Universität der Bundeswehr München

Temperature dependent Investigations of Dark Currents of SiPM

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KETEK

Motivation

Goal of this work:

- reduction of dark count rate of Silicon Photomultipliers
- gain initial information on dark generation and extract contributions to dark current

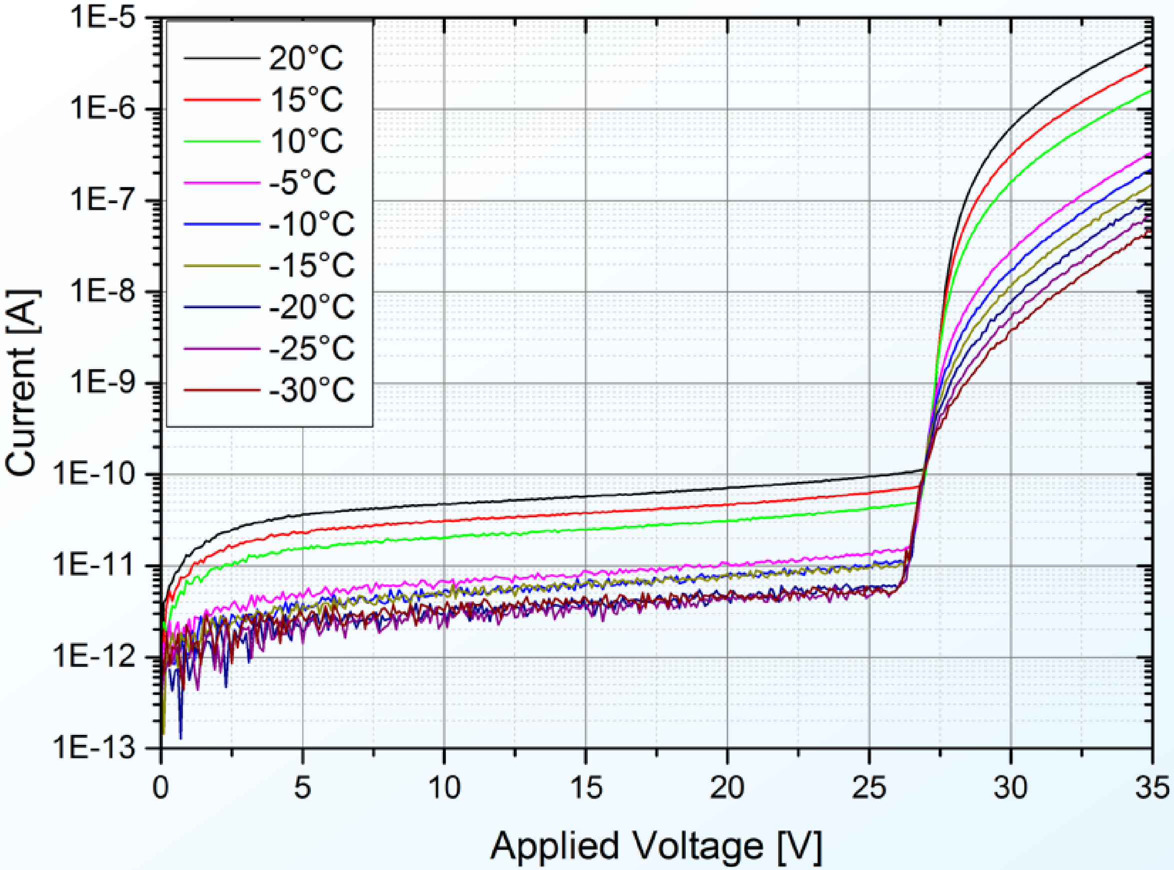
General approach:

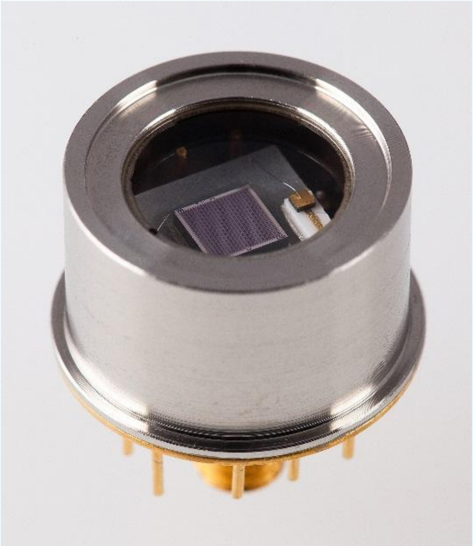
- activation energies determined from T dependencies are expected to be a good indicator of physical mechanisms
- conventional methods of extraction of E_{act} at fixed voltages/overvoltages may not be suitable
- effects dependent on voltage and overvoltage cannot be separated

Proposed method:

- independent measurements of photo- and dark-response
- separation of overvoltage dependent responsivity and voltage dependent high-field effects
- find expression for field-independent generation component

Setup

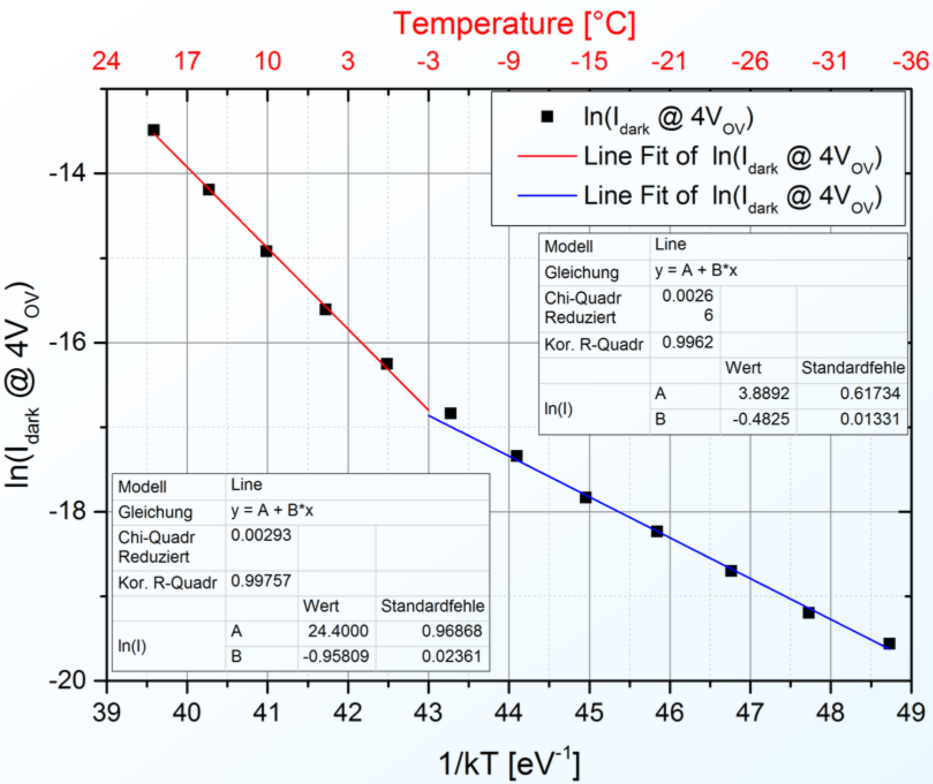


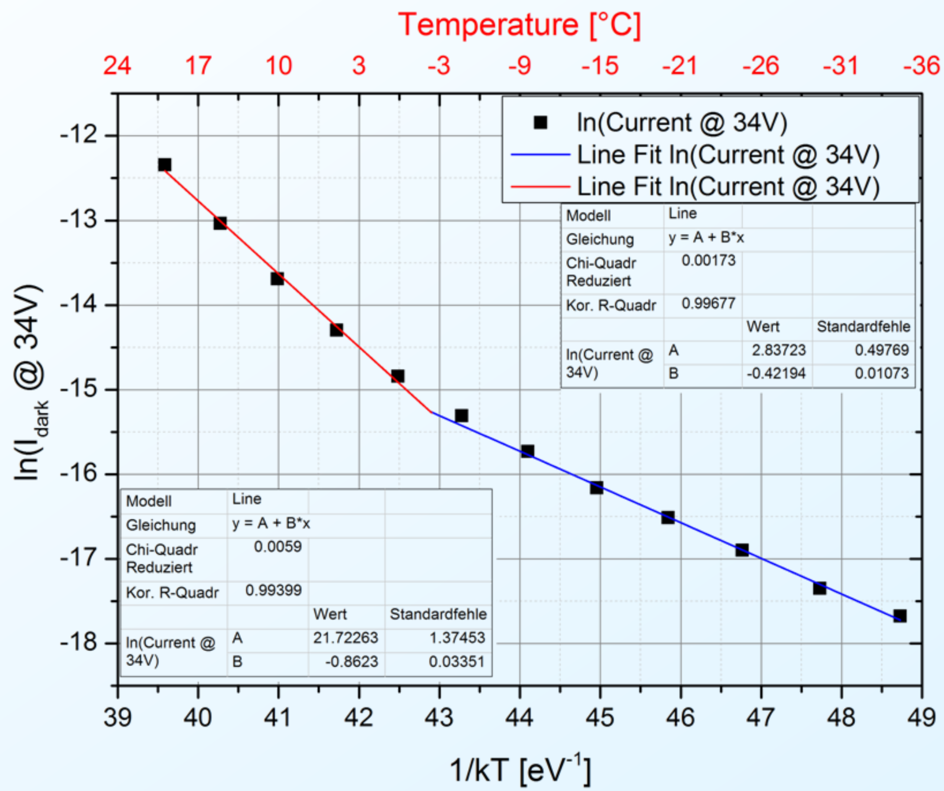


KETEK 3x3 mm^2 in a TO8

- temperature dependent investigations were performed in a range from 20°C to -30°C
- the measurements were executed on a KETEK 3x3mm^2 SiPM which was mounted on a Peltier element and evacuated in a TO8 module

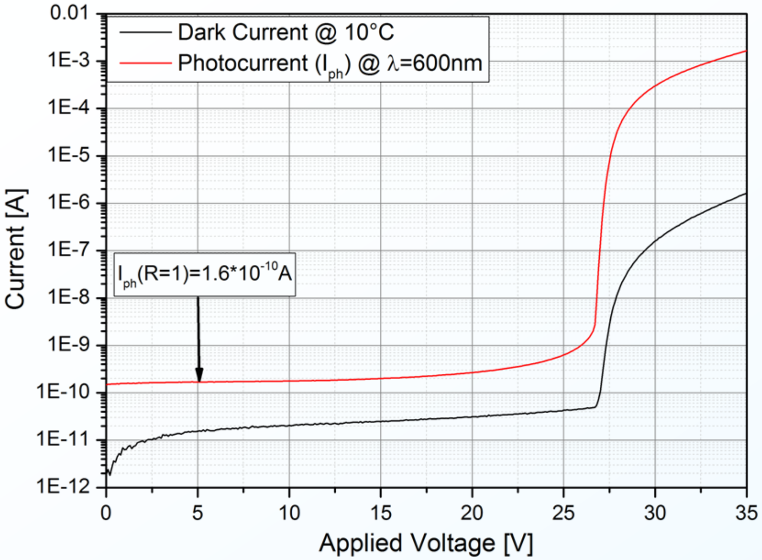
Conventional Method

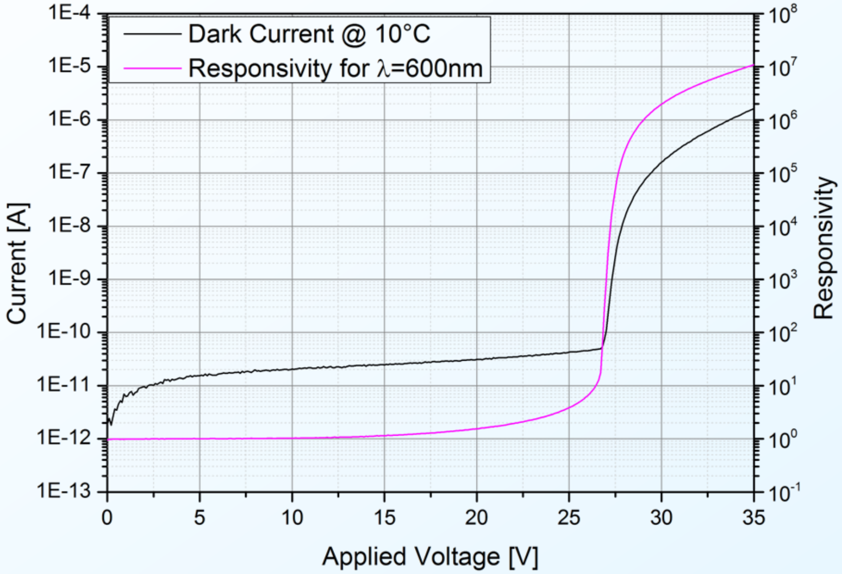




- conventional method as proposed in *R.Pagano et al.; „Dark Current in Silicon Photomultiplier Pixels: Data and Model“; IEEE Transactions on Electron Devices; Vol.59 NO. 9; 2012* is not suitable here
- E_{act} can not be attributed to a certain mechanism

Proposed Method





- dark and illuminated data was taken
- assumption of an equal responsivity R, for electrons originating from dark generation and photoelectrons

$$\rho(T, V, V_{OV}) := Response$$

$$R(V_{OV}) := Responsivity$$

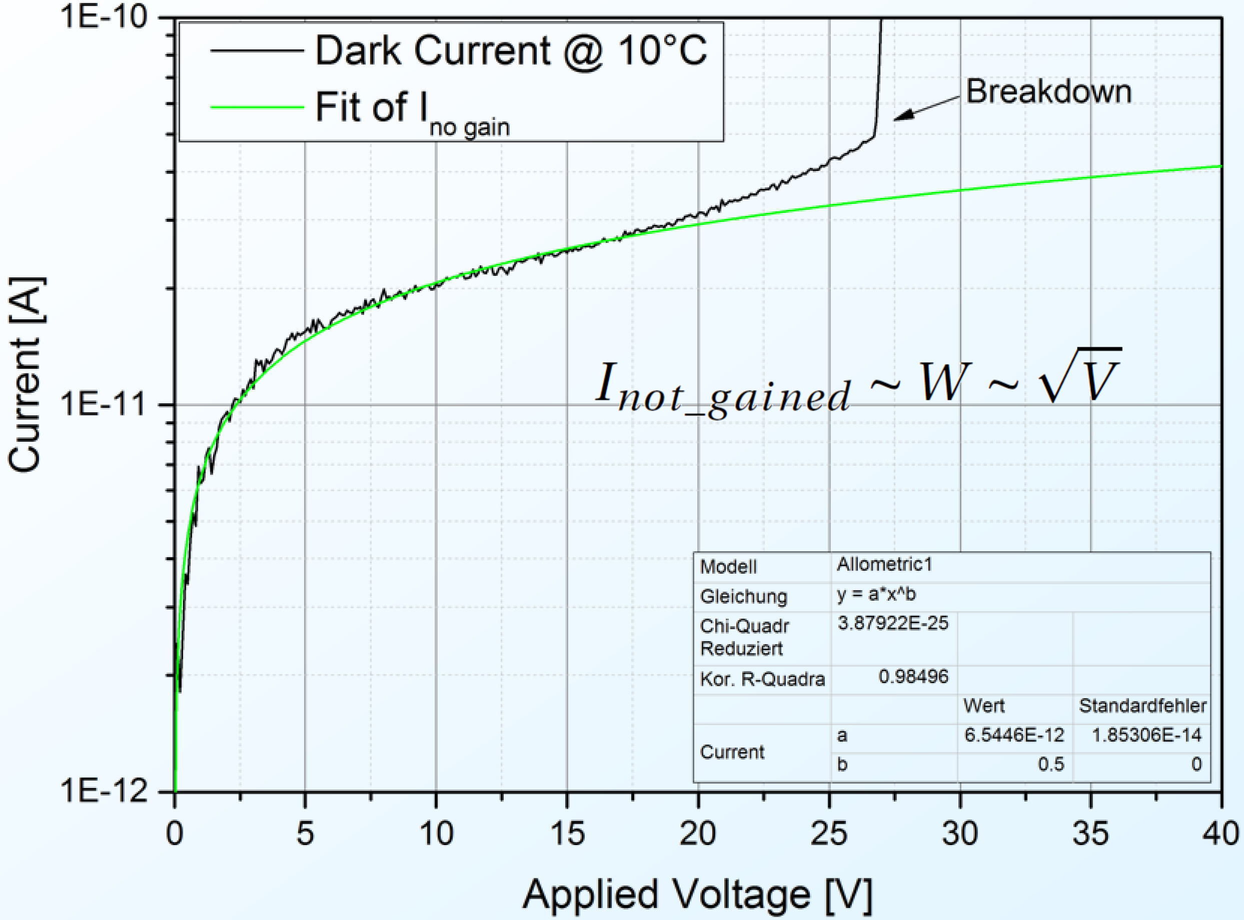
$$R_{dark}(V_{OV}) \approx R_{ph}(V_{OV}) = \frac{\rho_{ph}(V_{OV})}{\rho_{ph}(V_0)}$$

$$\rho_{dark}(T, V, V_{OV}) = \rho_{ini}(T, V) \cdot R_{ph}(V_{OV})$$

- in general this approach is applicable for any Response ρ, e.g. I_{dark} or DCR

Determination of I_{not_gained}

$$I_{dark}(T,V,V_{OV}) = I_{not\_gained}(T,V) + I_{gained}(T) \cdot F_{high\_field}(V) \cdot R_{ph}(V_{OV})$$



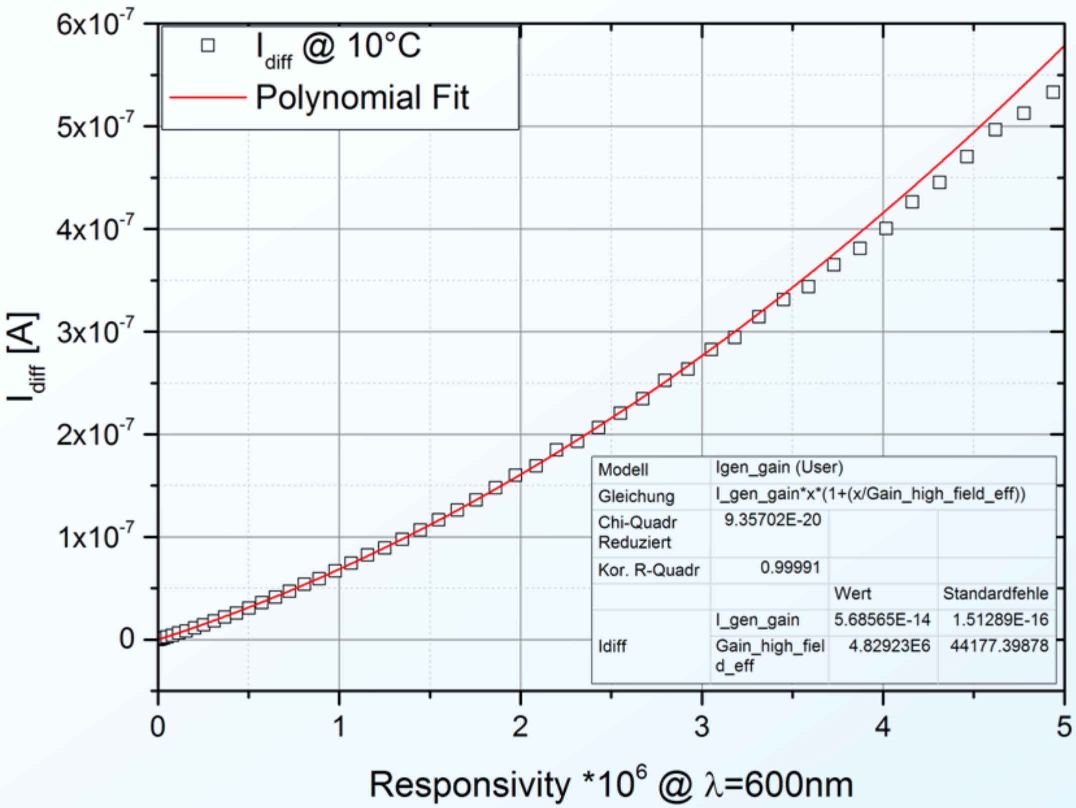
$$I_{not\_gained} \sim W \sim \sqrt{V}$$

Modell	Allometric1		
Gleichung	y = a*x^b		
Chi-Quadr Reduziert	3.87922E-25		
Kor. R-Quadra	0.98496		
		Wert	Standardfehler
Current	a	6.5446E-12	1.85306E-14
	b	0.5	0

Determination of I_{gained}

$$I_{dark}(T,V,V_{OV}) = I_{not\_gained}(T,V) + I_{gained}(T) \cdot F_{high\_field}(V) \cdot R_{ph}(V_{OV})$$

- in order to determine the multiplied component, the difference between the measured dark current and I_{not_gained} is investigated as a function of the responsivity

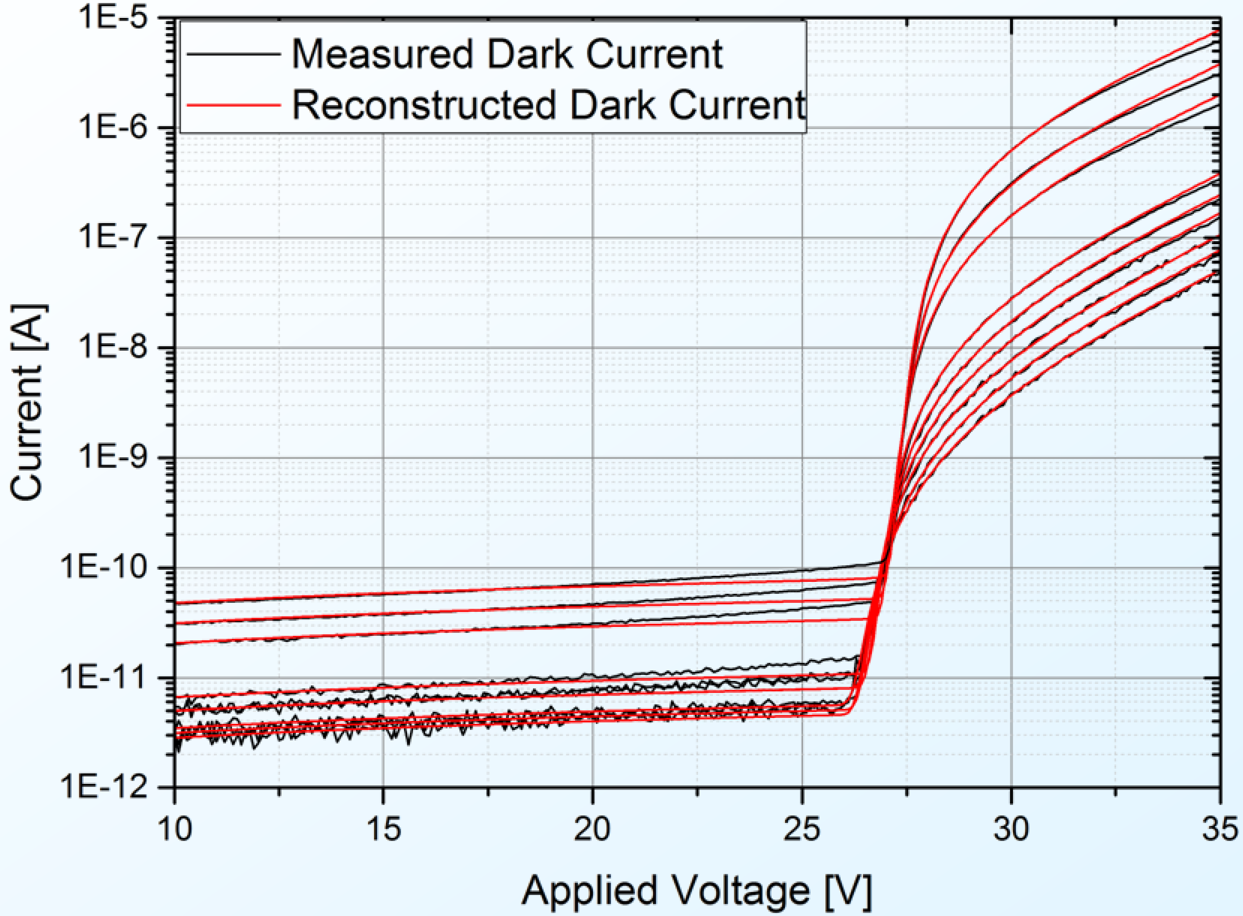


$$I_{diff}(R_{ph}) = I_{gained} \cdot R_{ph}\left(1 + \frac{R_{ph}}{R_{eff}}\right)$$

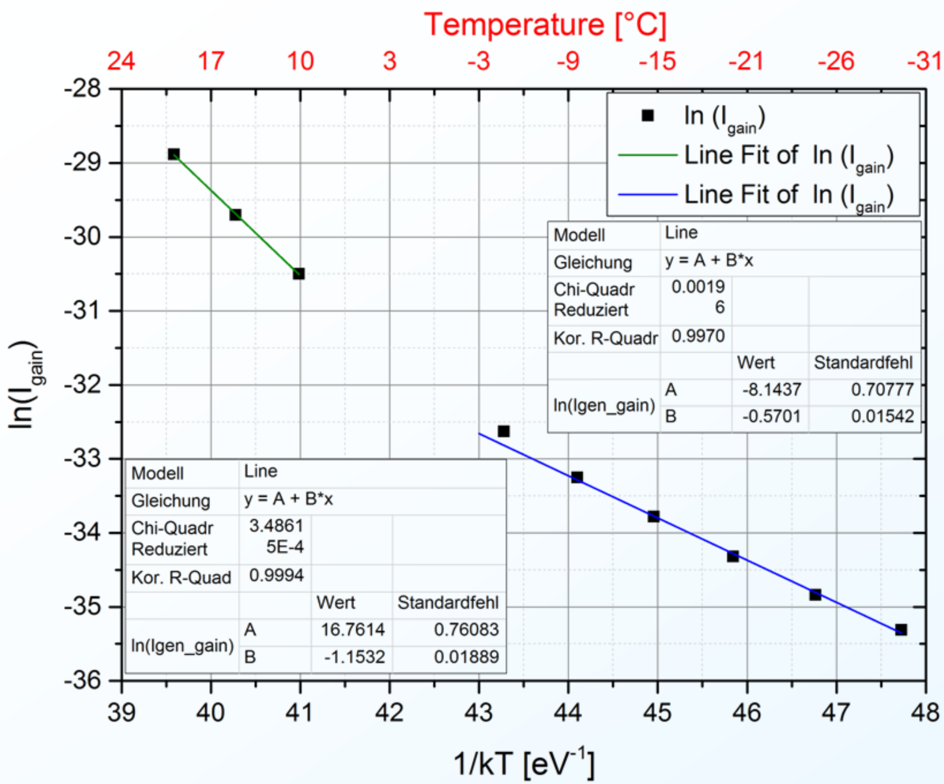
- I_{diff} could be described with a parabolic function in good agreement in the range between R=0 to R=4x10^6
- I_{gained} represents initial charge carriers generated or provided to the multiplication region

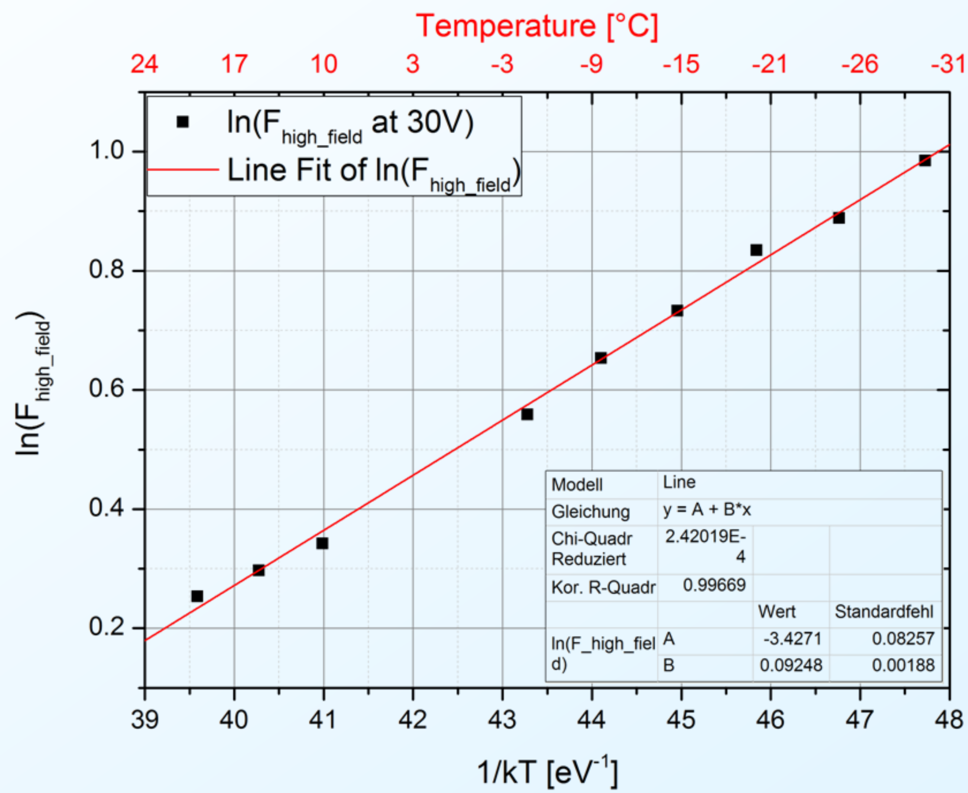
2nd Approach-Reconstruction of Dark Current

$$I_{dark}(T,V,V_{OV}) = I_{not\_gained}(T,V) + I_{gained}(T) \cdot F_{high\_field}(V) \cdot R_{ph}(V_{OV})$$



Results-Activation Energies





- I_{gained} shows two activation Energies $E^1_{act} \approx E_g$ and $E^2_{act} \approx E_g/2$
- F_{high_field} lowers the effective activation energy by ΔE_{act}
- ΔE_{act} is close to expected value for Poole-Frenkel effect

Summary

Results so far

- the chosen model for dark current could describe the measured data to a sufficiently precise level
- field-enhanced effects could be separated from generation components
- the extracted activation energies indicate that dark currents at T>-5°C are diffusion dominated, whereas currents at T<-5°C are dominated by generation (KETEK devices)

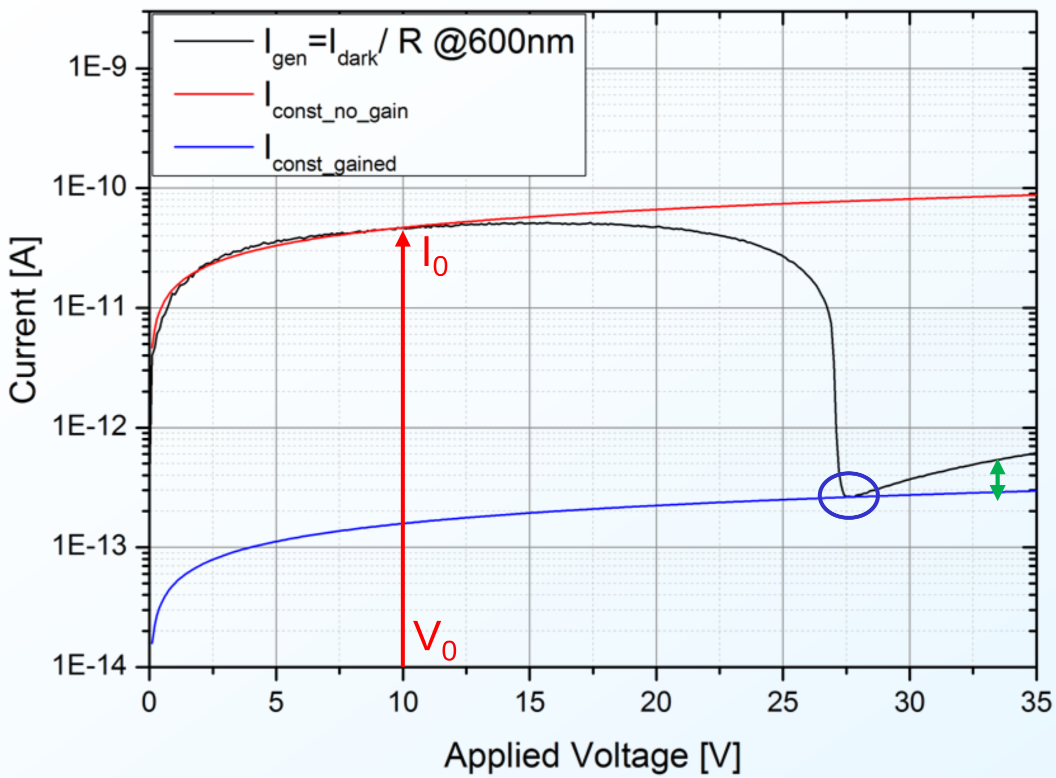
Further investigations

- confirmation of model for different type of devices
- identification of micro-cell regions as origin for diffusion currents
- change technological process in order to reduce DCR

Thank you for the attention

Additional Slides

1st Approach



- analysing I_{gen} consisting of a multiplied and non-multiplied component

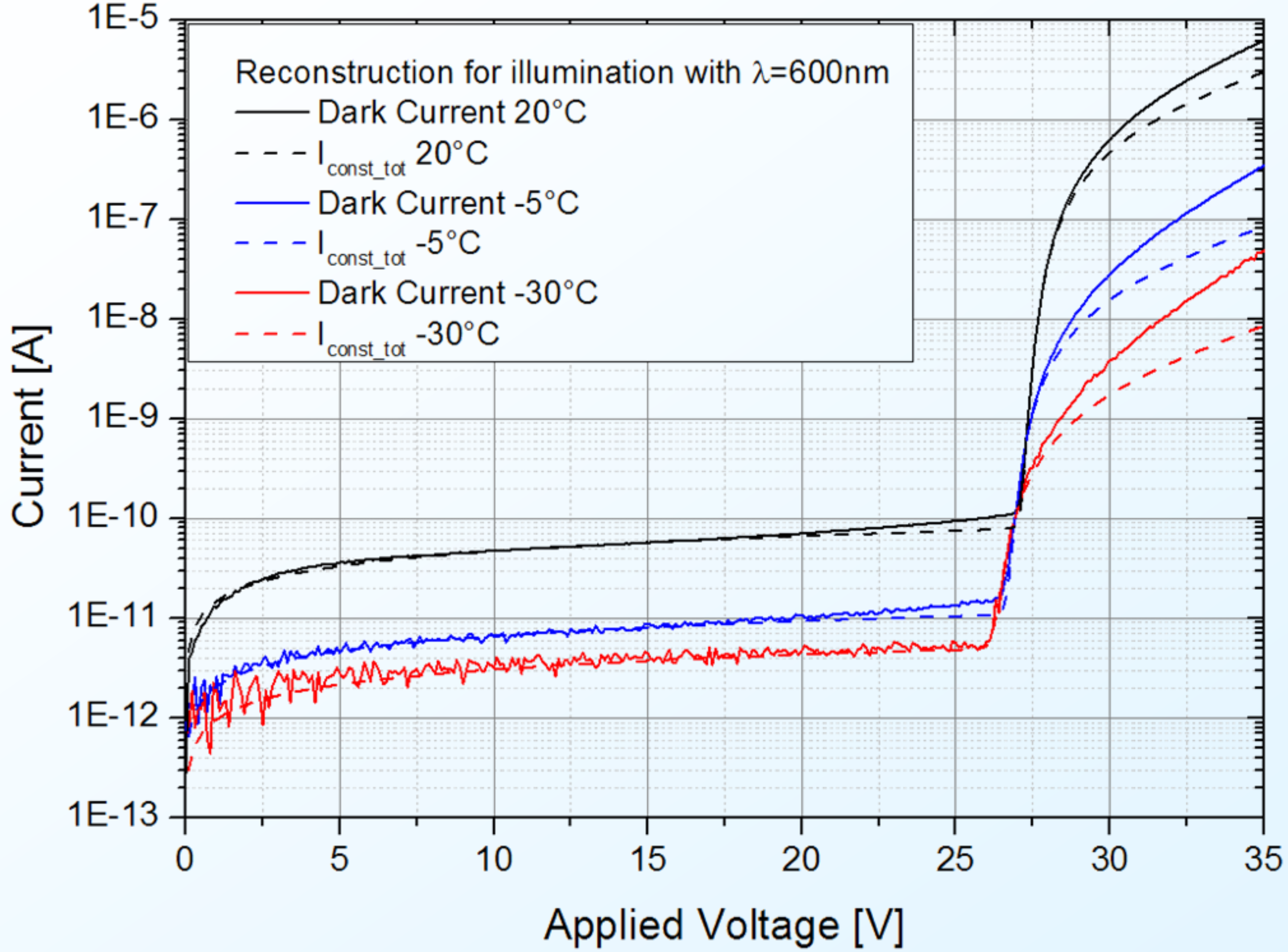
$$I_{dark} = I_{not\_gained} + I_{gained} \cdot R_{ph}$$

$$I_{not\_gained} = I_0 \cdot \sqrt{\frac{V}{V_0}}$$

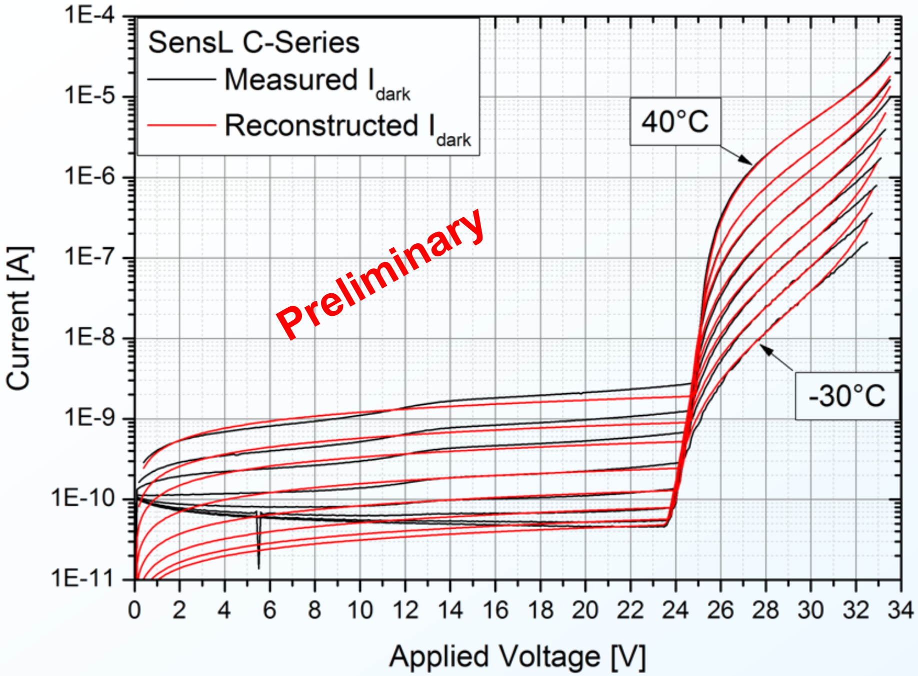
- I_{gained} is assumed to be a small fraction of I_{not_gained}

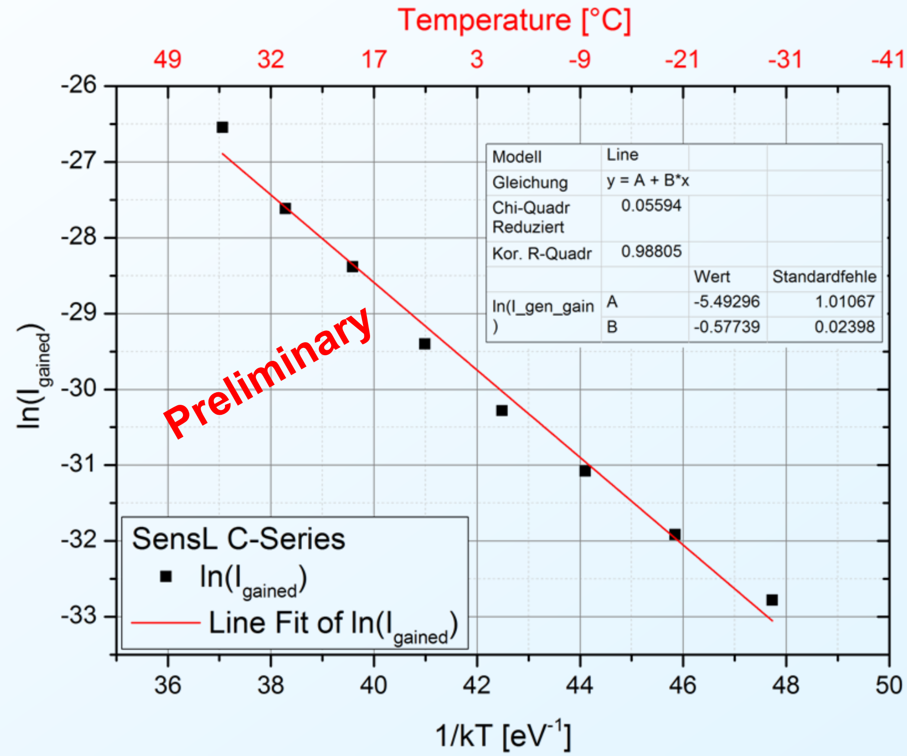
$$I_{gained} = \delta \cdot I_{not\_gained}$$

1st Approach-Reconstruction of Dark Current



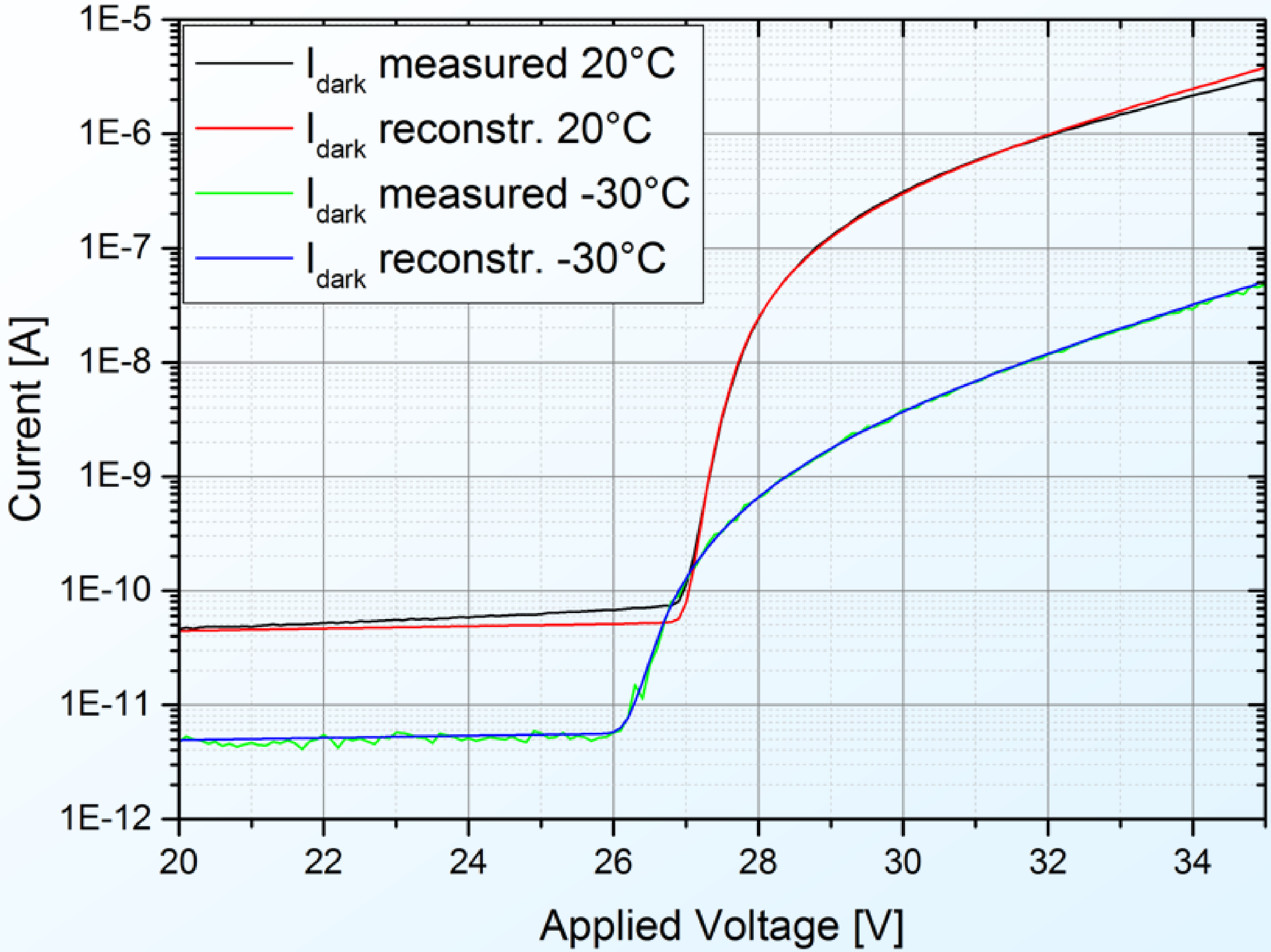
Results- SensL



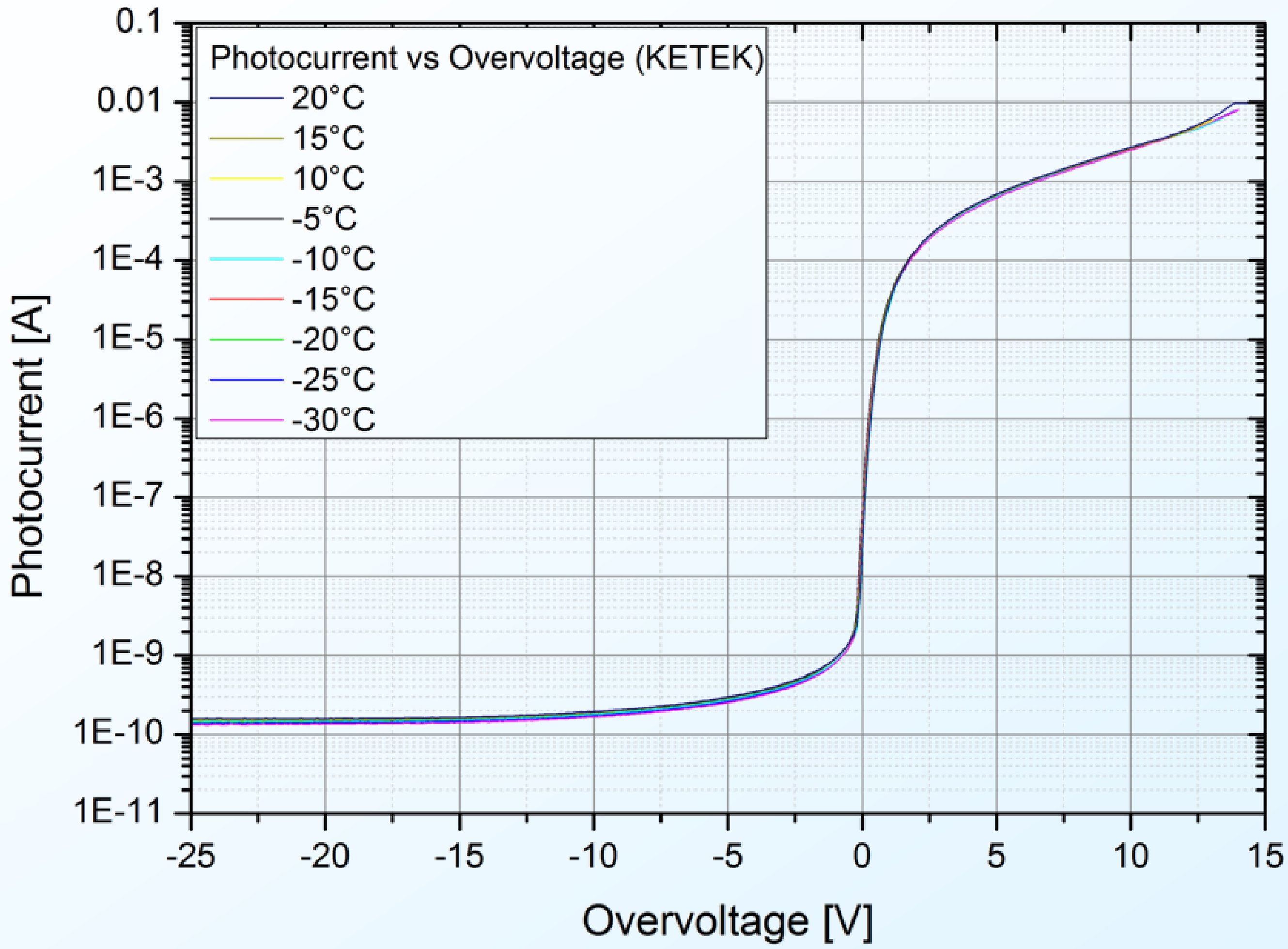


- a 3x3mm^2 C-Series device from SensL was investigated for comparison
- only one slope could be observed in the Arrhenius plot
- E_{act} of (0.57 ± 0.02) eV is attributed to generation current
- the contribution of diffusion current is expected to be suppressed for this device

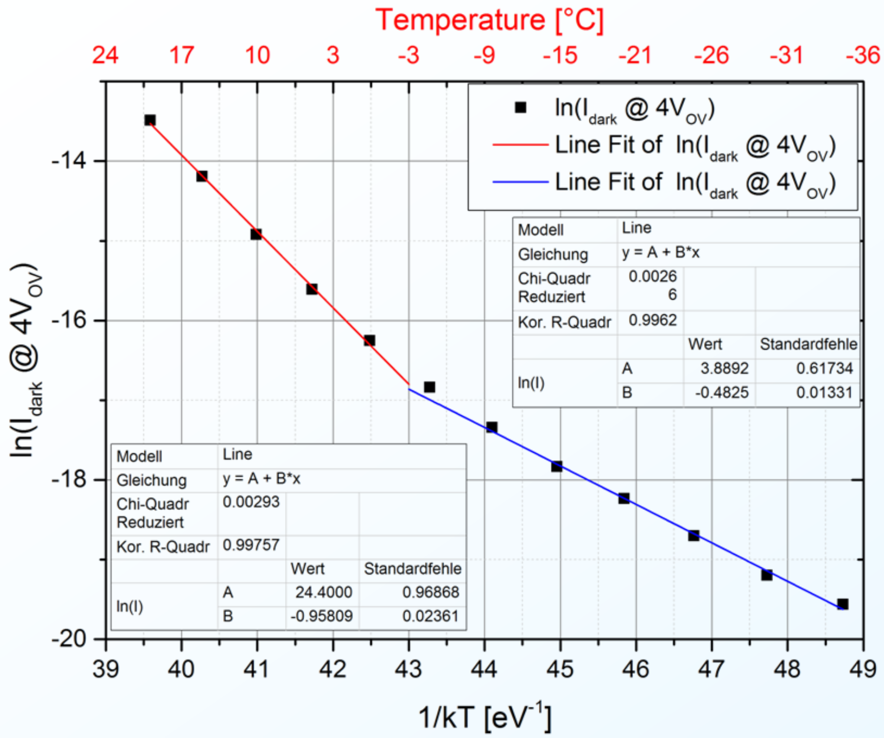
Reconstruction of Dark Current

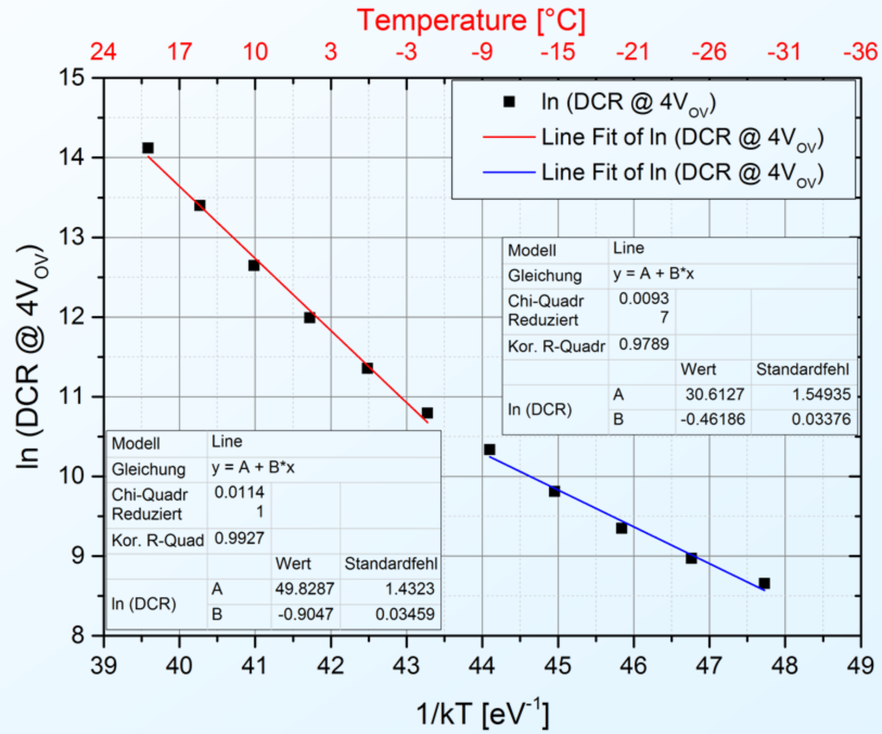


Photocurrent



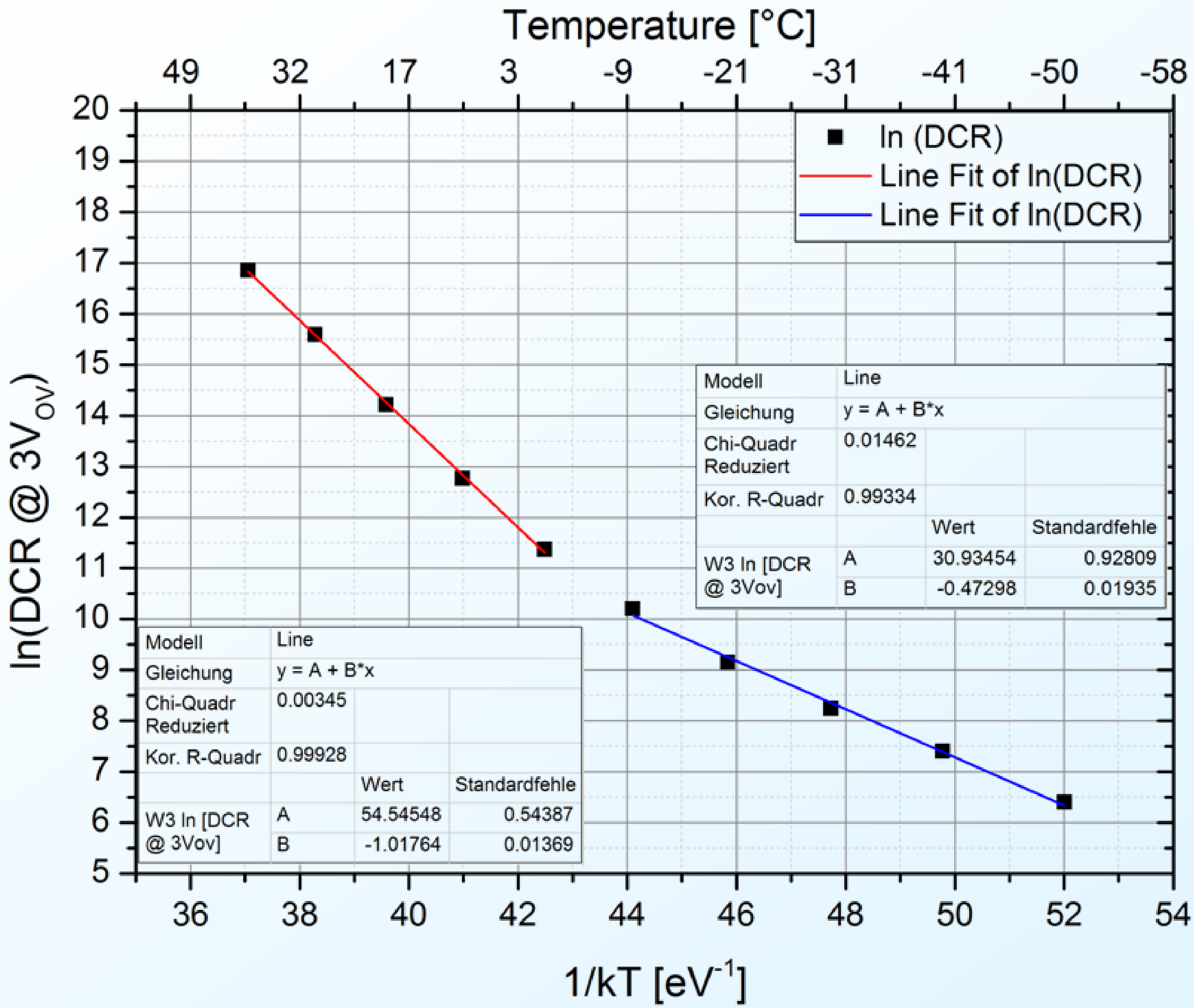
Results-E_{act} at fixed Overvoltage



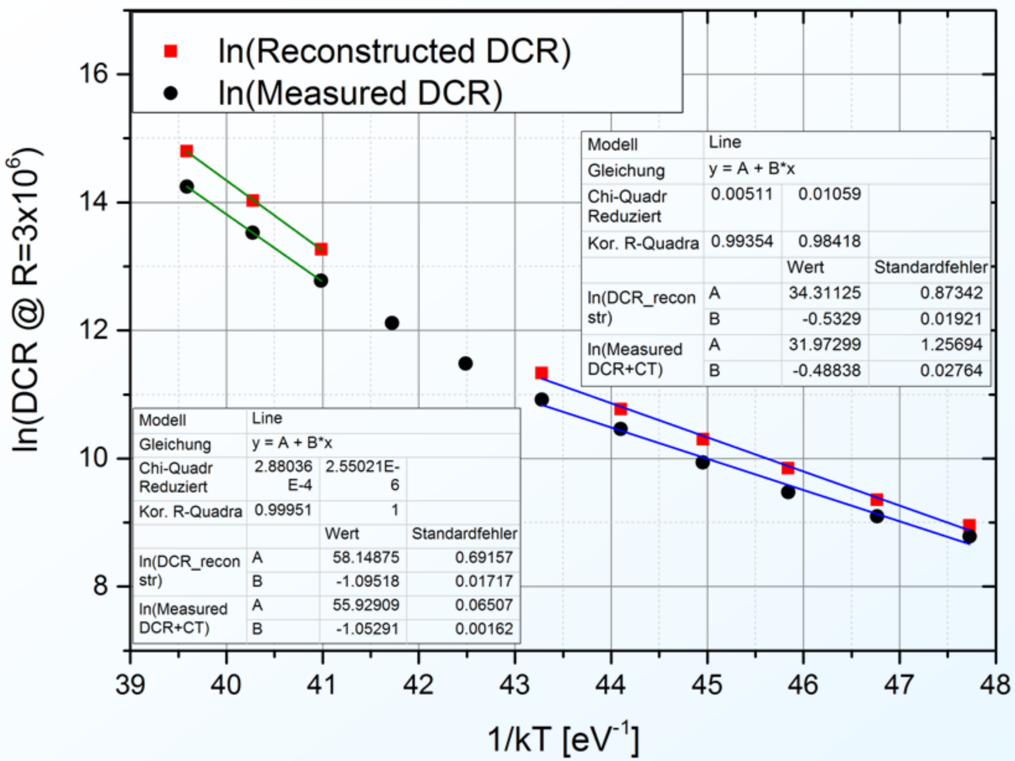


- the extracted E_{act} directly from I_{dark} (T) and DCR (T) at a fixed overvoltage show slightly different values, but agree within the uncertainties
- E_{act} from „raw“ data is an indicator for physical mechanisms
- for a precise analysis, a more advanced analysis is necessary

DCR in extended T range



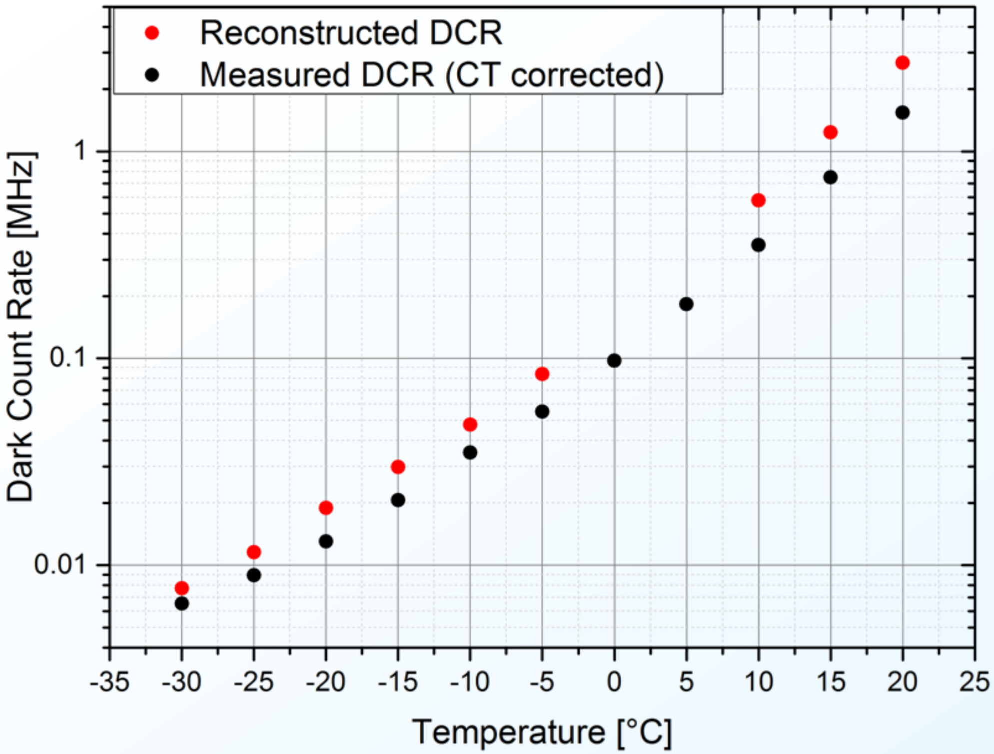
Confirmation of Model



$$DCR = \frac{I_{gain} \cdot F_{high\_field}}{q}$$

- E_{act} extracted from DCR is a sum of field-independent I_{gained} and field-dependent F_{high_field}
- $DCR_{measured}$ and $DCR_{reconstr}$ show comparable E_{act} within the uncertainties
- this result is an indicator of the parameter fit quality
- the measured DCR has to be addtionally corrected for avalanche triggering probability

Reconstruction of DCR



$$DCR = \frac{I_{gain} \cdot F_{high\_field}}{q}$$

- $DCR_{reconstr}$ overestimates $DCR_{measured}$
- internal generation rate of dark events is expected to be higher than DCR
- the measured DCR has to be addtionally corrected for avalanche triggering probability