Charge Coupled Devices (CCDs)

Nobel Prize in Physics 2009

"Two Revolutionary Optical Technologies"

Charles K. Kao - for initiating the search for and the development of the low-loss optical fiber

Willard S. Boyle and George E. Smith - for inventing the charge coupled device

"CCDs are widely used in digital cameras and in advanced medical and scientific instrumentation." Nobel Committee*

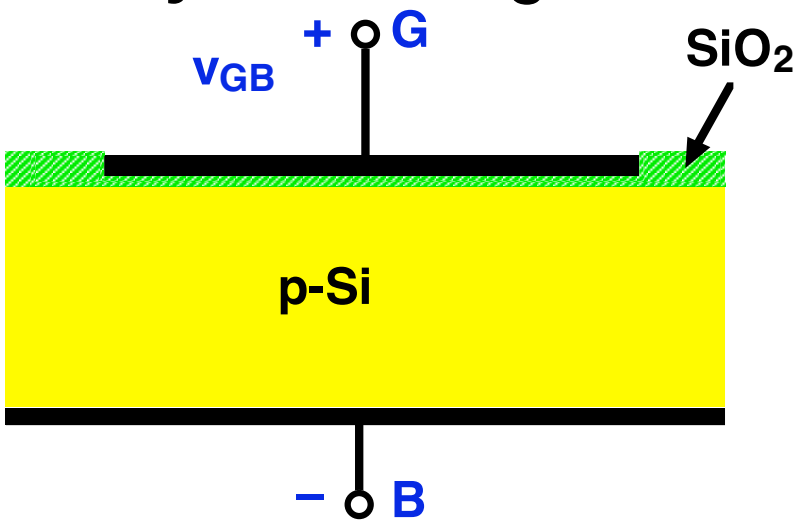
"And they are something you can understand in 6.012." me

* Lifted from Nobel website:
http://nobelprize.org/nobel_prizes/physics/laureates/2009/press.html

What if we don't have an adjacent n-region?

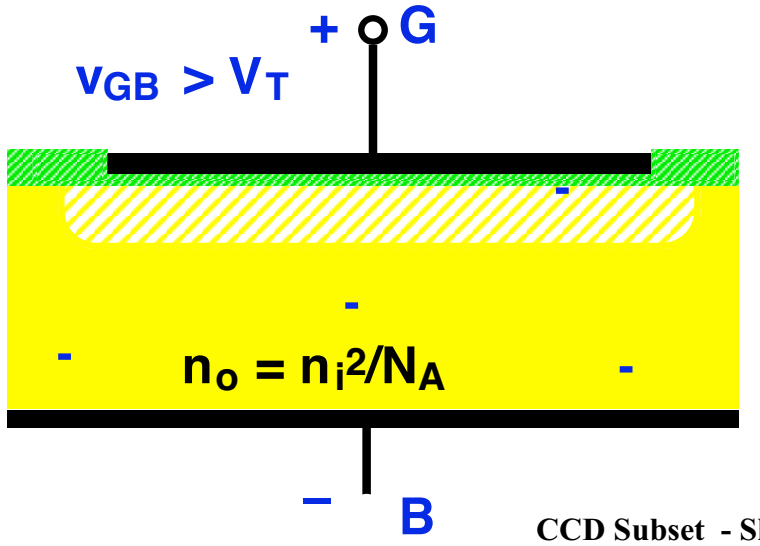
The two-terminal n-MOS capacitor

Right: Basic device



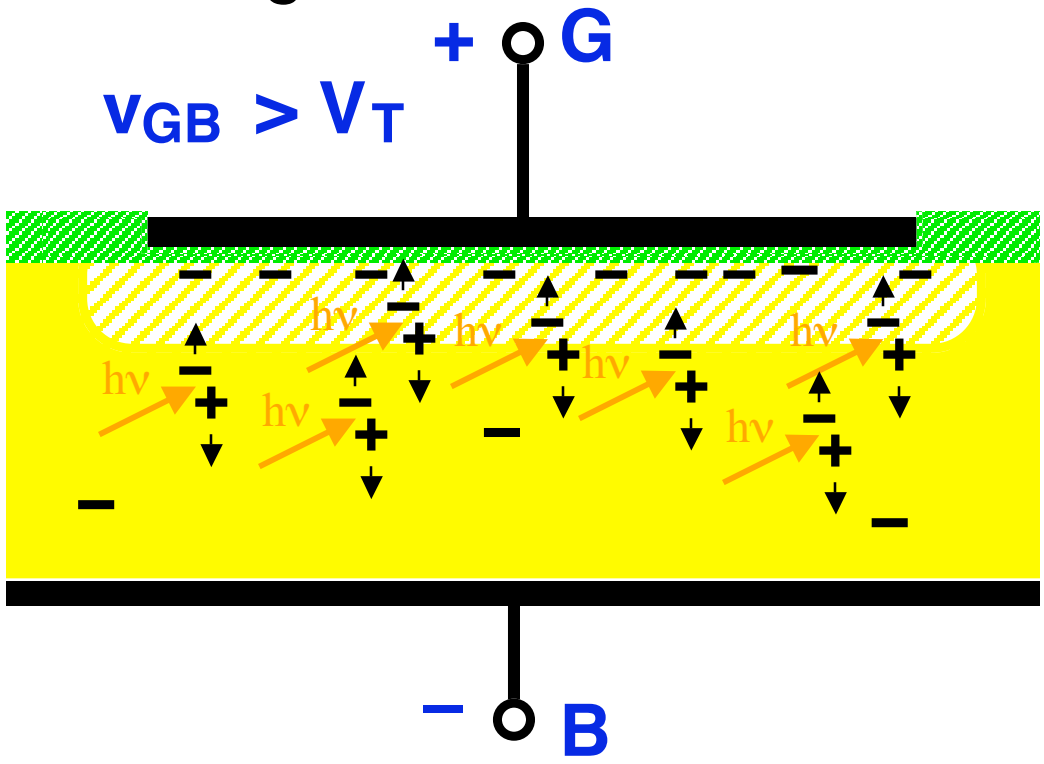
For $v_{GB} \leq V_T$ nothing is different, but when $v_{GB} > V_T$, where do the electrons for the inversion layer come from?

They diffuse to the edge of the depletion region from the bulk. This is like reverse bias diode saturation current and it takes a long time to build up the inversion layer charge.



The MOS light detector -

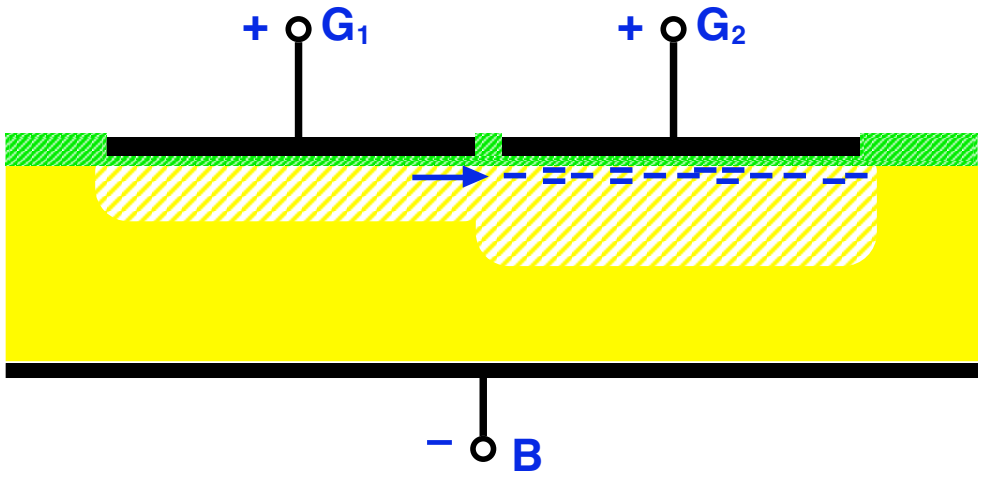
What if we shine light on our biased MOS capacitor?



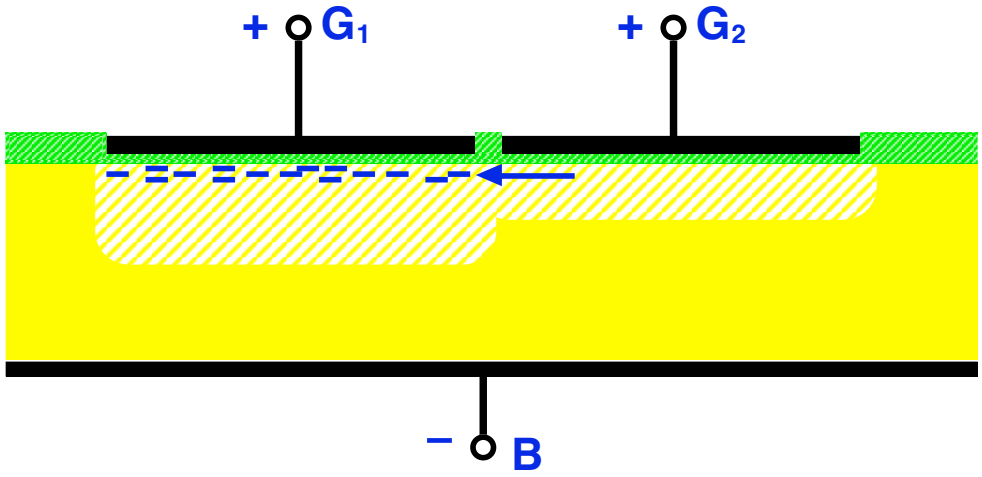
Electrons optically generated in and near the depletion region will be populate the inversion layer. The number collected in a frame time (clock period) is proportional to the light intensity.

Two adjacent MOS capacitors:

$V_{G2S} > V_{G1S} > V_T$



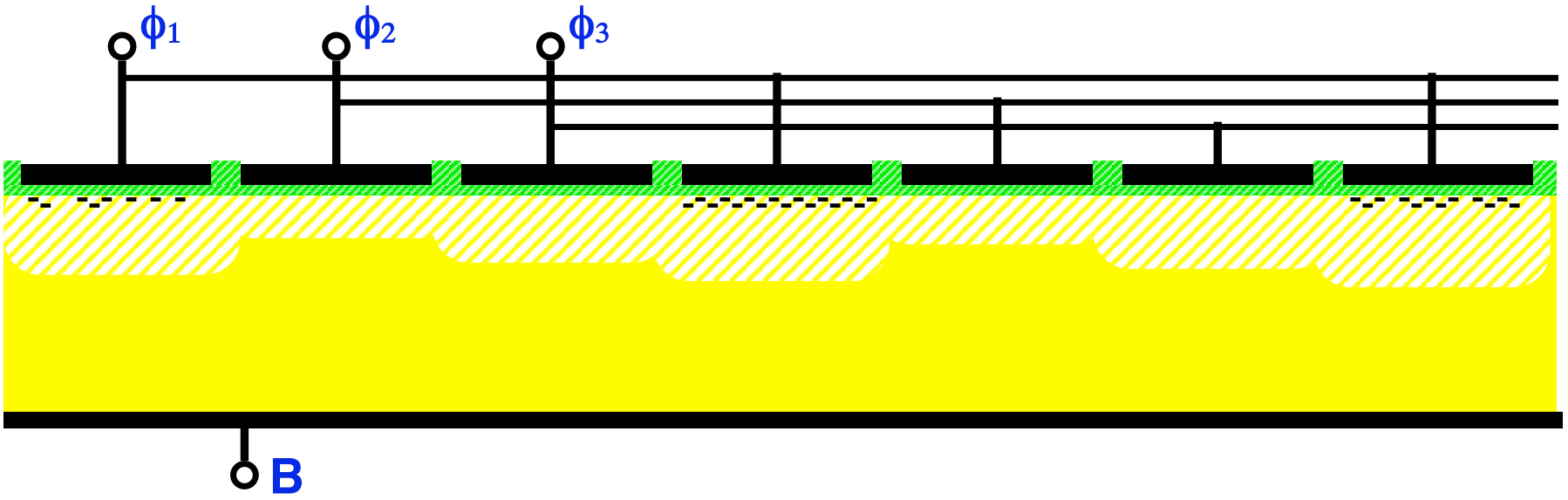
$V_{G1S} > V_{G2S} > V_T$



The charge can be passed back and forth between them.

Charge-coupled devices, CCDs: basically shift registers

$\phi_1 > \phi_3 > \phi_2 > V_T$



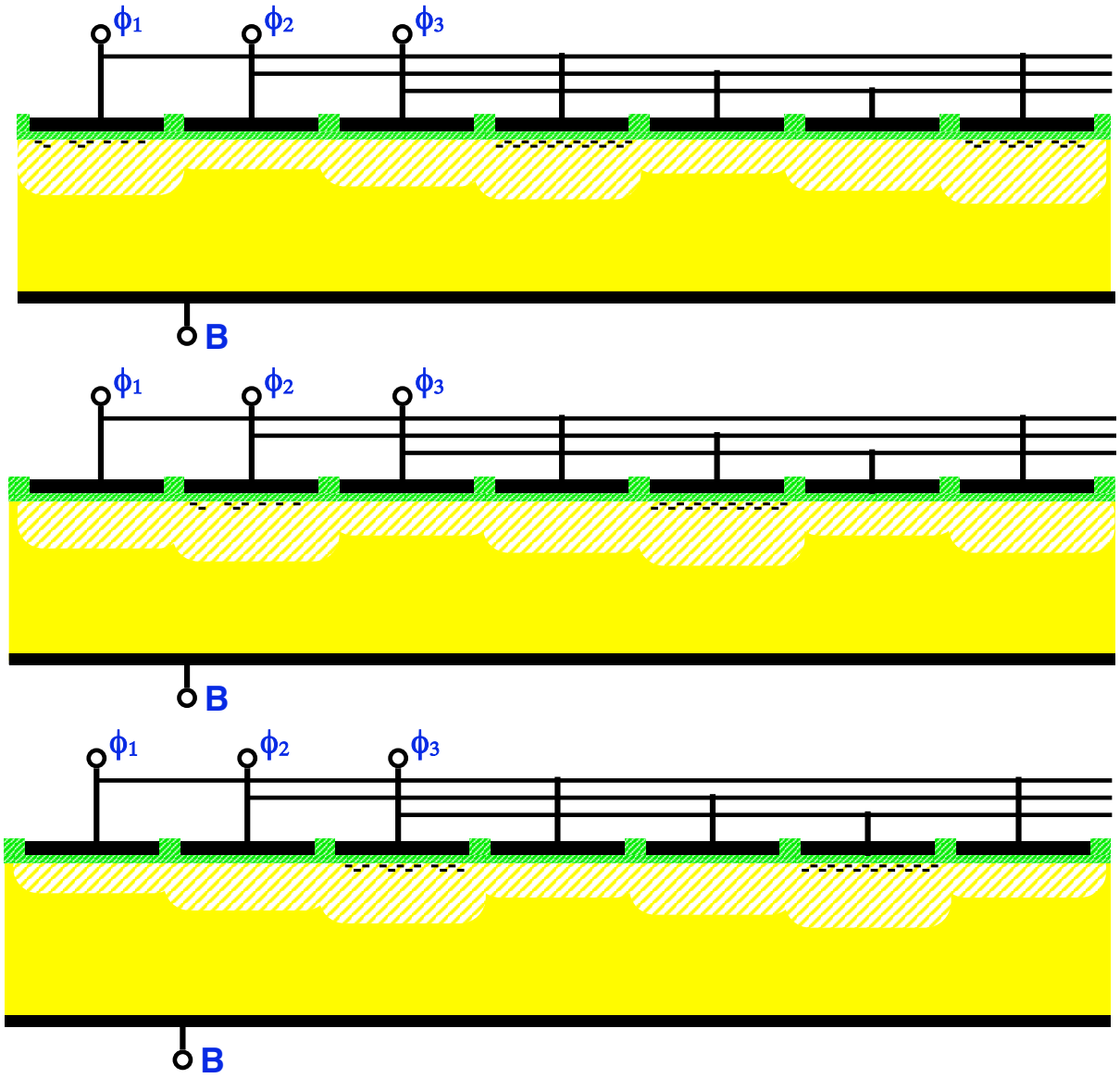
An array of closely spaced 2-terminal MOS capacitors can be used to shift data along in a serial bit stream in the form of packets of electrons.

Charge-coupled devices: CCD shift registers

$\phi_1 > \phi_3 > \phi_2 > V_T$

$\phi_2 > \phi_1 > \phi_3 > V_T$

$\phi_3 > \phi_2 > \phi_1 > V_T$



CCD read-out circuitry -

The charge is shifted along and read serially using a reverse biased diode and MOS source followers.

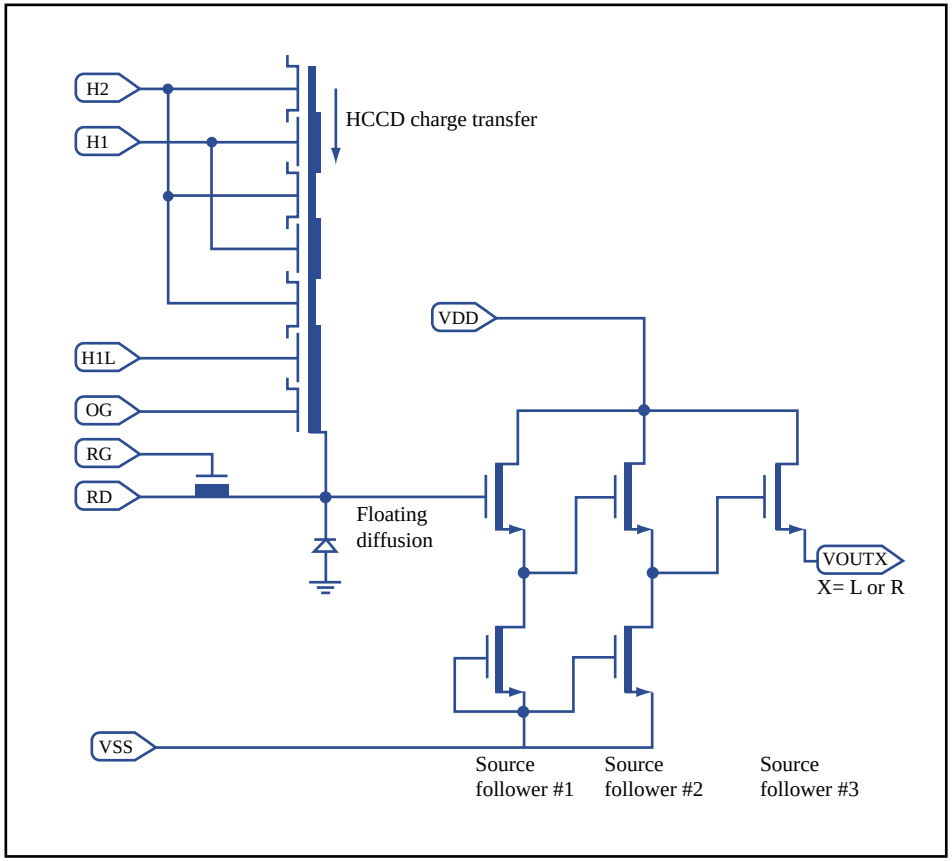


Figure by MIT OpenCourseWare.

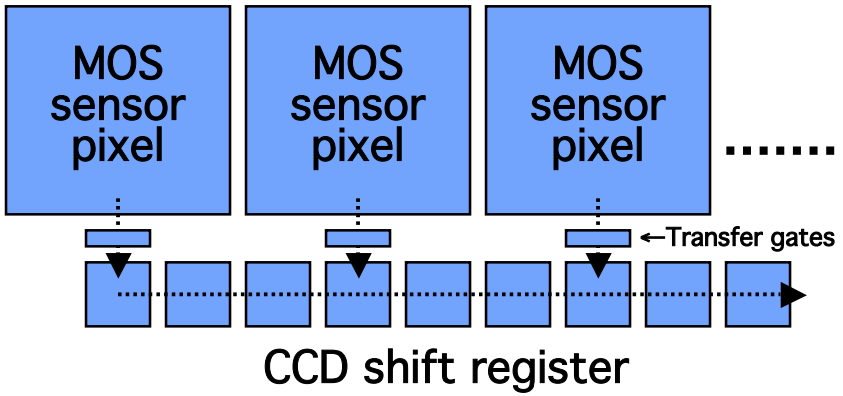
Lifted from a Kodak website:

http://www.kodak.com/global/en/business/ISS/index.jhtml?pq-path=11937

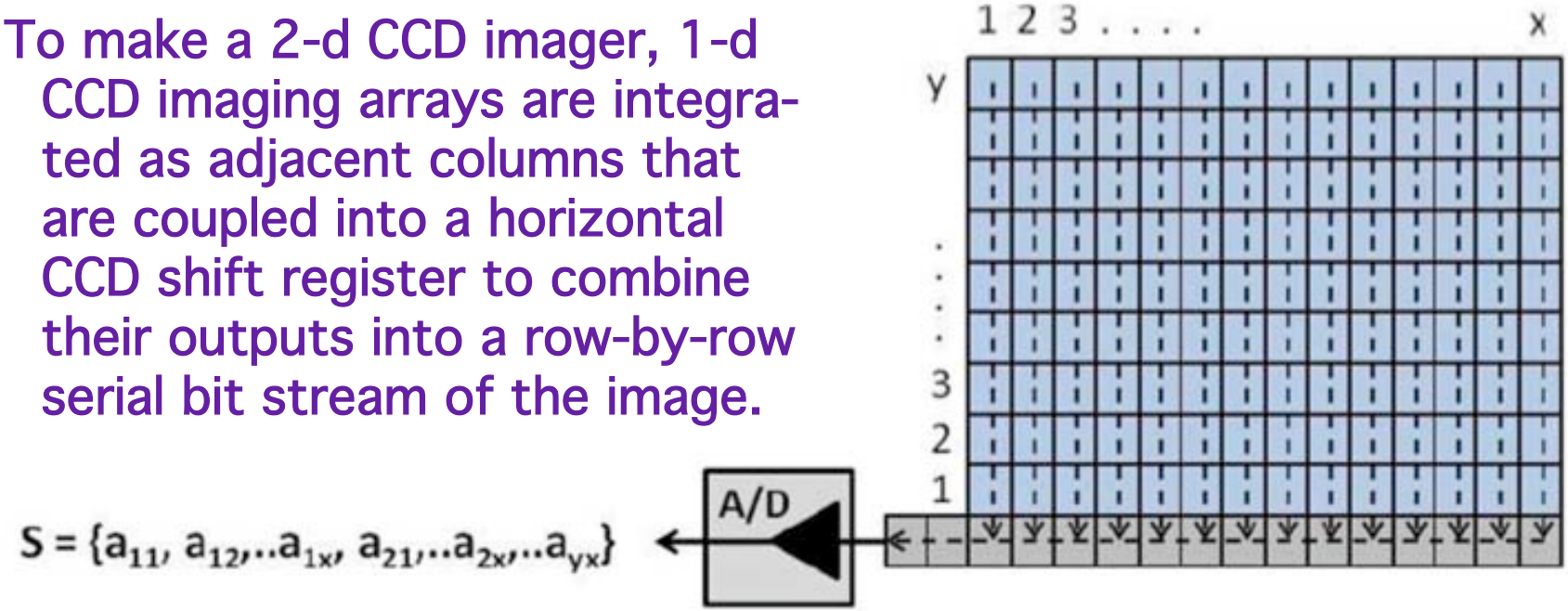
Courtesy of Eastman Kodak Company. Used with permission.

CCD imagers - 1-d and 2-d arrays

A linear CCD imaging array is made by placing MOS sensor pixels next to a CCD shift register, which collects their outputs and sends them out in a serial stream.



To make a 2-d CCD imager, 1-d CCD imaging arrays are integrated as adjacent columns that are coupled into a horizontal CCD shift register to combine their outputs into a row-by-row serial bit stream of the image.



2-d array figure lifted from Nobel website:
http://nobelprize.org/nobel_prizes/physics/laureates/2009/press.html

Source: The Royal Swedish Academy of Sciences.

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