Amplifier Luminescence and RBI

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Outline

- What is amplifier luminescence?
- What mechanism causes amplifier luminescence at the transistor level?
- How can it occur in a CCD output amplifier?
- Coping with Amplifier Luminescence

What is Amplifier Luminescence?

What is Amplifier Luminescence?

- It is what is commonly seen as a bright corner in a CCD image
- It is caused by at least one transistor in the CCD’s output amplifier self-generating light during operation (NIR light)
- NIR light travels through silicon easily, it is conducted laterally from the implicated transistor to adjacent pixels
- That light is sensed by the CCD in pixels physically close to the amplifier and shows up in images as will be shown in the next few slides

Example of Amplifier Luminescence

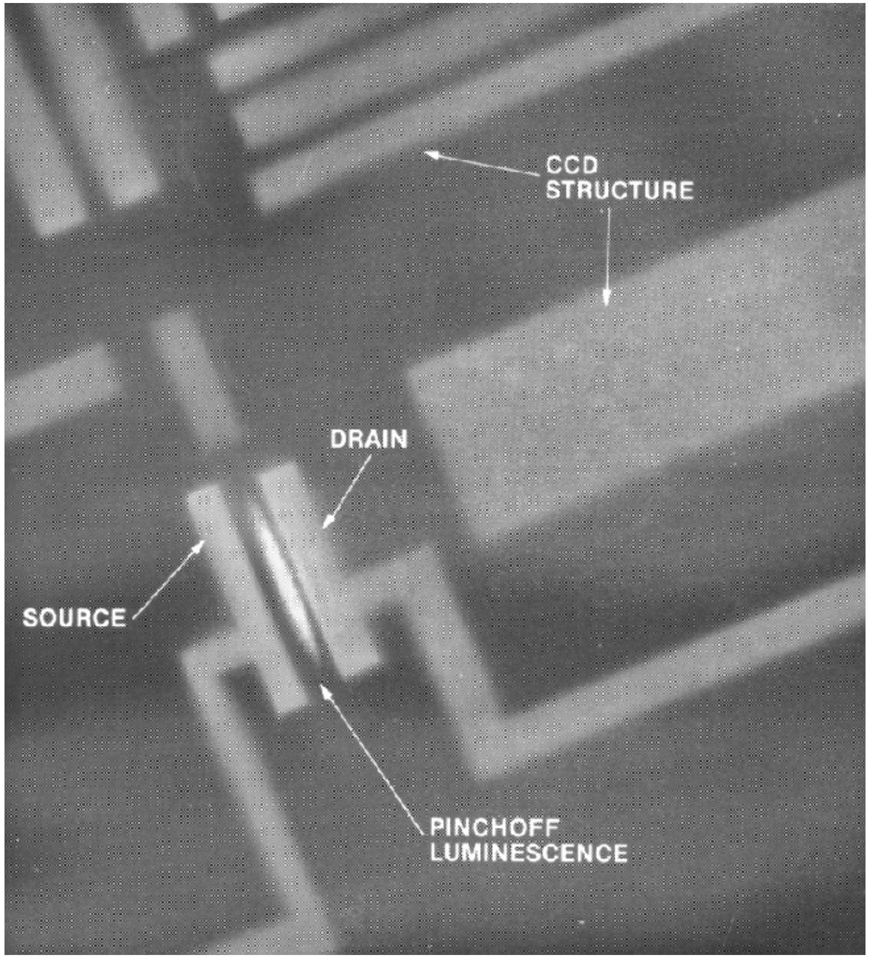
Amplifier
Luminescence

Example of Amplifier Luminescence: Photomicrograph of CCD's Video Output Amplifier Emitting Light

The Light is Near-IR light (NIR)

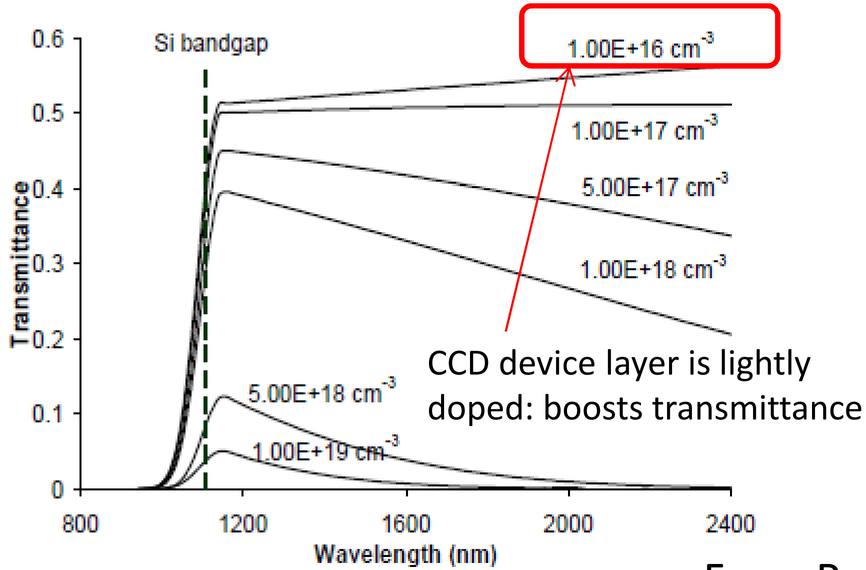
NIR light is highly transmissive in Silicon

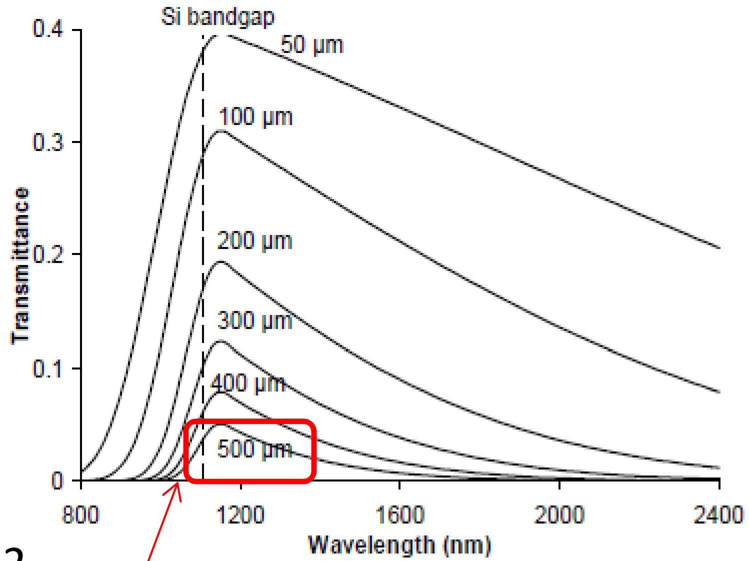
The light is conducted laterally through the silicon exposing pixels nearby



Source: Janesick

NIR Light Transmittance Through Silicon



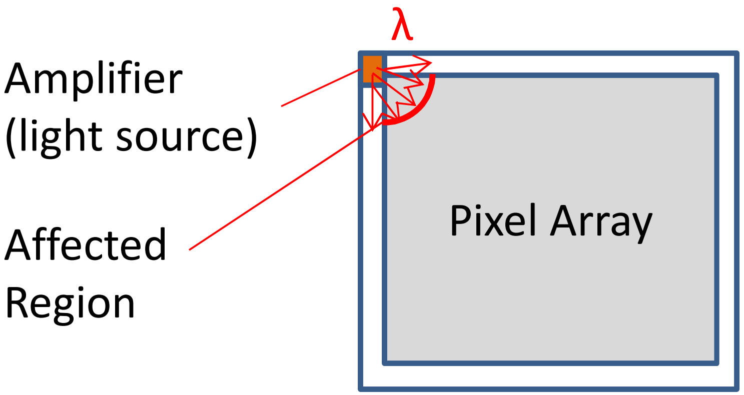


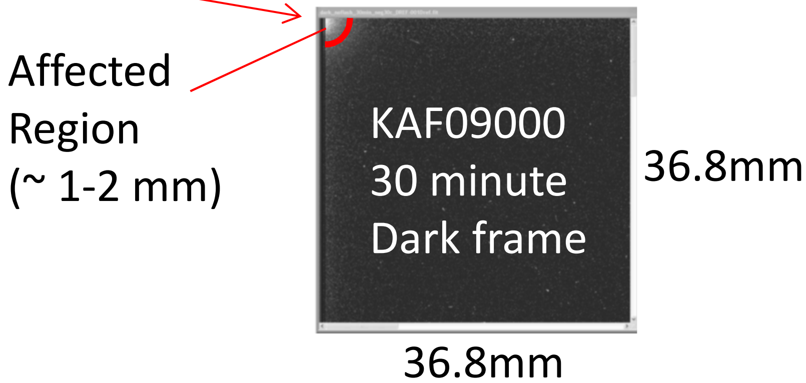
From Ref 2

Fig. 2a: Photon transmittance of 500 µm p-Si for different doping concentrations

Fig. 2b: Photon transmittance of p-Si doped at 10^{19} cm^{-3} for different backside thicknesses

Emission is in all directions



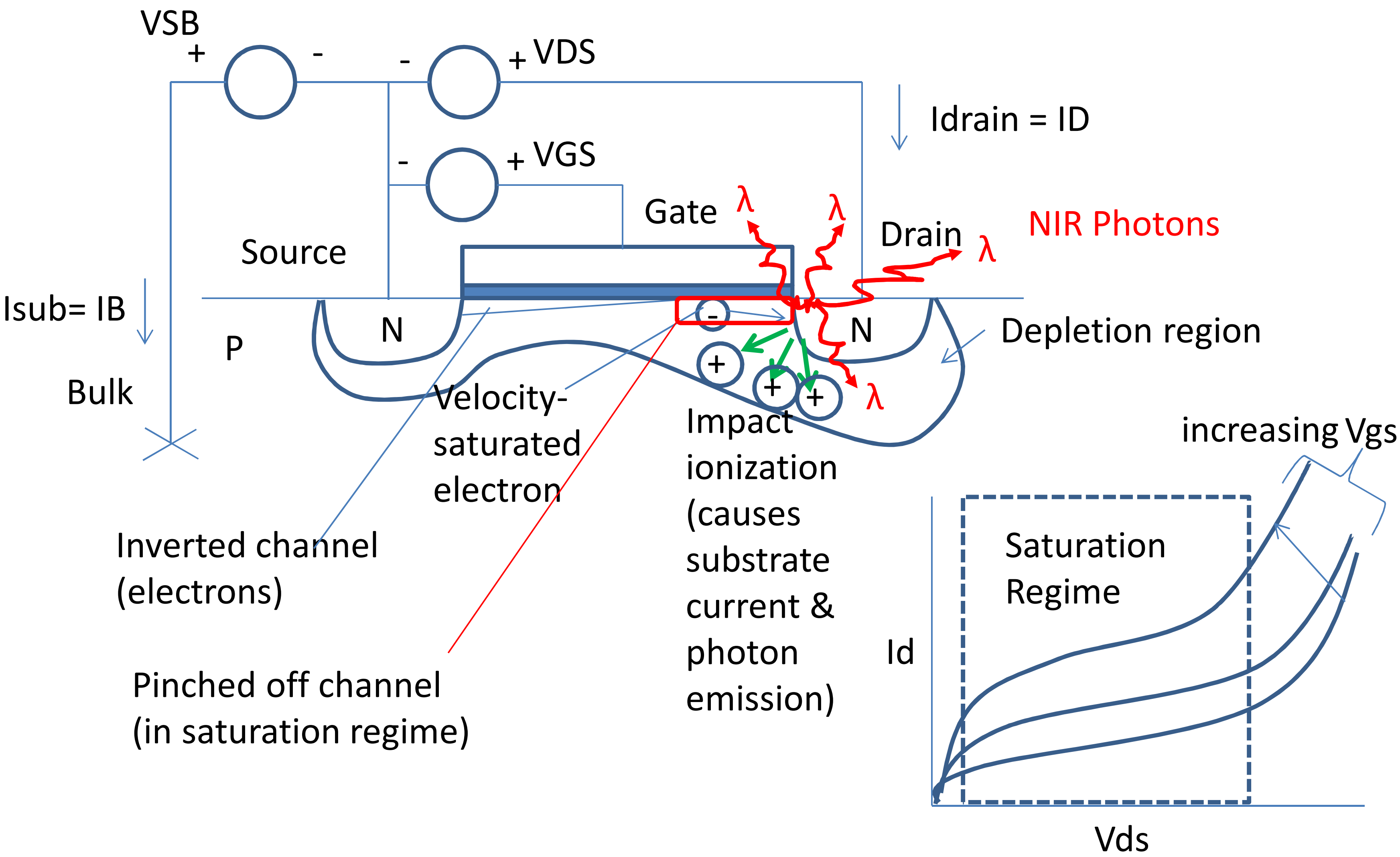


What mechanism causes amplifier luminescence at the transistor level?

What Causes the Amplifier to Emit Light?

- Under pinchoff bias conditions the electric field intensity surrounding the drain of the source follower MOSFET is high enough to accelerate channel electrons sufficiently to cause impact ionization at the drain junction
- That means as the electron slams into the drain, it creates hole-electron pairs by transferring its energy to the silicon. This ionizes lattice atoms creating hole-electron pairs and emits photons
- The hole-electron pairs create a substrate current and it is correlated to the photon emission flux

MOSFET in Pinchoff (saturation) Regime



Photon Emission from Pinched Off MOSFET

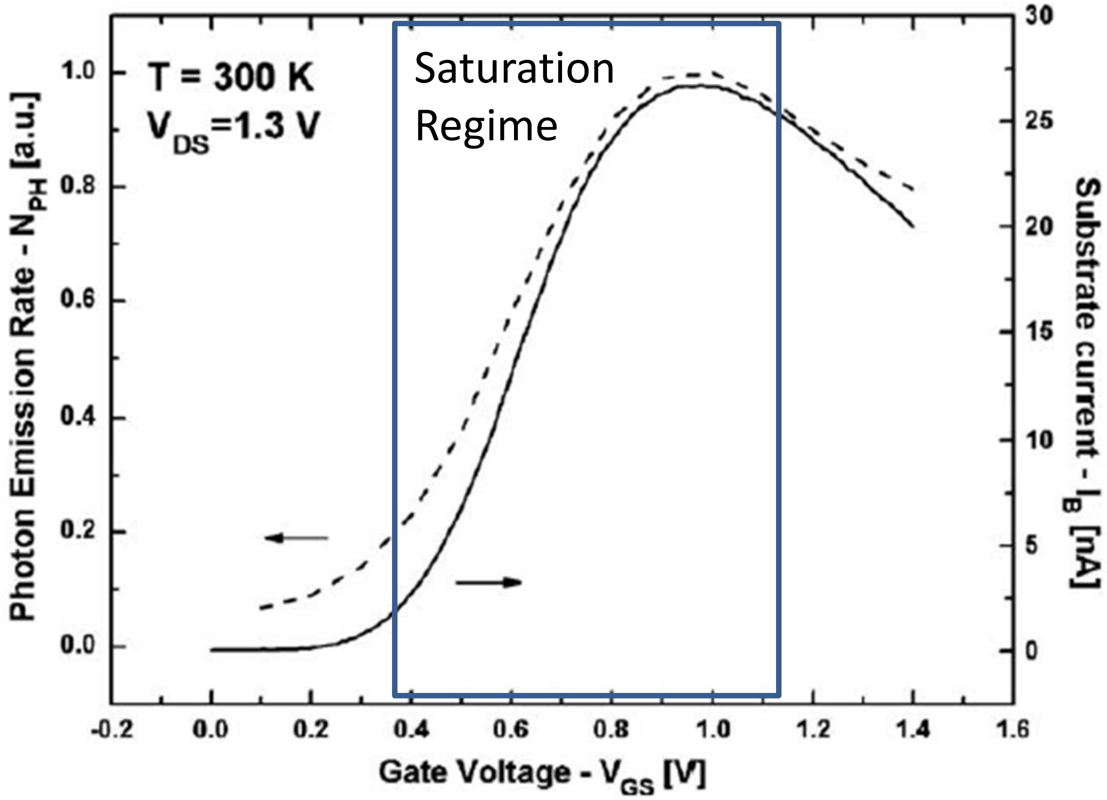


Fig. 1. Photon emission rate (dashed curve) and substrate current (solid curve) as a function of gate bias at $V_{DS} = 1.3$ V.

Saturation regime: VDS > (VGS – VT)

From Ref 1

Id & Isub vs VDS and Photon Emission Intensity vs Wavelength for Selected MOSFET Operating Conditions

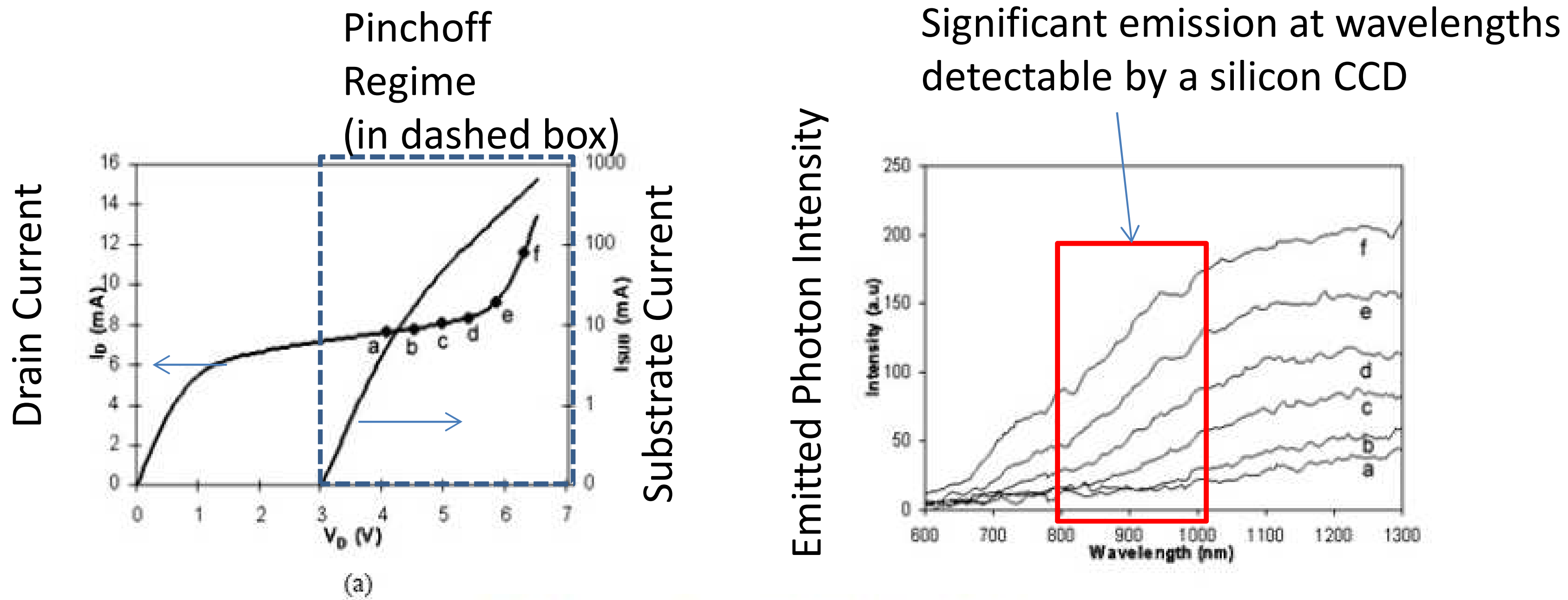
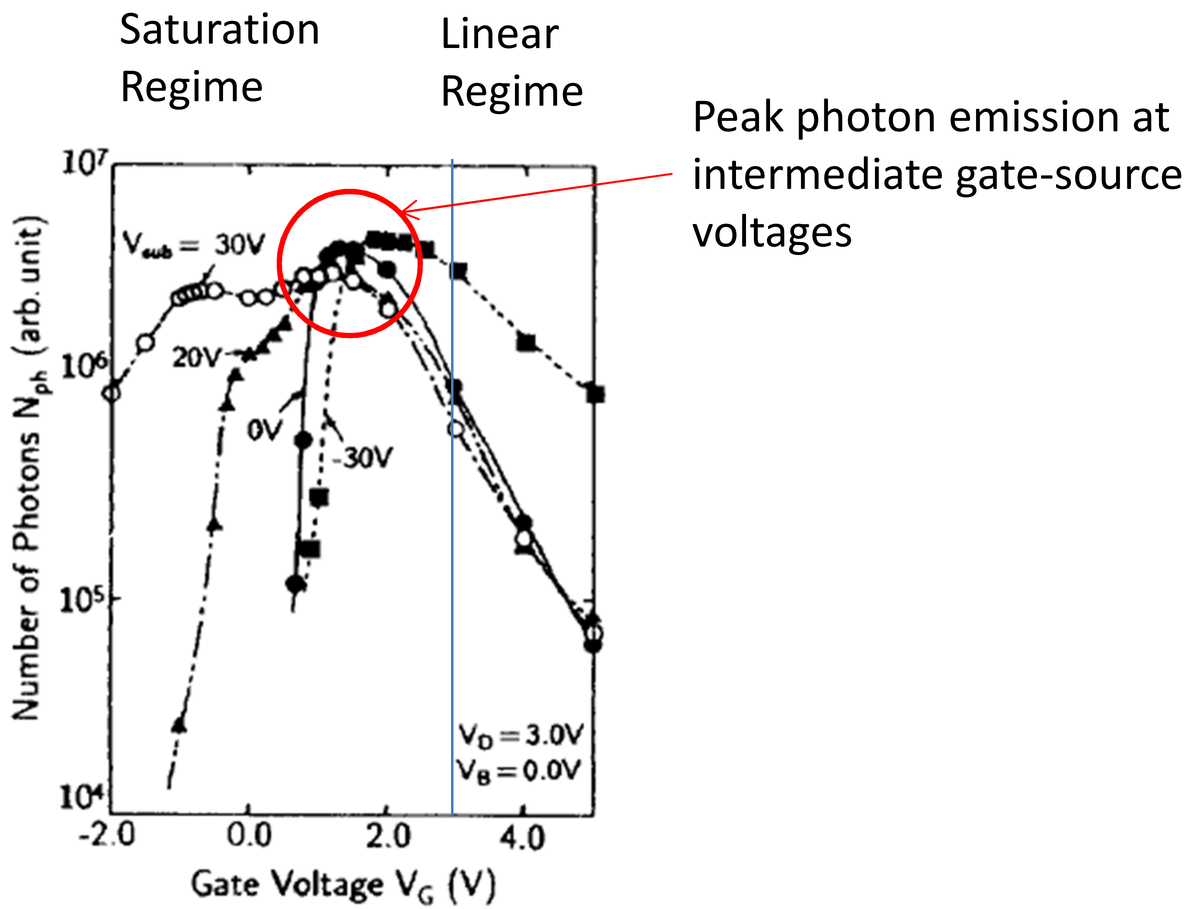


Fig. 11: (a) I_D and I_{sub} versus V_D at V_{GS} = 3V and (b) emission spectra at operating points a – f for 1.0μm gate length nMOSFET (nMOS1) [16]

From Ref 2

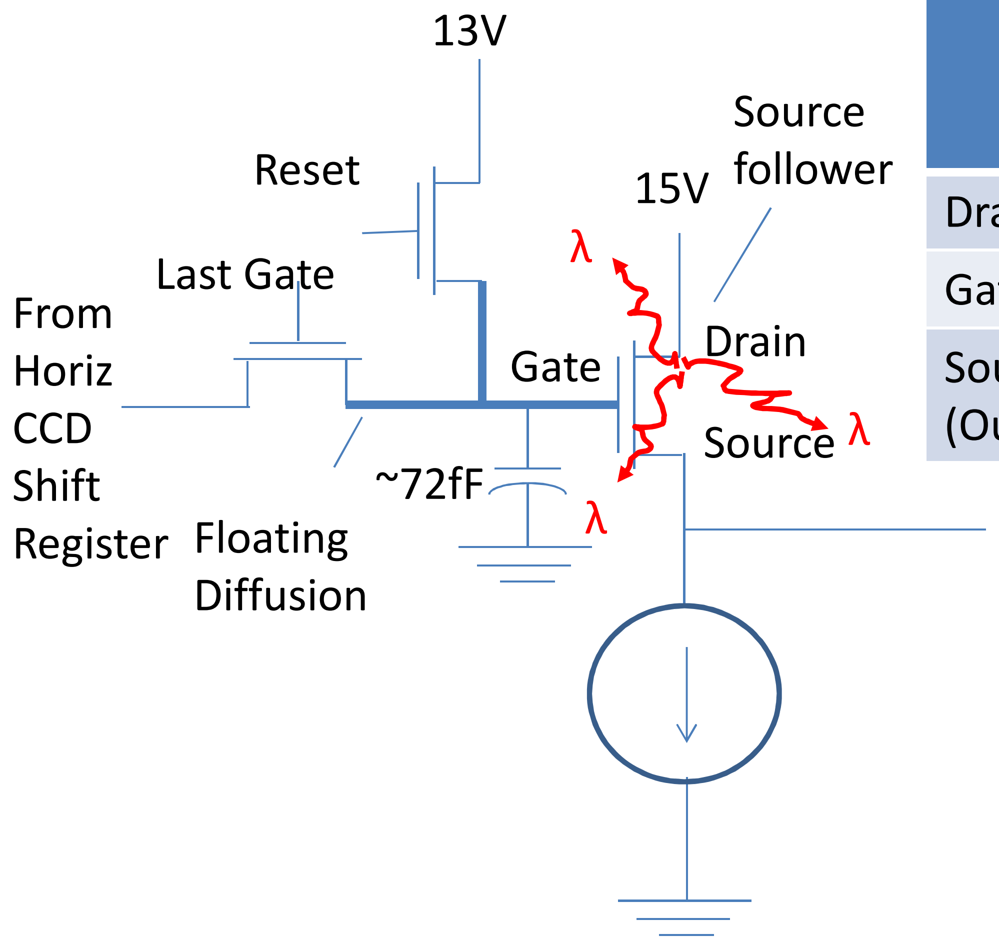
Photon yield vs Vgate for MOSFET



From Ref 3

How can Amplifier Luminescence Occur in a CCD Output Amplifier?

CCD Output Amplifier Structure & Nominal Operating Range



Node	Reset (0e-)	Full Well (100Ke-)	Small Signal Level (~5K e-)
Drain	15V	15V	15V
Gate	13V	~10.8V	12.9V
Source (Output)	10-11V	~7.8-8.8V	9.9V – 10.9V

(Ref 4 KAF16803)

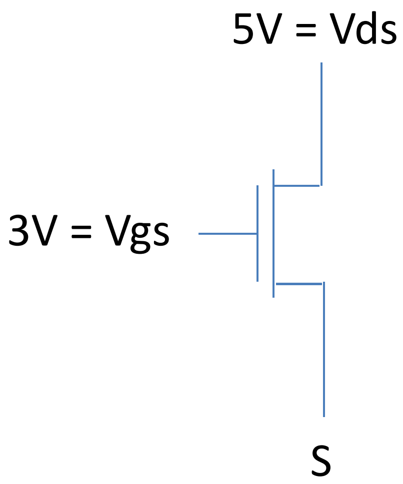
Signal Swing on Floating Diffusion (KAF16803)

22uV/e- signal from KAF16803 spec (~72.8 fF)

(Ref 4)

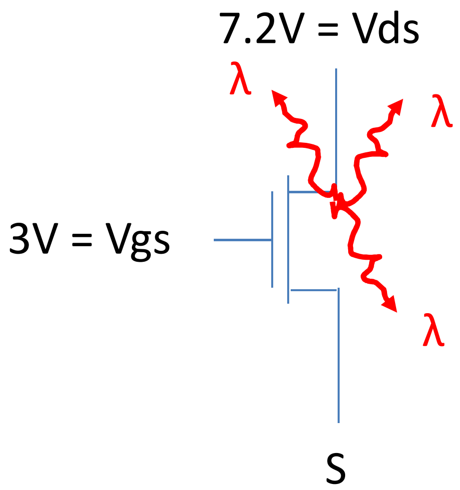
Signal (electrons)	Signal (coulombs)	Signal Delta Swing from Reset (volts)
0 (reset state)	0	0
1	1.602 E-19	22 uV
10	1.602 E-18	220 uV
100	1.602 E-17	2.2 mV
1,000	1.602 E-16	22 mV
10,000	1.602 E-15	220 mV
100,000 (full well)	1.602 E-14	2.2 V

CCD Output Amplifier Source Follower Operating Regimes (KAF16803)



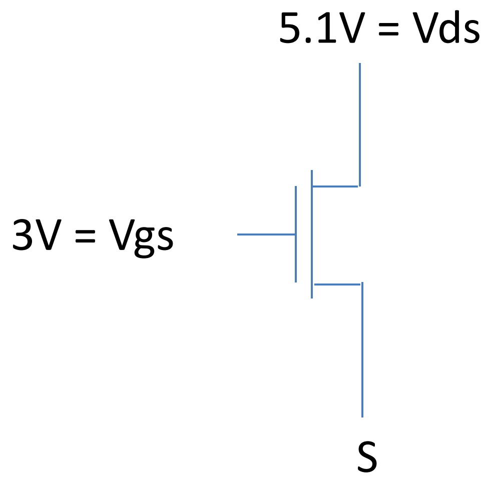
Reset

Near Pinchoff
(little to no
luminescence)



Full Well

Deep Pinchoff
(significant luminescence
risk)



Small signal
(~5K e-)

Near Pinchoff
(little to no
luminescence)

Normal Camera Operation and Luminescence

- When camera has power applied from a depowered state the sensor's wells are normally filled. Luminescence may occur during array flushes. Empirical data suggests this may be the dominant mechanism explaining most observed Luminescence (more later)
- Whenever camera's sensor reaches full well or is close to it, Luminescence may occur during readout or flushing
- ***<u>It is not sufficient</u>*** to gate off the power to the amplifier during integration: depending on array signal level, amplifier saturation/pinchoff may occur during readout

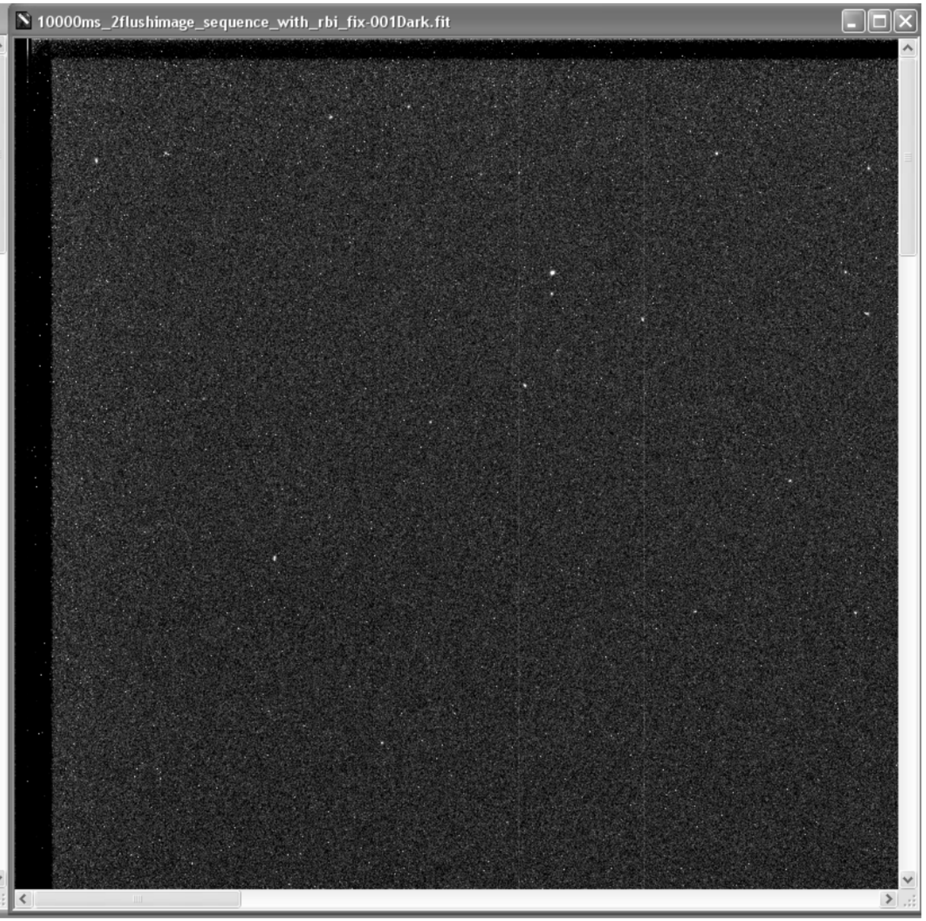
Coping with Luminescence

Potential Options for Coping with Luminescence

1) Prevent it from occurring: operate outside Pinchoff Regime, by reducing amplifier Vdd and increasing Reset Voltage level
    a) Adversely affects linearity and dynamic range
    b) Increases amplifier gain uncertainty (ref 5)
    c) Not practical
2) Gate off Vdd to Amplifier during times of sensor Saturation
    a) Easy enough to do for camera initial power-up
    b) How can it be done during normal operation? (it cannot and therefore is not a viable solution)
3) Turn off amplifier during integration (already done in many cameras)
    a) Beneficial since it reduces the time the amplifier may be emitting
    b) But not a complete solution since the sensor's amplifier may luminesce during readout
4) Gate off VDD to the amplifier during initial power up flushing
    a) Prevents the fully saturated sensor's array from initiating output amplifier luminescence during flushing
    b) RBI can "store" the luminescence and release into many subsequent integrations
    c) Use RBI mitigation if you have a full-frame sensor

Impact of RBI Mitigation on Amplifier Luminescence

30 minute dark with no flood.
Significant amplifier luminescence



Post-flood 30 minute dark frame
Negligible amplifier luminescence

The result hints at a power-up transient bias condition initiating impact ionization in CCD's output amplifier

Full Frame Sensors, Amplifier Luminescence and RBI

- As has been noted previously nearly all KAF series full frame sensors exhibit RBI to varying degree
- Like with any other signal trapped in RBI, the amplifier luminescence creates RBI
- If not mitigated with the RBI flood-flush protocol, the Amplifier Luminescence that occurs during the power-up sequence, will be trapped and will leak into subsequent exposures as it decays. Each subsequent exposure has less than the previous. Since each are different they cannot be dark-subtracted
- This puts the sensor into a non-calibratable scenario.
- **The solution is to use the RBI flood flush protocol.**
  - **It puts the sensor into a known and identical state prior to any integration.**
  - **If any amplifier luminescence from the power up transient was captured, it will be destroyed**
  - **<u>If any further Amplifier Luminescence occurs in subsequent integration/ readouts, it will be identical in each and will be removed via Dark Subtraction (just like Dark Fixed Pattern Noise). This is a key and very important point!</u>**

References

Ref 1:

Study of leakage-induced photon emission processes in sub-90 nm CMOS devices

Y. Weizman [a,*], M. Gurfinkel [b], A. Margulis [a], Y. Fefer [a], Y. Shapira [b], E. Baruch [a]

[a] *Freescale Semiconductor Israel Ltd., Herzlia 46725, Israel*
[b] *School of Electrical Engineering, Tel-Aviv University, Ramat-Aviv 69978, Israel*

Received 6 April 2006; accepted 13 April 2006

Ref 2:

A Review of Near Infrared Photon Emission Microscopy and Spectroscopy

JCH Phang[1,2], DSH Chan[1], SL Tan[1], WB Len[1], KH Yim[1],
LS Koh[2], CM Chua[2], LJ Balk[3]
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Ref 3:

Photon Emission from SOI MOSFET with Body Terminal

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†Hamamatsu Photonics K. K.
††ULSI Laboratory, Mitsubishi Electric Corporation

References

Ref 4:

DEVICE PERFORMANCE SPECIFICATION

Revision 3.0 MTD/PS-0994

May 21, 2008

KODAK KAF-16803 IMAGE SENSOR R

4096 (H) X 4096 (V) FULL-FRAME CCD IMAGE SENSOR

Ref 5: http://www.narrowbandimaging.com/images/gain_uncertainty.pdf