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Responsivity-Dark Current Relationship of Quantum Dot Infrared Photodetectors (QDIPs)

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Quantum Structure Infrared Photodetector (QSIP) 2009, 20 January 2009.

Outline

1) Brief Description of QDIPs

2) Proposal of R-I_d plot

3) R-I_d plot of QDIPs

4) Discussions

5) Summary

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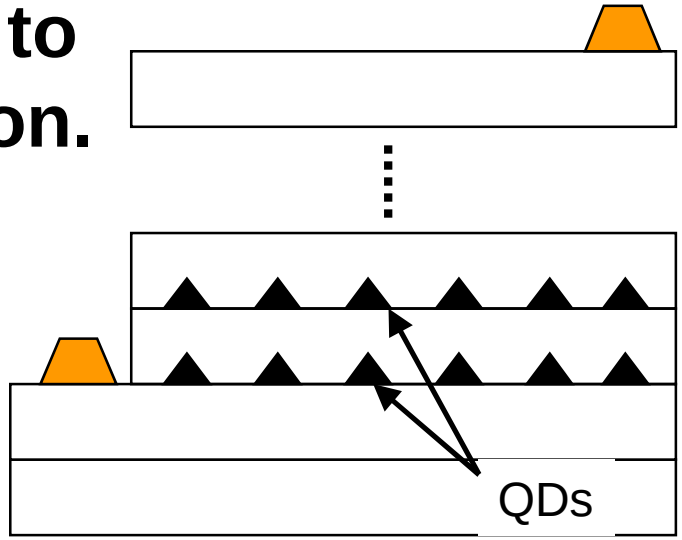
Advantages of using QDs as IR detectors

- **Zero-dimensionality of the QD quantum confinement makes QDIP:**

i) principally sensitive to normal incidence.

ii) offer low dark current owing to the reduced thermal activation.

iii) provide higher current gain because of the longer carrier lifetime.



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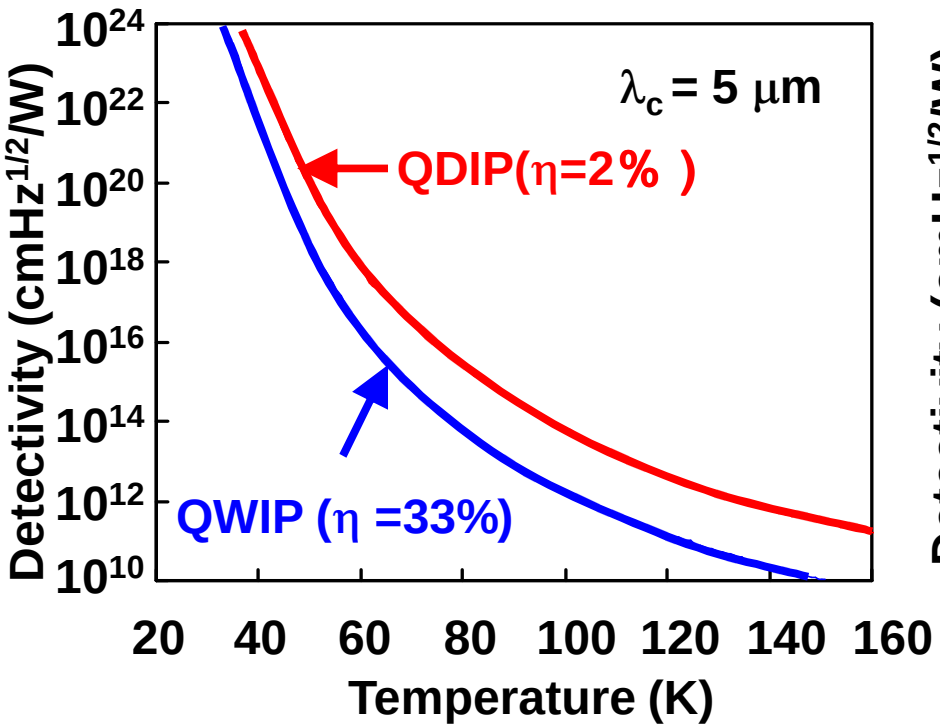
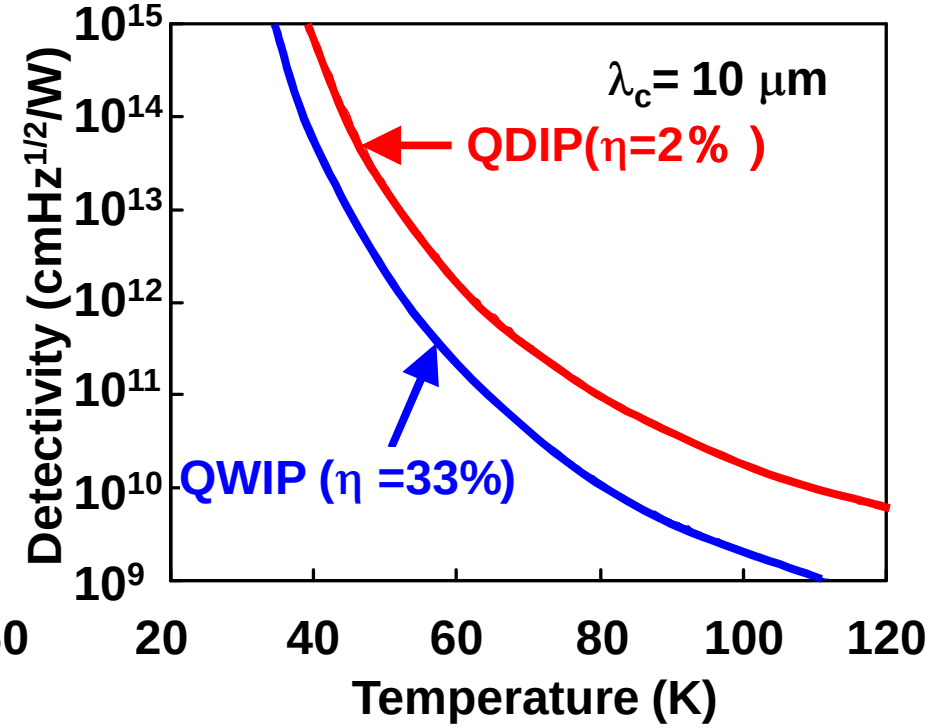
Theoretical prediction of QDIP S/N





Ref. P. Martyniuk and A. Rogalski, *Proc. of SPIE* Vol. 6940, 694004 (2008).

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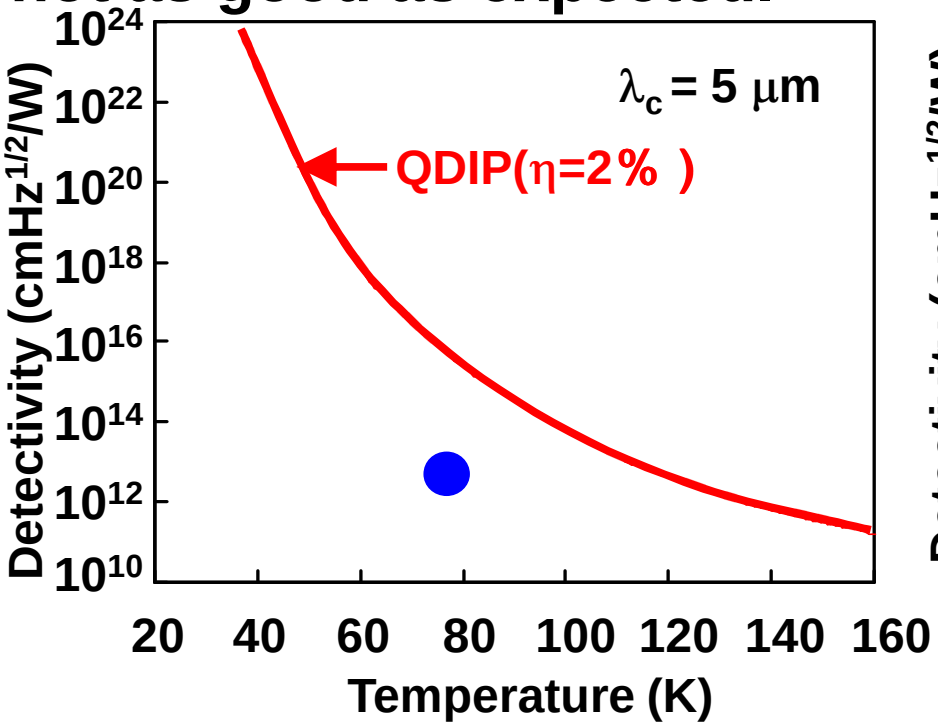
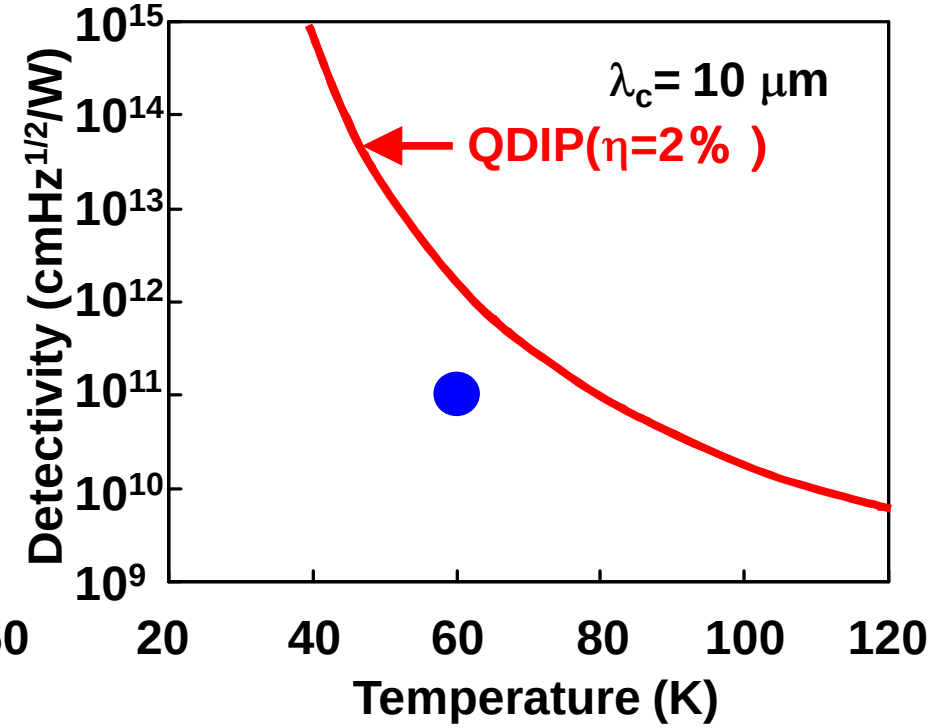
Importance of elemental R & Id evaluation

Some QDIPs reported so far exhibit good performance, but not as good as expected.





M. Razeghi *et al.*,

Proc. of SPIE Vol. 6206, 62600I (2006).

(λp approx. 4.5 μm)

S. D. Gunapala *et al.*,

Proc. of SPIE Vol. 6206, 62600J (2006).

(λp approx. 8.5 μm)

We need to scrutinize the elementals, *i.e.* R&Id, to achieve a breakthrough.

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Device R and I_d in Literature

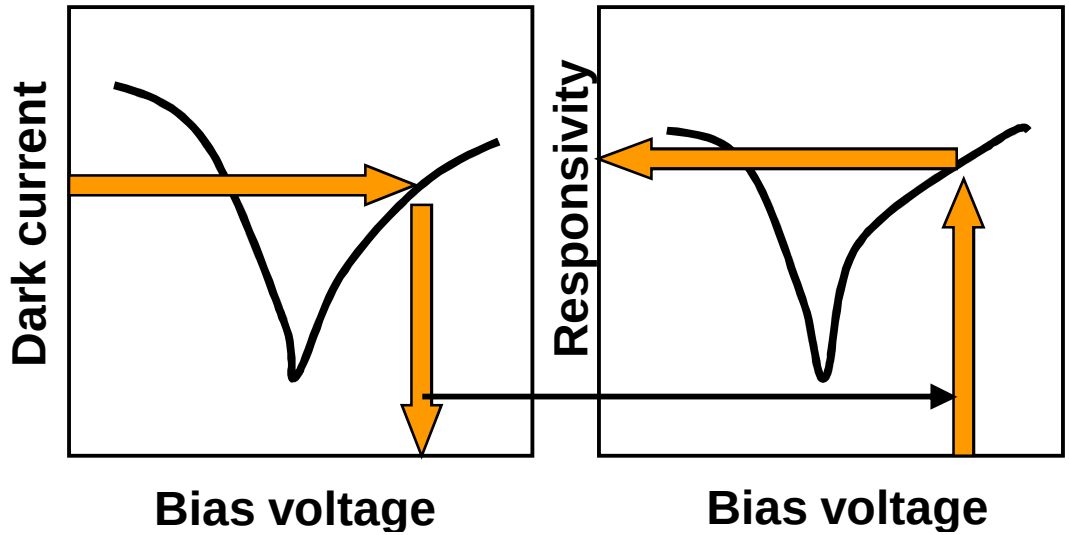
Bearing applications such as FPA in mind, the facts that:

i) total current is limited by T_{int} and C_{int}, and

ii) (G-R) noise is determined by device current

should be taken into consideration.

Responsivity at a certain I_d should be discussed. However, in literature…



Complicated procedure

	R (A/W)	I_d (A)
A	1.0	1×10^{-3}
B	0.1	1×10^{-8}

Which is better?

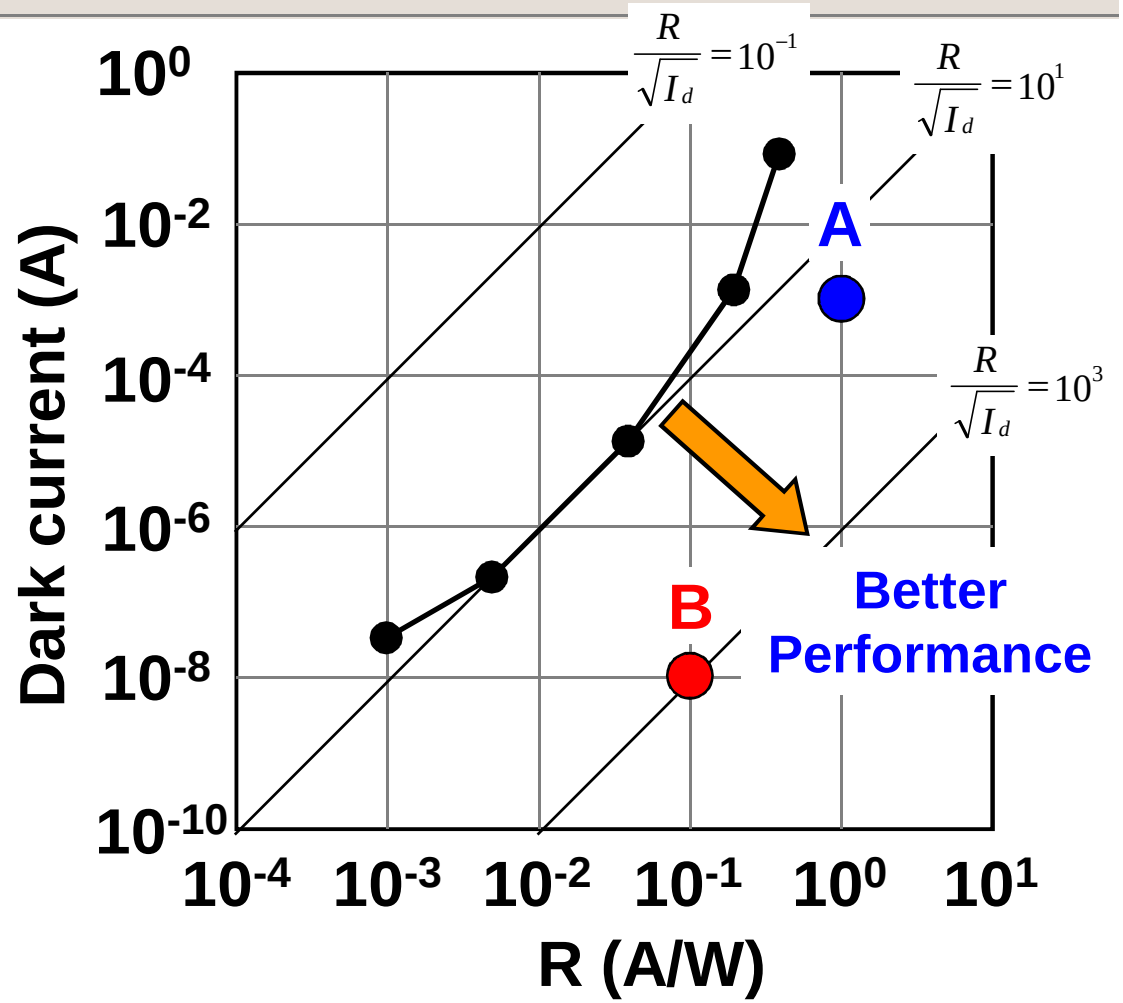
Proposal of R-Id plot for direct S/N assessment

$$D^* = \frac{R\sqrt{S\Delta f}}{i_n} \cong \frac{R\sqrt{S\Delta f}}{\sqrt{4eg\, I_d\, \Delta f}}$$

$$= \sqrt{\frac{S}{4eg}} \cdot \frac{R}{\sqrt{I_d}} \approx D_0^* \frac{R}{\sqrt{I_d}}$$

S : Detector area

	R (A/W)	Id (A)
A	1.0	1×10^{-3}
B	0.1	1×10^{-8}



With an R-Id plot, we can DIRECTLY compare the device S/N characteristics of photoconductive detectors such as QWIPs and QDIPs.

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List of QDIPs included in this study

Institution(s)	Literature	Data used in this study		
		R	I_d	Noise
Univ. of Massachusetts	*Proc. of SPIE*, 6542, 65420Q (2007).	✓	✓	✓
Univ. of Southern California & Univ. of Texas	*Appl. Phys. Lett.*, Vol. 84, 3277 (2004).	✓	✓	✓
	J. of Appl. Phys., Vol. 92, 7462 (2002).	✓	✓	✓
Australian National Univ.	*IEEE Electron Device Letters*, Vol. 26, 628 (2005).	✓	✓	
Academia Sinica	*Infrared Phys & Tech*. Vol. 50, 116 (2007).		✓	✓

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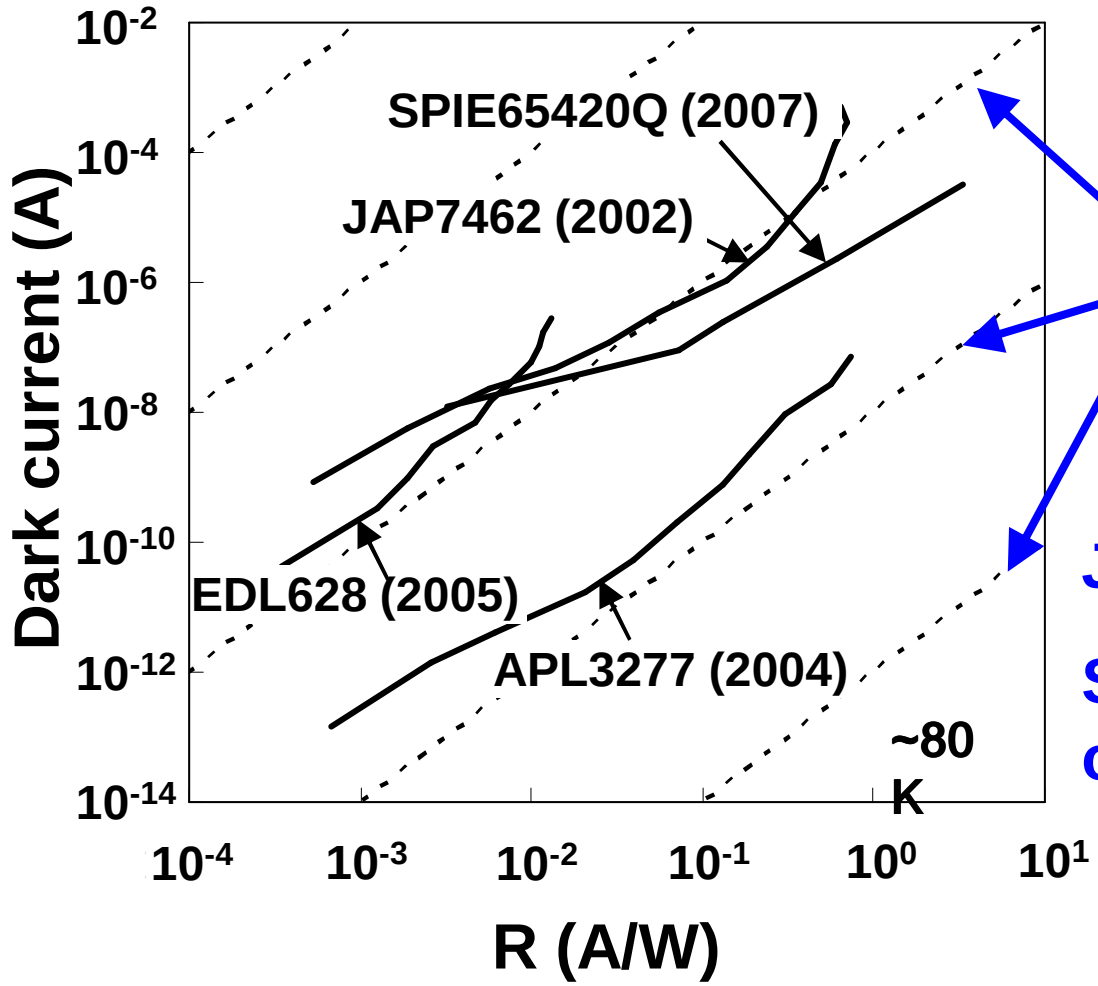
$I_d \propto R^2$ relation in R-Id plot of QDIP



$I_d \propto R^2$

Just a coincidence?

Some physical origins?

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Possible origin of I_d dependence of R

Responsivity R is represented as:

Almost constant

$$R = \frac{e\lambda\eta g}{hc}$$

Universal constants (i.e., no I_d dependence)

η or g must be the origin of the I_d dependence.

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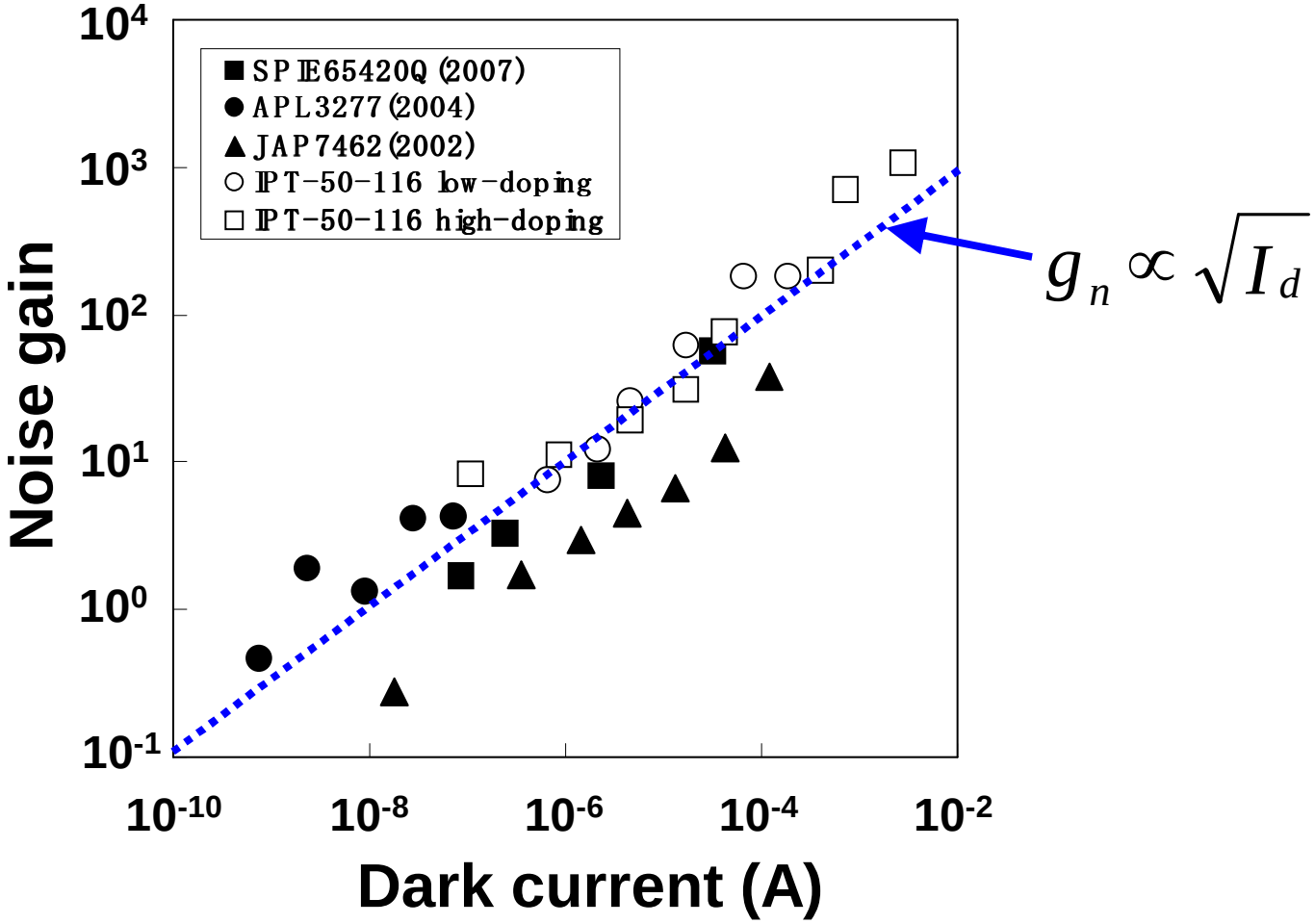
(Noise) gain g of reported QDIPs



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Explanation for $R \propto I_d^2$ relation

Substituting the relation $g \propto I_d^{0.5}$ into R, we obtain:

$$R = \frac{e\lambda\eta g}{hc} = \frac{e\lambda\eta A\sqrt{I_d}}{hc} = \frac{e\lambda A}{hc}\eta\sqrt{I_d} = B\eta\sqrt{I_d} \qquad A, B = const.$$

$$\therefore \log I_d = 2\log R - \log\left[B\eta\right]^2$$

g is the origin of the I_d dependence.

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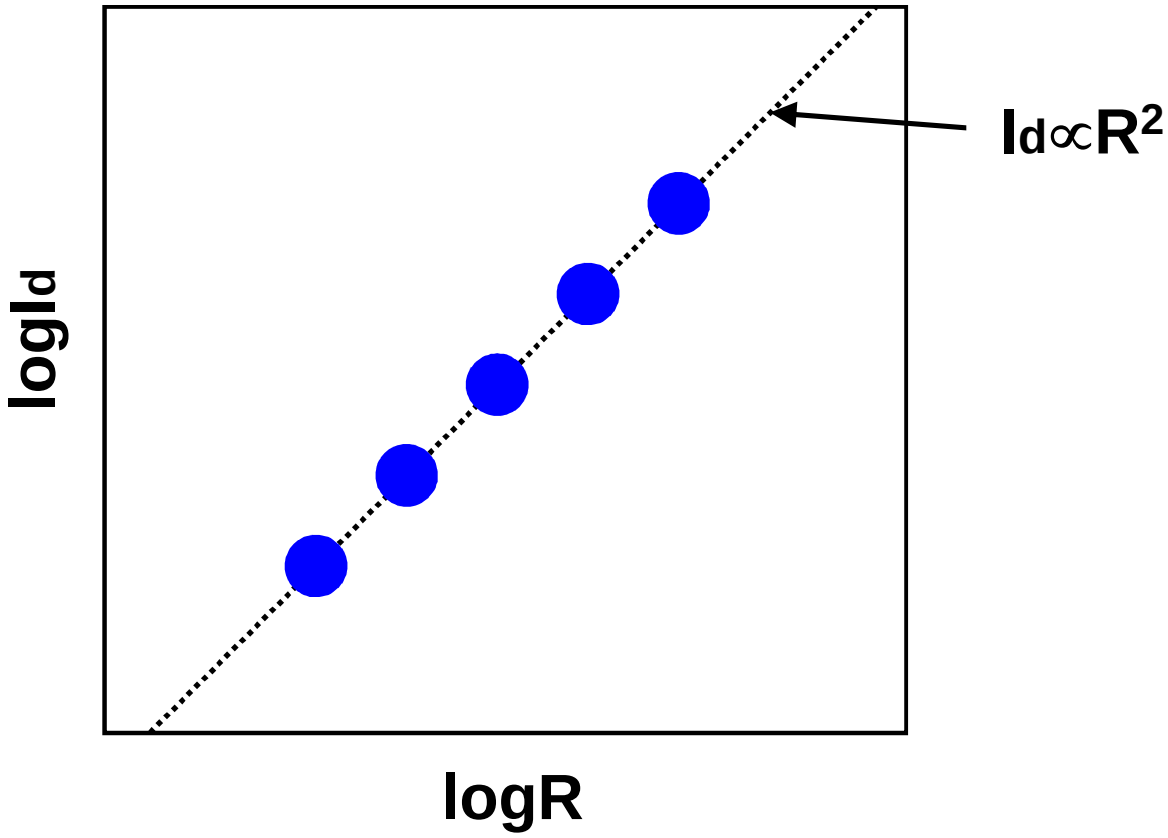
R-Id plot in the case of constant η

$$\log I_d = 2\log R - const.$$



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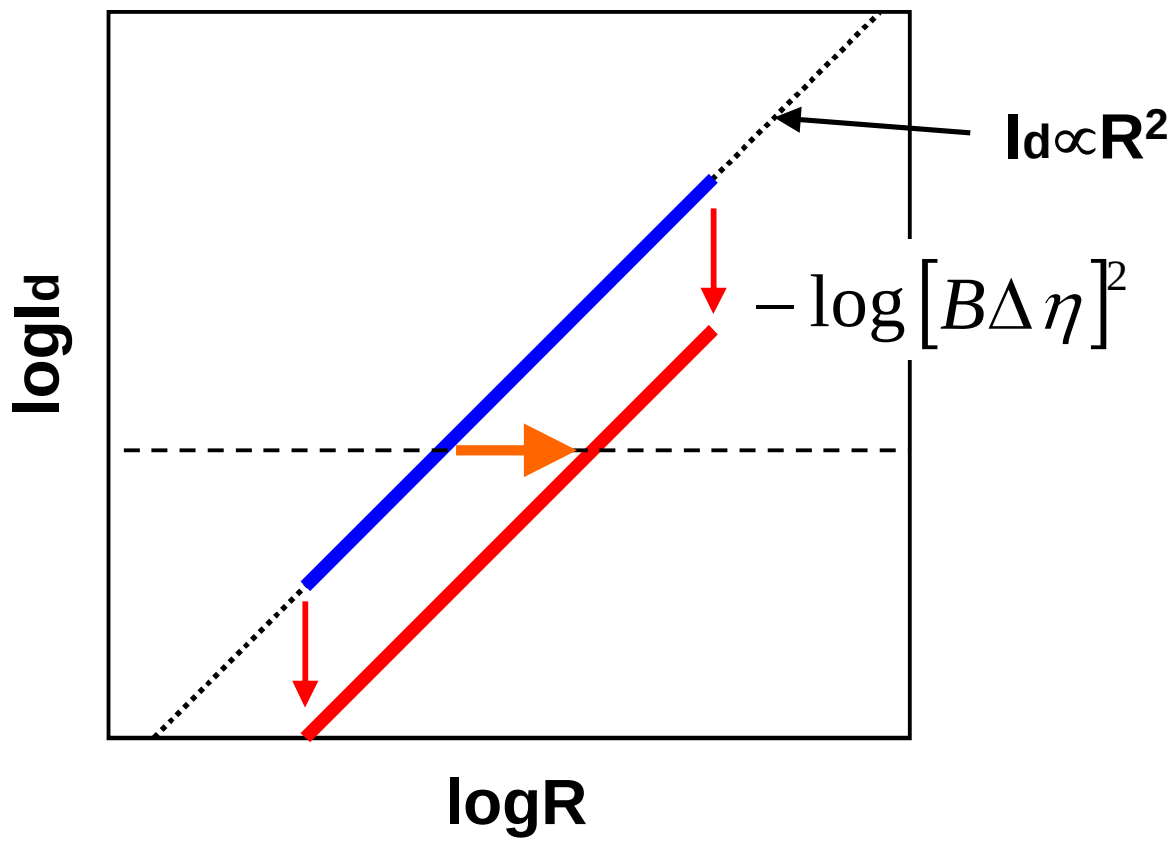
Performance improvement by larger η

$$\log I_d = 2\log R - \log\left[B\eta\right]^2$$



R-Id vs. S/N in the case of QDIPs

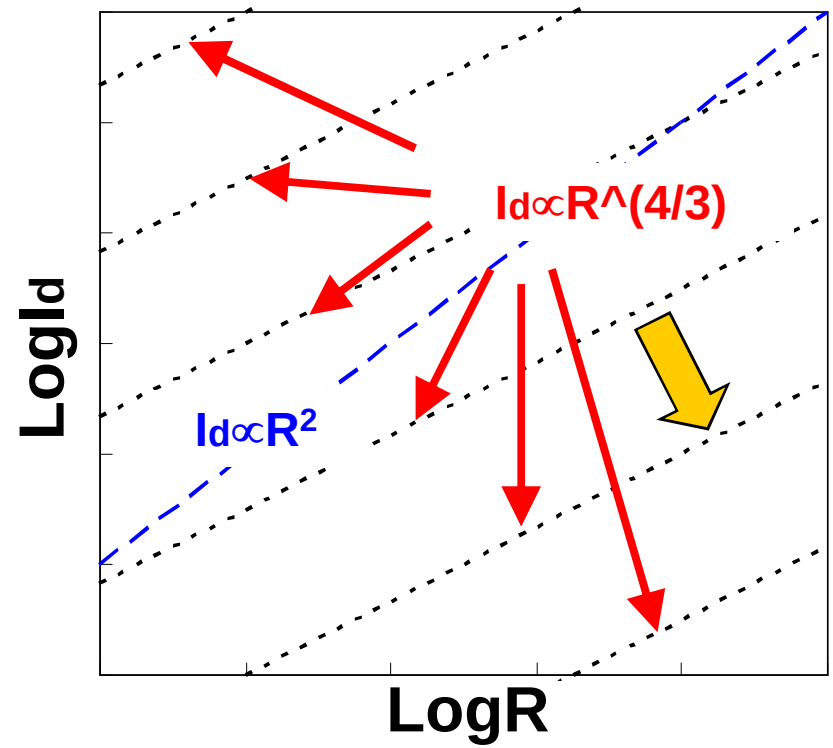
If we assume g∝Id$^{0.5}$ and G-R noise is dominant:

$$D^* = \frac{R\sqrt{S\Delta f}}{i_n} \cong \frac{R\sqrt{S\Delta f}}{\sqrt{4eg\, I_d\, \Delta f}}$$

$$= \sqrt{\frac{S}{4eA}} \cdot \frac{R}{\sqrt{I_d}\sqrt[4]{I_d}} = D^*_{00} \cdot \frac{R}{\sqrt[4]{I_d}^{\,3}}$$

$$\therefore I_d = \left[\frac{D^*_{00}}{D^*}\right]^{4/3} \cdot R^{4/3}$$

S : Detector Area



To improve device S/N, improvement in η is crucial.

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Summary

- We studied the responsivity-dark current relationship of QDIPs.
- We proposed the introduction of an R-I_d plot instead of conventional R-V or I-V characteristics, to characterize photoconductive IR detectors such as QWIPs and QDIPs.
- R-I_d plot of QDIPs exhibits an $I_d \propto R^2$ relationship.
- From an investigation of the gain, we conclude that this $I_d \propto R^2$ relationship is the result of $g \propto I_d^{0.5}$.
- These results indicate that, in order to improve QDIP S/N characteristics, improvement in η is crucial.
- With an R-I_d plot, we can directly compare S/N characteristics of photoconductive detectors.

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