for the passive thermal control version. Please note that increasing environmental temperature will lead to increasing dark count contribution. The TEC thermal control version has a reduced allowed temperature range of 10°C ... 35°C. Dark counts will not increase with increasing environmental temperature for this version.

ALV-CorrTector, Figures

Figure 1.0 ALV-CorrTector typ. Correlation Function Output

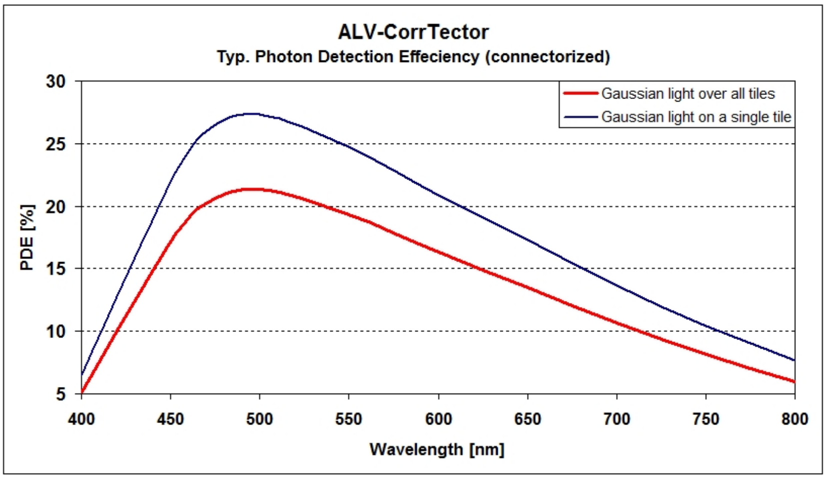


Low (300 kcps) and high (15 Mcps) average count rate correlation functions shown with afterpulsing correction applied.

Despite the high average count rate of 15 Mcps, the red intensity correlation function still shows nearly 85% modulation compared to the (ideal) 100% of the black low average count rate correlation function.

Neither significant afterpulsing, nor significant dead times are visible in either correlation function, showing the successful application of the apropriate corrections.

Figure 2.0. PDE versus Wavelength

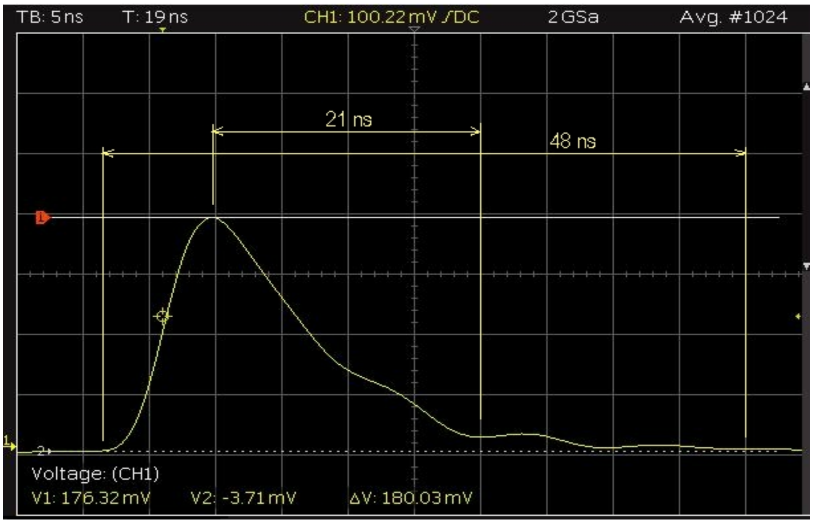


Peak PDE of ~27% can be expected around 500 nm wavelength.

Illuminating a single tile ensures highest PDE, wereas illuminating all tiles simultaneously gives rise to a certain tile-to-tile gap loss, which reduces the PDE by about 20% for gaussian illumination.

PDE ranges from 400 nm to 800 nm with nearly 15% PDE for 632.8 nm.

Figure 3.0 ALV-APD typ. pulse timing of a single APD tile, amplified and averaged over 1024 output pulses.



The figure shows a 10% recovery time for the APD tile of 21 ns, which is equivalent to below 50 ns recovery time to 1% and thus well within the total pulse length.

Pulse discrimination is set about to the center height of the pulse, thus two pulses can be individually detected after ~11 ns delay time to each other, as long as the secondary pulse reaches the required trigger voltage and taking the pulse rise time into account.

Technical Details

- **Development Motivation: Simply the best for Photon Correlation Experiments**

Practically all APD-based single photon detectors commercially available by today seem to set their main focus on highest obtainable Photon Detection Efficiency, thus the ability to convert incoming photons to electrical pulses at utmost probability. While this does indeed seem useful for pure photon counting experiments, in particular for extremely low detection light levels, a high PDE does not by itself fulfill the requirements of high quality photon correlation experiments, but other detector parameters become much more important for this kind of experiments, such as detector self-correlation contribution or count rate linearity.

Most notably this is true for DLS/SLS or DWS experiments, which seldomly fall short in light level, but in contrast may show varying light levels over several decades, maybe even within a single experiment whenever time-dynamic sample behaviour is to be investigated. For these reasons, the ALV-CorrTector does not follow the route of pronounced PDE optimization, but instead optimization was performed on best photon correlation experiment results with a ‘high enough’ PDE set as additional design requirement.

- **Extra-High PDE: But what for ?**

Higher PDE does lead to higher detector count rates compared to lower PDE detectors at equal detector light level - that is obvious. Still, keeping in mind that photon correlation experiments analyse the fluctuation of this light level in first place, it must be as obvious that the best mapping of actual light level to number of pulses per time unit must be considered an even more important parameter for judging a single photon detector’s usability for photon correlation experiments. This parameter, usually being refered to as ‘count rate linearity’, was a top focus while developing the ALV-CorrTector.

So far, commercially available avalanche photo diode based single photon detectors were limited to around 10...15 Mcps as their maximum pulse output count rate for randomly arriving photons (thus not used in gated mode), which prohibited their use in DLS/SLS or DWS experiments with average count rates much above a few 100 kcps due to the notable count rate non-linearity effects for larger average such count rates.

In contrast to these, the ALV-CorrTector ensures >80 Mcps as maximum pulse count rate for randomly arriving photons and thus more than a factor of five higher value than obtainable with the so far commercially available avalanche photo diode based single photon detector modules. In addition, the use of a quenching/pulse detection scheme significantly different from the typically used ‘active quenching and reload’ scheme used ensures the ALV-CorrTector shows less susceptability for paralyzation effects due to photons arriving within the quenching/reload time.

With a typical -5% count rate deviation point as high as 7,5 Mcps, the ALV-CorrTector allows average count rates in the lower Mcps regime to be used (with all the benefits from doing so in terms of shot noise contributions on the photon correlation functions) without distorting the further signal analysis significantly by count rate non-linearitiy - a major improvement compared to so far existing APD solutions.

- **Short Lag Times: Large Problems ?**

Short-lag time access, that is deep sub-µs lag time access, does not really seem to be an easy task with commonly used single photon counting APDs. The reasons are significant dead times after each avalanche generation process (typically detection/quench/reload in an active quenched/reloaded APD) on one hand, but as well the quite pronounced tendency to generate after-pulses and with that a significant tendency for self-correlation that does primarily inflict the sub-µs lag times.

Special APD by APD selection for lowest afterpulsing does help a little, but in general the lag time range below 1 µs is not at all accessible with just a single such detector for ungated experiments and at still tolerable distortion of the correlation function, but at least a pseudo-cross correlation setup has to be used with two such units and each working on an individual branch of a splitted optical input signal.

Yet again, best after-pulsing and quench/reload behaviour was a major parameter in the APD development, coupled with appropriate features to be able to obtain a real-time measure of the influence of these effects on the photon correlation function, simply for the reason of correcting them as good as possible.

Given the fact that correlation function lag times as small as 500 ns (typ.) are accessible with less than 1% residual distortion in the intensity correlation function and even at count rates a low as 20 kcps and 25 ns sampling time, this design goal obviously is met by the APD as such already. The particularly stable and fast nature of the residual afterpulsing effects even allow additional correction of the resulting correlation function, which further enhances the quality to a level even comparable to that of a pseudo-cross correlation setup.

- ## Four, not just one

Without any doubt a single such APD would already be a quite remarkable single photon detector taking the above mentioned timing parameters into account (and, as a matter of fact, every ALV-CorrTector APD can principally be configured to act as such a detector, whenever optimum PDE is the main requirement), but the enormous dynamic range of the ALV-CorrTector is reached by the use of four independent APD tiles in a check-board layout with a few µm gap inbetween, leading to a fourfold higher dynamic range whenever all of these four tiles are equally illuminated by the optical input. The gap is kept as small as possible to ensure minimum efficiency loss (photons hitting the gap region will of course not lead to avalanches), but still large enough to ensure smallest electrical cross-talk between the four tiles.

Logically, four independent amplifier setups are now required and it is the small thermal load of these (<150 mW) that allows the amplifiers to be located nearest to the APD itself, minimizing stray capacities and inductivities and with that ensuring the full timing potential of the APDs can be exploited.

Having four independent detectors illuminated by one and the same light source allows different correlation modes to be applied, noteworthy are auto correlations of individual signals, as well as auto correlations of sum of tile responses and of course several cross correlations of individual tiles or sum of tile responses. The last seems to be striking, because it should be possible to de-correlate afterpulse contributions of the individual tiles by the use of cross correlation.

Indeed, for large enough gaps and small enough electrical crosstalk, afterpulses can be decorrelated, however the close vicinity of the tiles on one and the same silicon waver will allow optical crosstalk to become dominant. Such optical crosstalk is generated by photons emitted in the avalanche by the accelerated electrons, which are then travelling through the silicon structure and trigger an avalanche on any of the nearby tiles. However, due to the significantly different time scales of classical afterpulses within a single tile and optical crosstalk effects, the computation of certain additional signal analysis can be used to correct for these effects to a very good extend. Using such corrections can boost the correlation function quality near to the quality obtainable with a pseudo-cross correlation setup (note: all above stated technical data is without such correction applied).

- ## Optional TEC based thermal control minimizes dark count drift

For best count rate stability the use of a passive thermal control usually might not be good enough. The reason is the dark count drift with environmental (APD) temperature. Unless rather high average count rates are to be expected, this cark count drift ultimately limits the total count rate stability. For experiments requiring highest count rate stability a TEC-based thermal control can be used in the ALV-CorrTector that ensures an APD temperature of ~18°C with better +/-0.1°C stability. This further reduces the dark count contribution by ~30% compared to standard room temperature, but mostly ensures the dark count contribution remains constant even for changing environmental temperatures.

Active thermal control via a TEC requires additional power, of course, and the additional power requirement will depend on the effective environmental temperature. Worst case, additional 0.8 W of electrical power consumption must be expected compared to passive thermal control mode. The operational temperature range can be expected to be limited to +35°C as upper environmental temperature, compared to +50°C for the passive thermal control version.

- ## ALV-7004/USB Correlator in the ALV-CorrTector

To ensure optimum compatibility to all the other ALV-Multiple Tau Digital Correlators, the internal correlator used in the ALV-CorrTector is practically identical to an ALV-7004/USB type correlator. As standard, this correlator type features 25 ns initial sampling time and more than 12 decades in lag time using the usual ALV Multiple Tau Correlation Scheme. All APD information can be counted and correlated without any scaling/clipping even for maximum APD tile count rate.

Several of the different correlation schemes the ALV-7004/USB offers can be used (tile-wise auto-correlation or block-wise cross-correlation, for example), however if additional afterpulsing correction schemes are to be invoked, the actually used correlation scheme is fixed to a specific such scheme.

All communication to/from the ALV-CorrTector can be performed via a single USB2 connection, which, if used, as well acts as +5V power supply.

Using the USB2 interface with a multitude of ALV-CorrTectors in a single experiment would nevertheless lead to a slightly inefficient setup, either using up a good number of USB resources in the master PC, or using HUBs and thus sharing power and bandwidth resources.

While this might be still OK with two ALV-CorrTectors used, it will most certainly fall short for a significant number - say eight or sixteen - such devices. For this reason, the ALV-CorrTector has an additional proprietary interface that allows the communication to up to 32 ALV-CorrTectors simultaneously and - by using a small additional electronics - feeds all data to/from to a single USB2 interface via the 16-pin extension connector.

This extension connector as well features a +5V supply line. In this configuration, the individual USB interfaces of the ALV-CorrTectors can be switched off, which further reduces the power consumption of the individual ALV-CorrTector device by 200 mW per device.

The ALV-APD in the ALV-CorrTector

- ## Small-sized, thin structure

The major ingredient of the ALV-CorrTector is a thin avalanche photo diode structure with small-sized (20 µm x 20 µm) optically active area. This allows fast avalanche quenching and fast reload even in a fully passive quenched design due to the exceptionally small capacity of the diode itself. What needs to be sacrificed with thin APD structure is highest PDE, because the photon absorbtion layer thickness is not large enough to allow high efficiency interaction of the incoming photon and with that electron/hole pair generation. As a side effect of thin APDs the wavelength dependency of the PDE is usually shifted to blue/green for the peak PDE value, simply due to the shorter wavelength of blue/green light and thus larger interaction depth within the APD structure.

Still, a thin APD coupled with the appropriate silicon process allows low break-down voltages and with that low 'over-break-down voltage' operation at a still remarkable PDE of 20-25% peak value. In the ALV-CorrTector APD this is reached with signicifcantly less than 5 V over breakdown voltage, which itself is below 30 V at room temperature. Small sized APD structures do have additional advantages, in particular when coupled with thin absorbtion layers, most notably a very small dark count contribution (~50-100 cps at room temperature) and a very small breakdown voltage vs. temperature drift. For these reasons and the fact that the thermal load onto the APD stays rather insignificant even at max. count rate, the standard version of the ALV-CorrTector operates the APD in a passive thermal control mode, with just the breakdown voltage adjusted for the actual diode temperature.

- ## Optimum Passive Quenching and Reload

For such an APD structure, optimum passive quenching will lead to quench times smaller than 2 ns and reload times as short as 50 ns for 99% reload only. The total current through the APD is limited by the quenching resistor value and, for a certain voltage applied, can not exceed a given maximum, which necessarily limits the total power dissipated by the APD.

The total charge flowing within an avalanche will be very small as well, typically << 10^7 electrons, which ensures that 'on-time fluctuations' are small even at higher overvoltage as well. Smaller charge flow has very positive influence on the afterpuls contribution (the smaller the number of electrons in the avalanche, the smaller the number of trapped electrons that can lead to afterpulses), the resulting inconveniency is that such a small number of electrons lead to a as small current/voltage pulse at the APD output and pulse detection requires high quality pulse amplification and discrimination.

- ## High Gain/Bandwidth Amplification/Discrimination

To solve this, the ALV-CorrTector uses a high gain/high bandwidth amplifier (A ~ 49 dB / BW > 120 MHz) with exceptionally small power requirement and a ~ 300 MHz bandwidth pulse discriminator for fast and clean pulse generation. For a single APD, limiting maximum count rates of 20 Mcps or more are then possible, mostly depending on the setting of the discriminator's threshold and hysteresis.

- ## Inherently safe: Is there a too high light level for the ALV-APD ?

'Too high light levels quickly lead to detector deterioration' - a commonly heard attribute if it comes to active quenched avalanche photo diodes.

Indeed, most active quenched/reloaded APDs, but in particular those optimized for highest PDE, do suffer from a relatively large charge flow through the diode within each avalanche and, due to the significant voltage typically required for such APDs to break-down, in summary leads to a very significant total power dissipated by the structure. Power values in the Watt regime for a few Mcps count rates are not uncommon for high PDE/high break-down voltage APDs and with that the rather small APD area heats-up quickly to temperatures that can lead to deterioration.

Within reason the cooling facilities in-built in most APD detectors can cope with this thermal load and make certain the APD structure itself stays below the max. allowed temperature even at higher light levels. Nevertheless, additional electronical measures must be taken to ensure that active quenching takes place under all circumstances and too high count rates are avoided by switching the detector to a safe condition for a certain period of time. It is noteworthy that these electronical measures can easily be seen in the resulting correlation functions whenever they are invoked, because they do of course impose severe additional correlation to the detector output.

This, coupled with the fact that there necessarily needs to be a certain trade-off between safe mode threshold and max. count rate obtainable and the rather difficult thermal stabilization in fast high to low light level transitions (because in these cases the thermal load on the APD quickly changes by a few magnitudes) lead ALV to the conclusion that a APD detector well suited for photon correlation experiments should not follow that route, but instead should be inherently safe for too high light levels.

The APD used in the ALV-CorrTector completely fulfills this requirement and is inherently safe for all light levels even in excess of the light level of bright sunlight (10^3 W/m²), simply due to the fact that the power dissipate by the APD structure can never be higher than a few mW by design. Besides light levels that high that by themself lead to a high thermal load due to adsorption, there simply is no 'too high light level' for the ALV-CorrTector.