Plasma Displays

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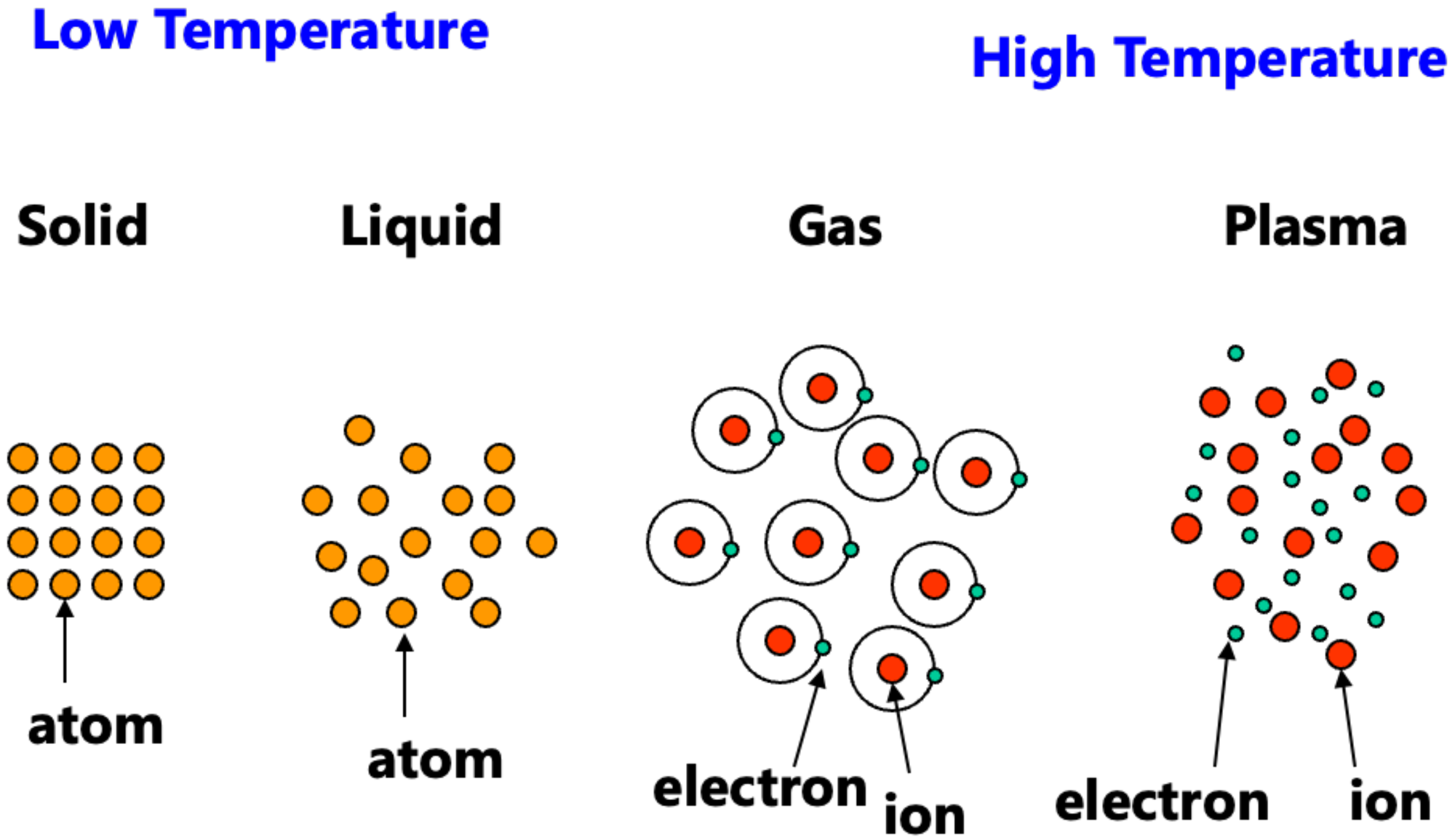
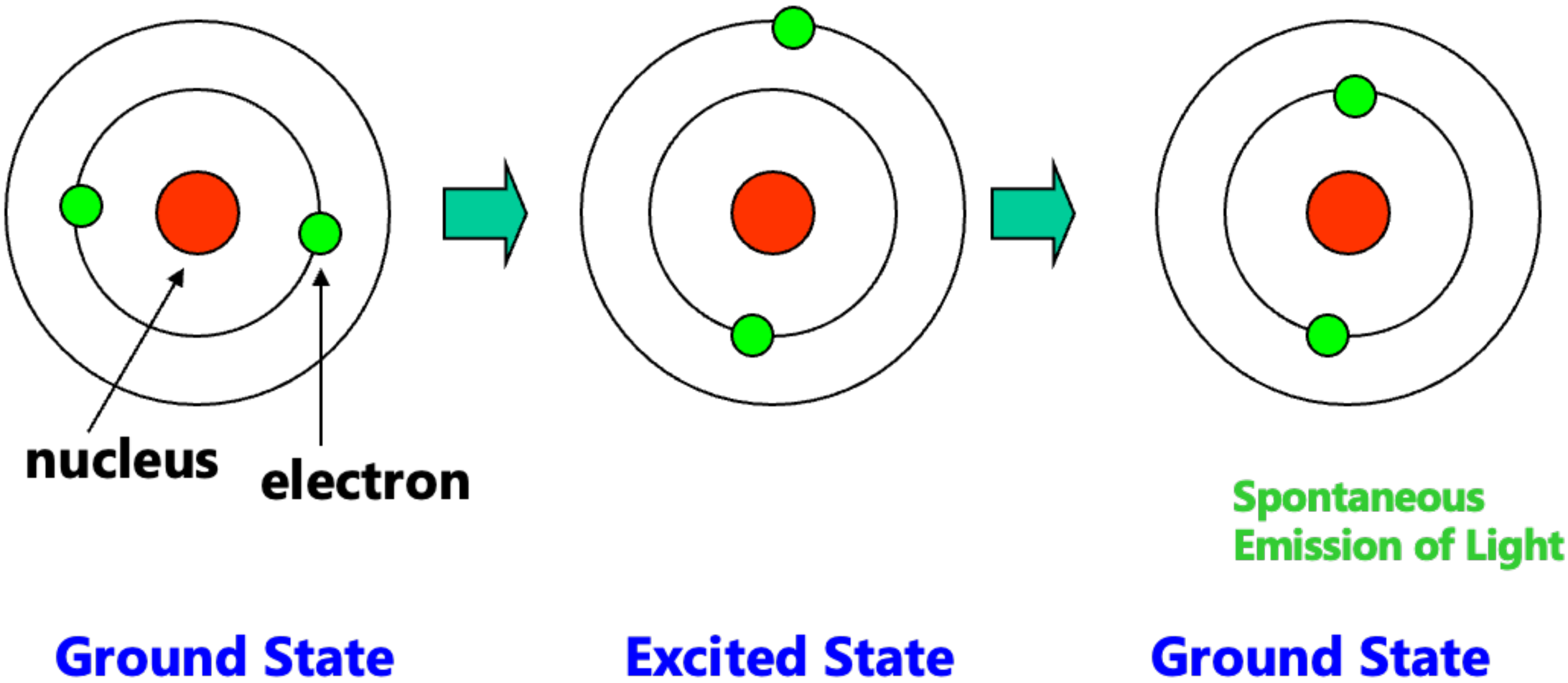
Outline

- Plasma displays are “legacy” at this point
- But, they were the first large flat-panel displays commercially available
- They have great luminance and vivid colors
- What we’ll cover today:
  - What is plasma?
  - How do plasma displays work?
  - Why can’t you buy them anymore?

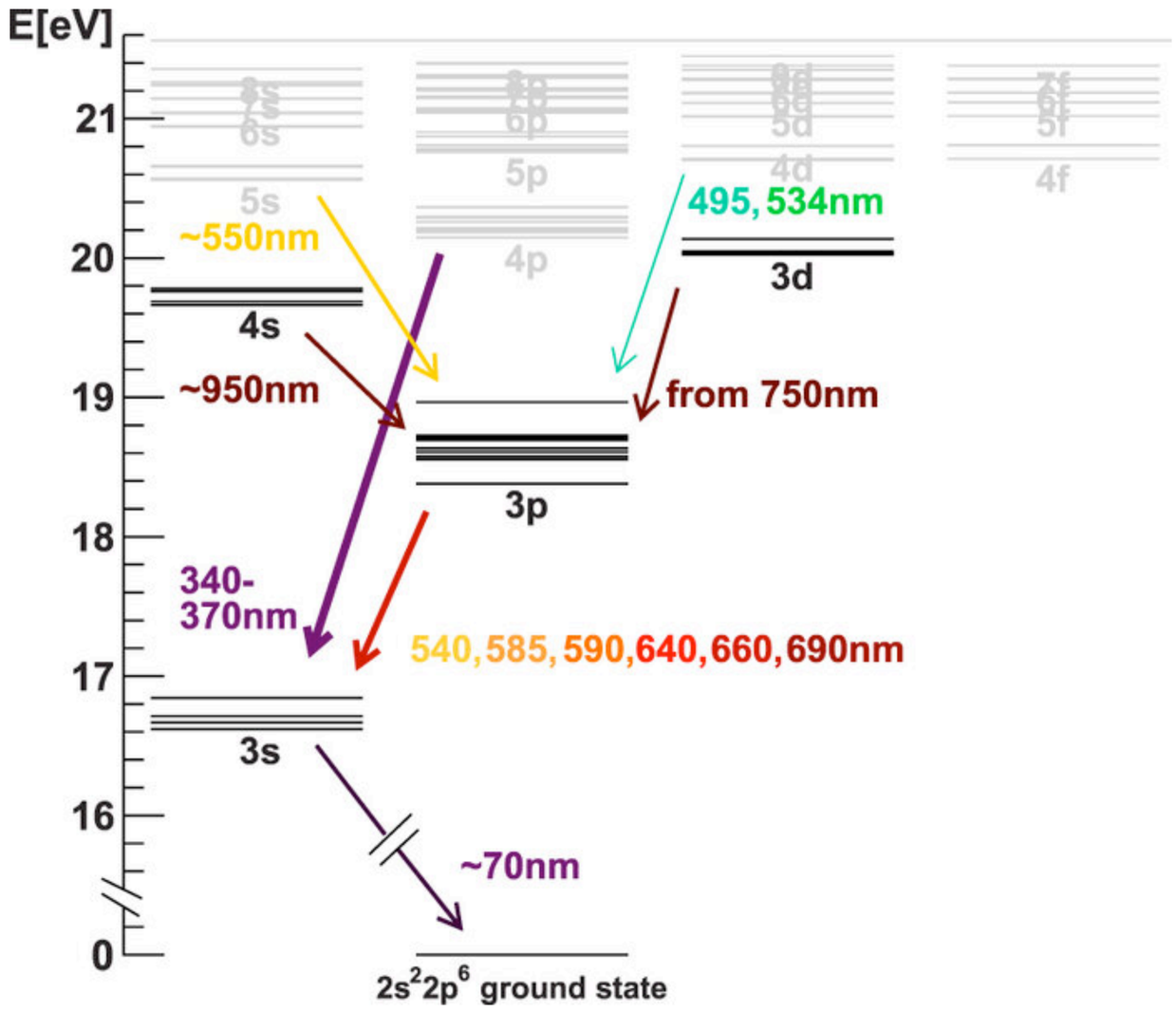
What is Plasma?



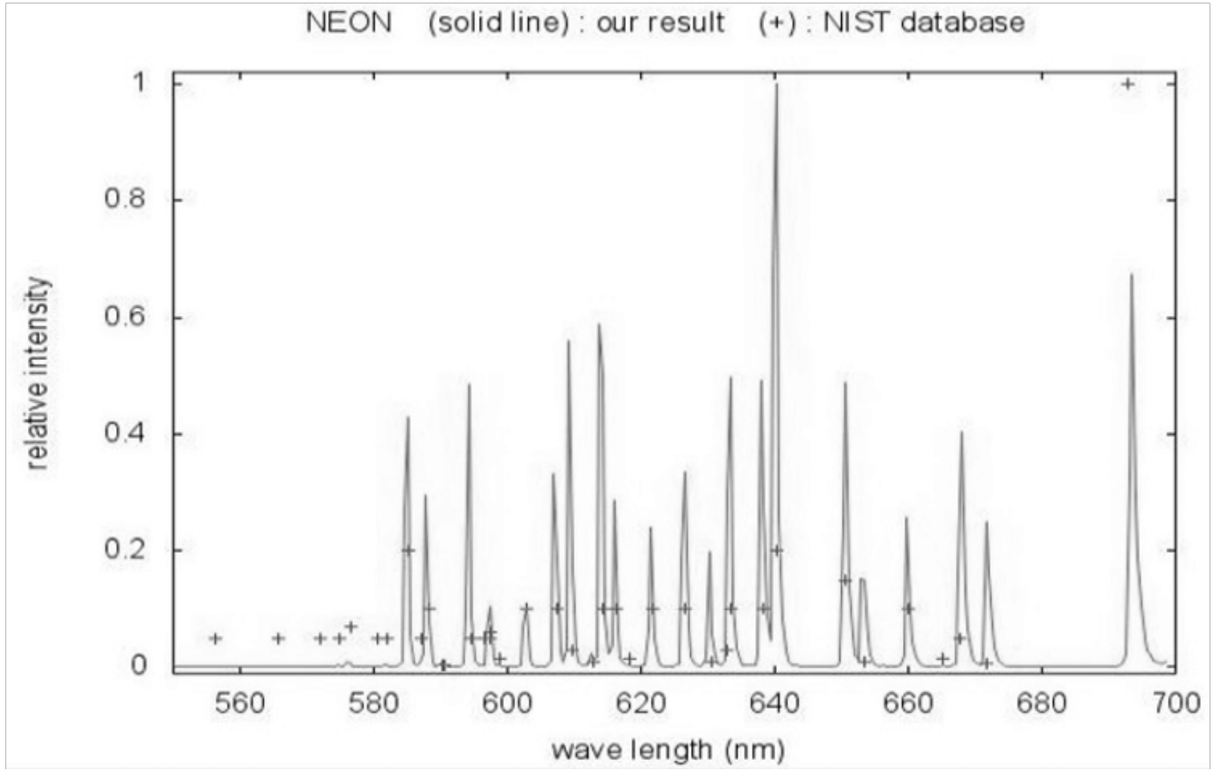
Where Does The Light Come From?



Neon Energy Levels



Credit: Bartschat in *Journal of Physics: B* 2018



Credit: Miyazaki et al. in *Forma* 2019

Neon Lights

- In the early 20th century, neon lighting is invented
- It becomes popular for use in signage because it's so bright
- Today, there are fewer and fewer examples
- Plasma displays went out of style for similar reasons
- We'll get to exactly why later…

Credit: CNN and New York Times

Penning Mixtures

- Neon is a popular gas for plasma bulbs
- But it turns out we can lower the discharge energy with mixtures of gases
- Lowers breakdown voltage of the bulb
- Ne and Ar mixtures are popular because they are both noble so they don't corrode electrodes etc.
- The optimal (lowest breakdown V) mixture is called the "Penning mixture"

Direct ionization (higher breakdown voltage)

$$\mathrm{Ar} + \mathrm{e}^- \rightarrow \mathrm{Ar}^+ + 2\mathrm{e}^-$$

Penning ionization (lower breakdown voltage)

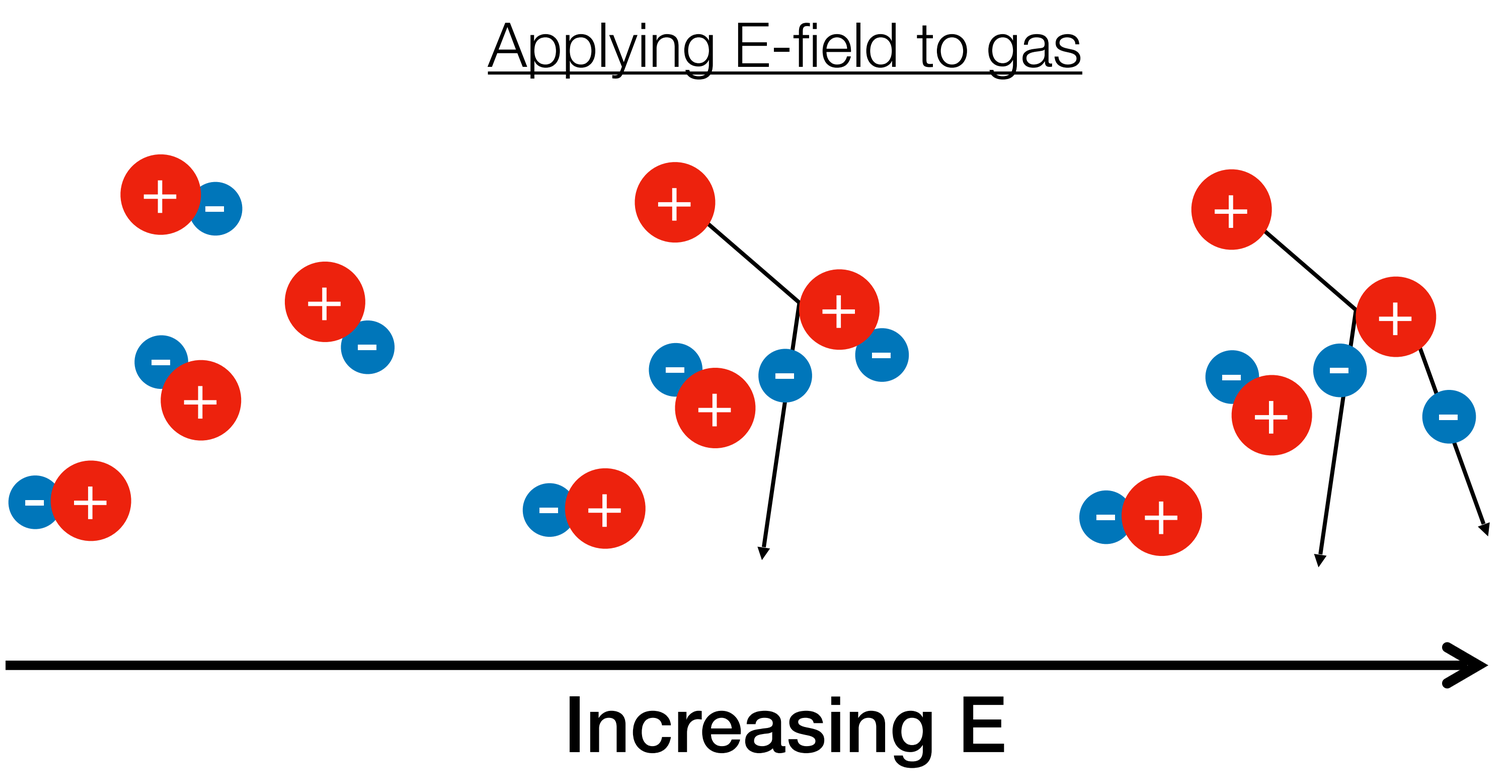
(16.6 eV)

$$\mathrm{Ne} + \mathrm{e}^- \rightarrow \mathrm{Ne}^* + 2\mathrm{e}^-$$

$$\mathrm{Ne}^* + \mathrm{Ar} \rightarrow \mathrm{Ne} + \mathrm{Ar}^+ + \mathrm{e}^-$$

(16.6 eV) (15.8 eV)

Sustaining Plasma



- When voltage is applied across the gas some electrons are freed
- Free electrons accelerate towards the anode
- If they accelerate enough, they may free other electrons when they collide with neutral atoms
- Simply: if $E[\#\text{additional ions}] > 1$ then an "avalanche" is achieved and many atoms are ionized
- Else if $E[\#\text{additional ions}] < 1$ then the gas remains mostly unionized

How Many Atoms Are Ionized?

Well, it depends on pressure…

Mean free path:

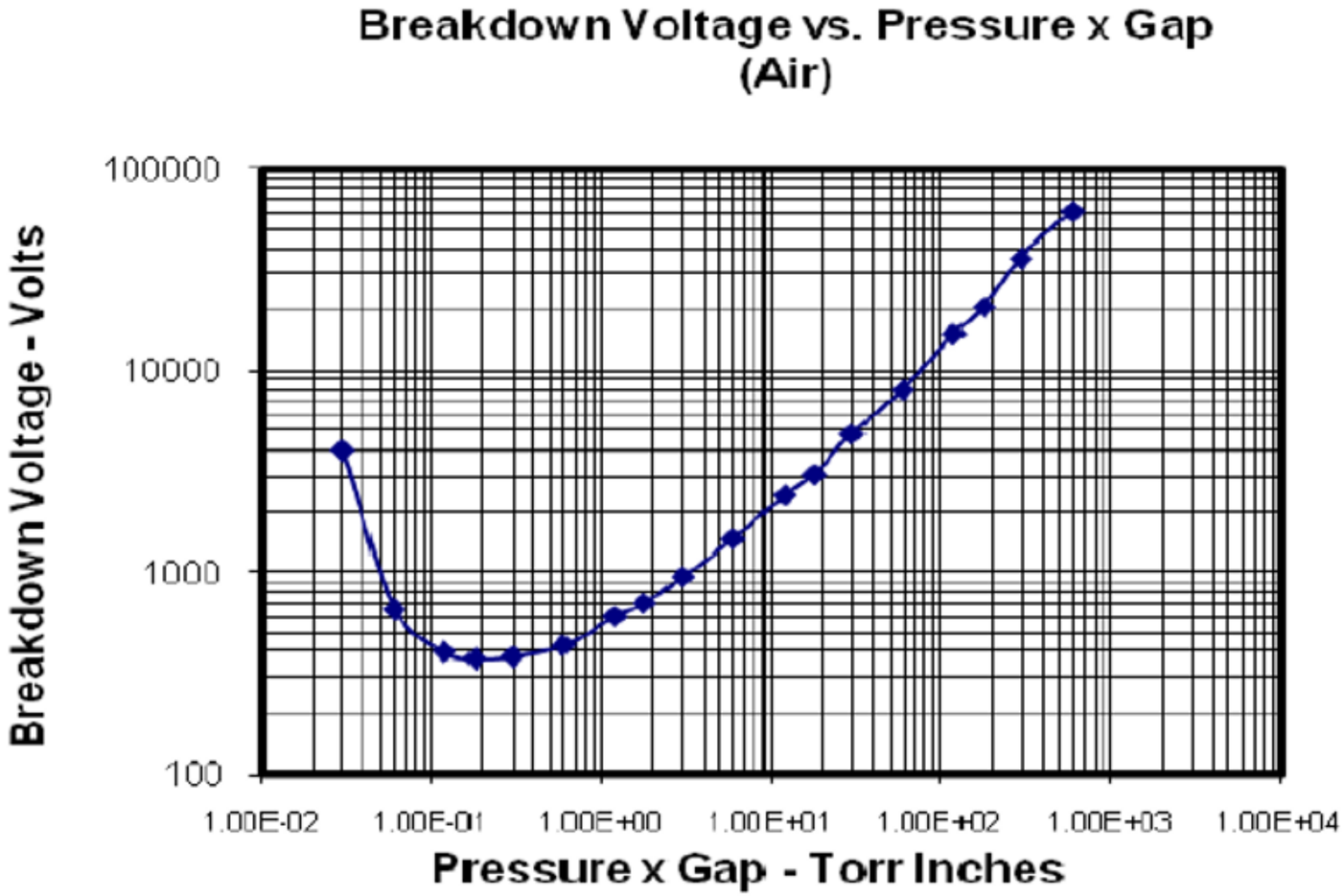
$$\lambda = \frac{RT}{\sqrt{2}\pi d^2 LP}$$

Pressure Fractions of Atm	Pressure	Number Density (cm^{-3})	Mean Free Path	Particle Flux (cm^{-2} sec^{-1})	Time - One Monolayer to stick	
1	760 torr	2.5×10^{19}	65 nm	2.9×10^{23}	3 nsec	
10^{-3}	.76 torr	2.5×10^{16}	65 microns	2.9×10^{20}	3 µsec	Rough pump
10^{-5}	7.6 mtorr	2.5×10^{14}	6.5 mm	2.9×10^{18}	300 µsec	
10^{-8}	7.6×10^{-6} torr	2.5×10^{11}	6.5 m	2.9×10^{15}	30 msec	HV
10^{-13}	7.6×10^{-11} torr	2.5×10^{6}	650 km	2.9×10^{10}	3.5 days	UHV

Credit: colorado.edu phys3340

Engineering Breakdown Field

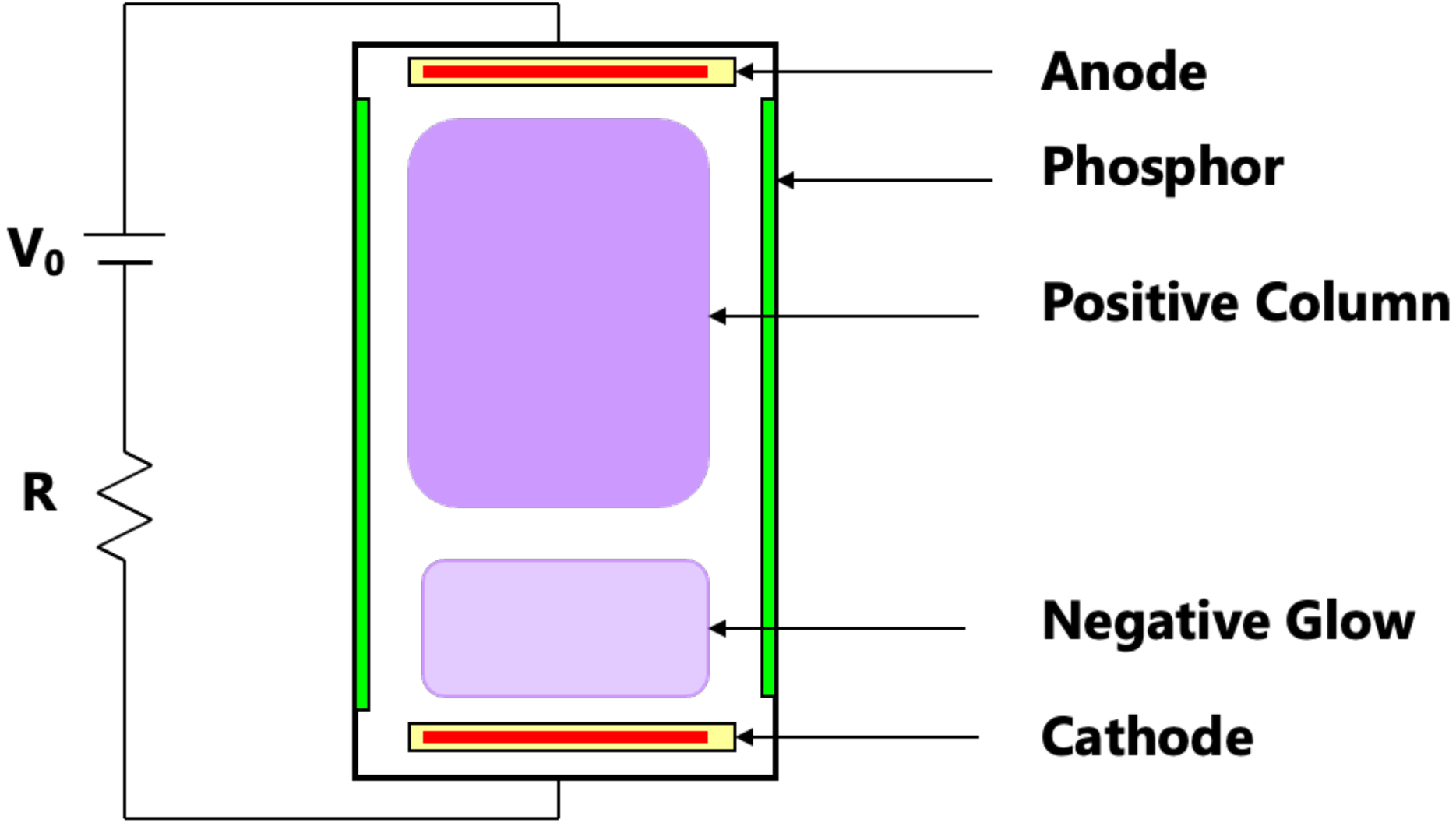
- Lower pressure means longer MFP → higher electron energy
- But lower pressure also means fewer atoms to collide with
- There is an optimal pressure (dependent on gap width) to balance this tradeoff
- This combination gives allows the plasma to strike at the lowest voltage



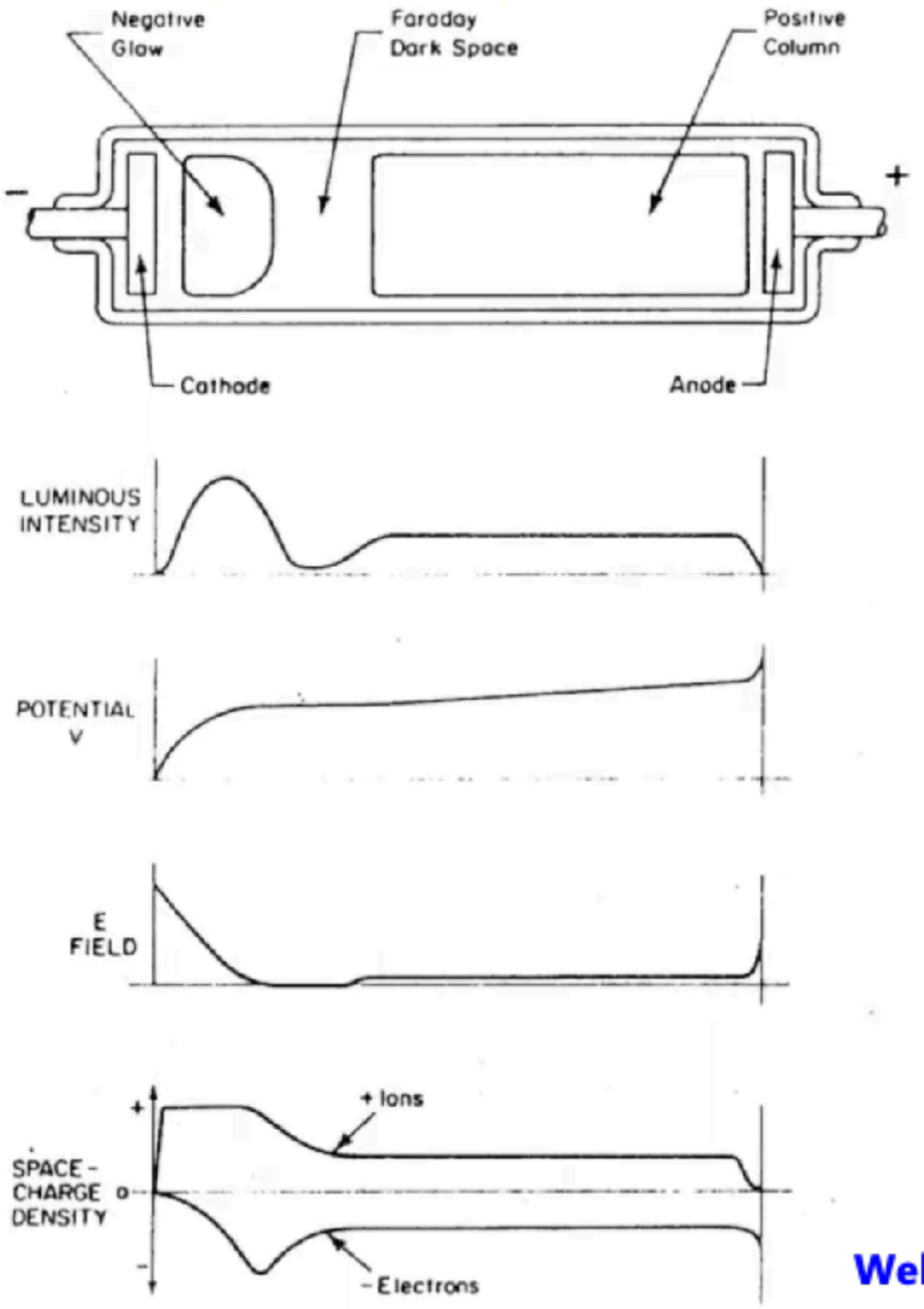
Credit: Duniway Stockroom

DC Plasma Cell Structure

- Recombination quenches glow at electrodes
- Positive column larger because $m_e \ll m_{ion}$
- Field is canceled between columns → third dark region



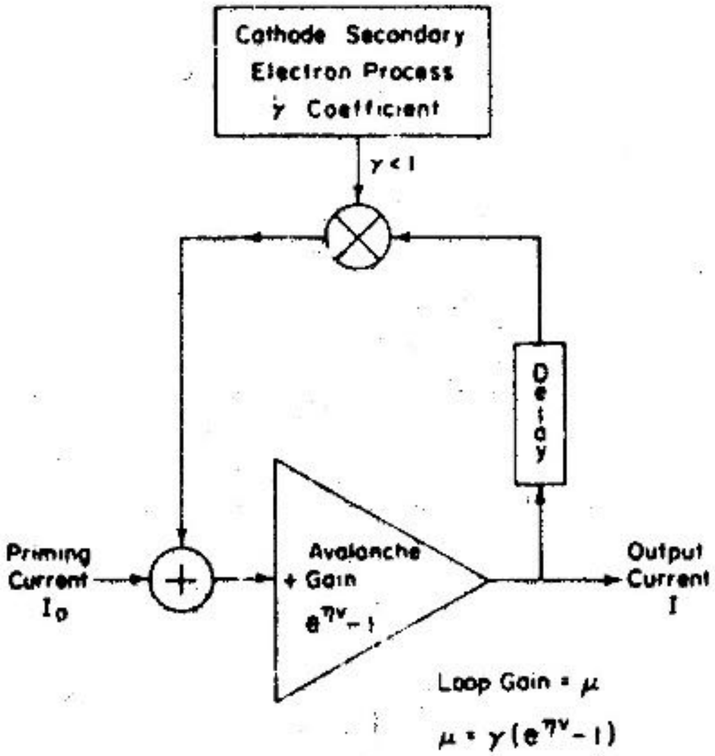
DC Plasma

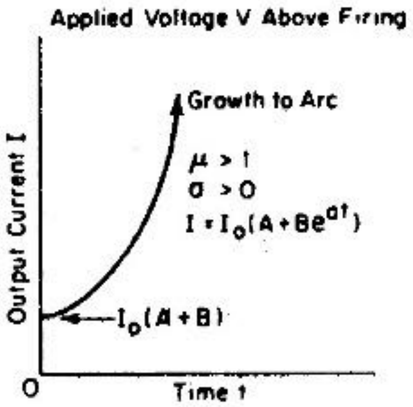


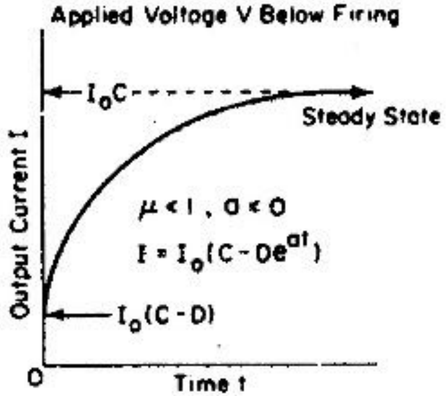
Weber, SID Seminar Notes, 1996

Feedback Model

- What is the current-voltage relationship across a plasma cell? Complicated…
- High R at low bias, low R at high bias
- It can be modeled as a positive feedback loop
- Below threshold → Stabilizes
- Above threshold → Exponential growth





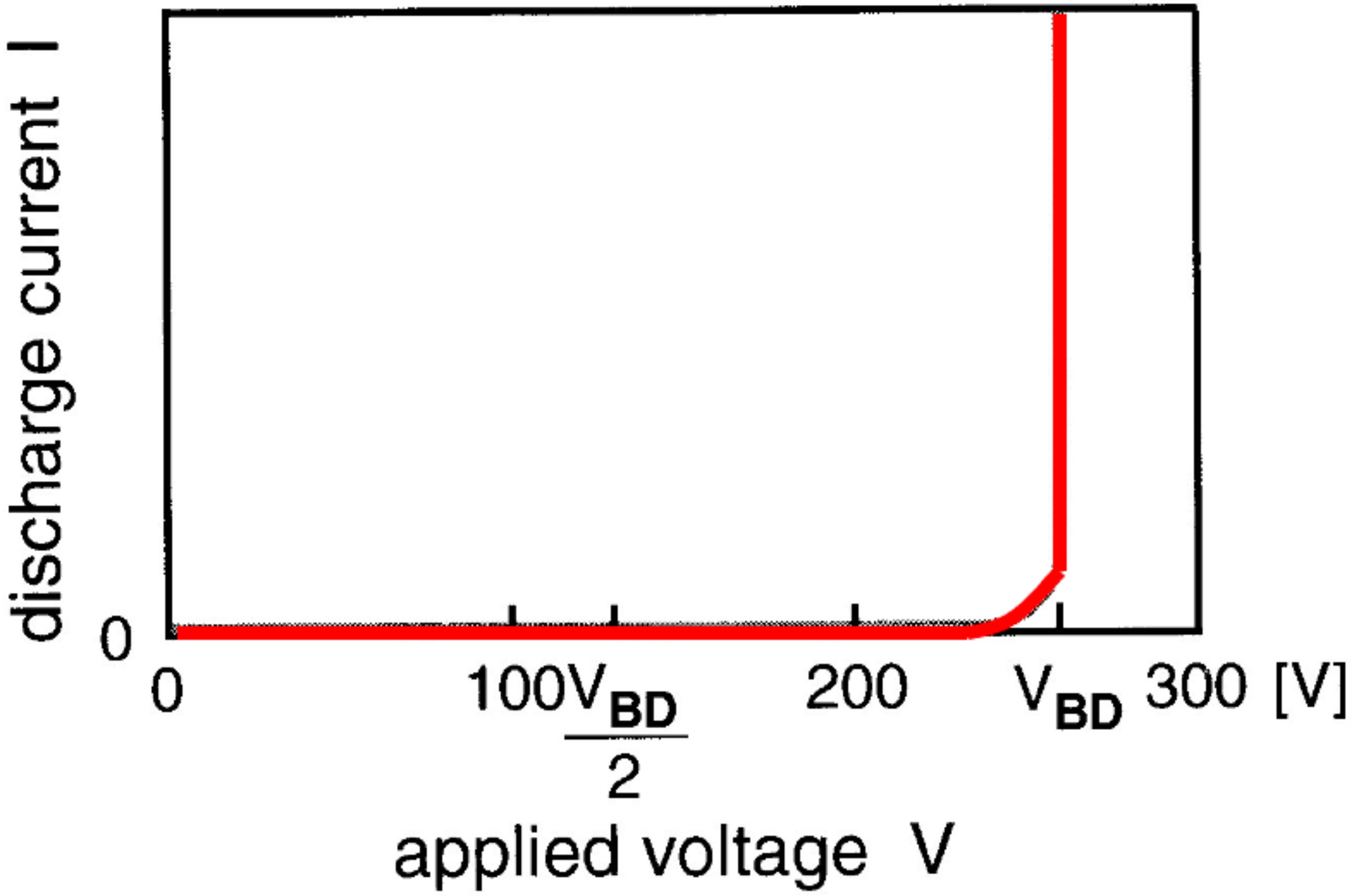


η=ionization coefficient
γ=secondary electron coefficient
μ=loop gain

Weber, SID Seminar Notes, 1996

Plasma Pixel I-V Characteristic

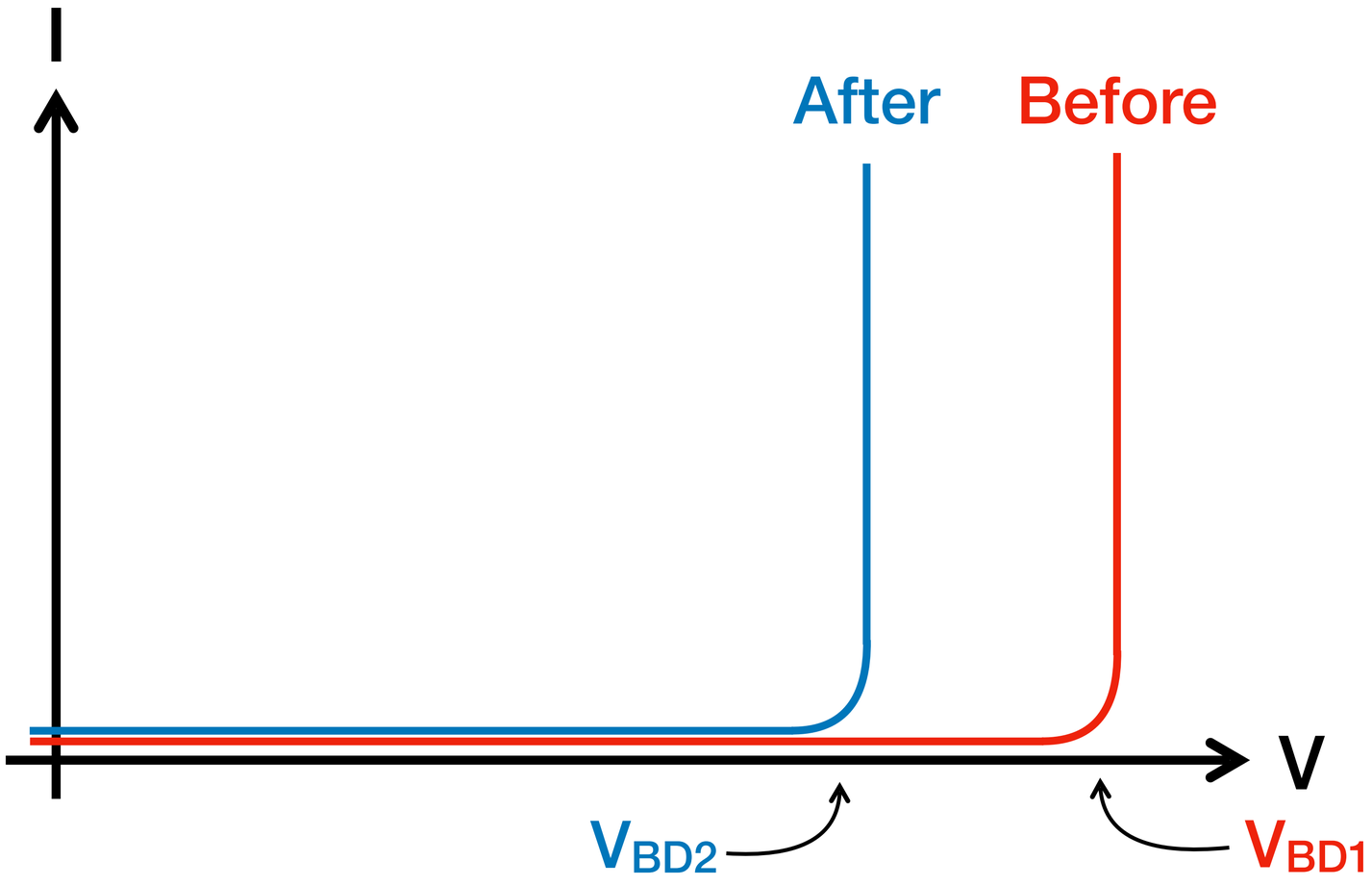
- Much more practically, it looks like this
- Effectively zero current until breakdown
- Then R goes to zero → Massive current



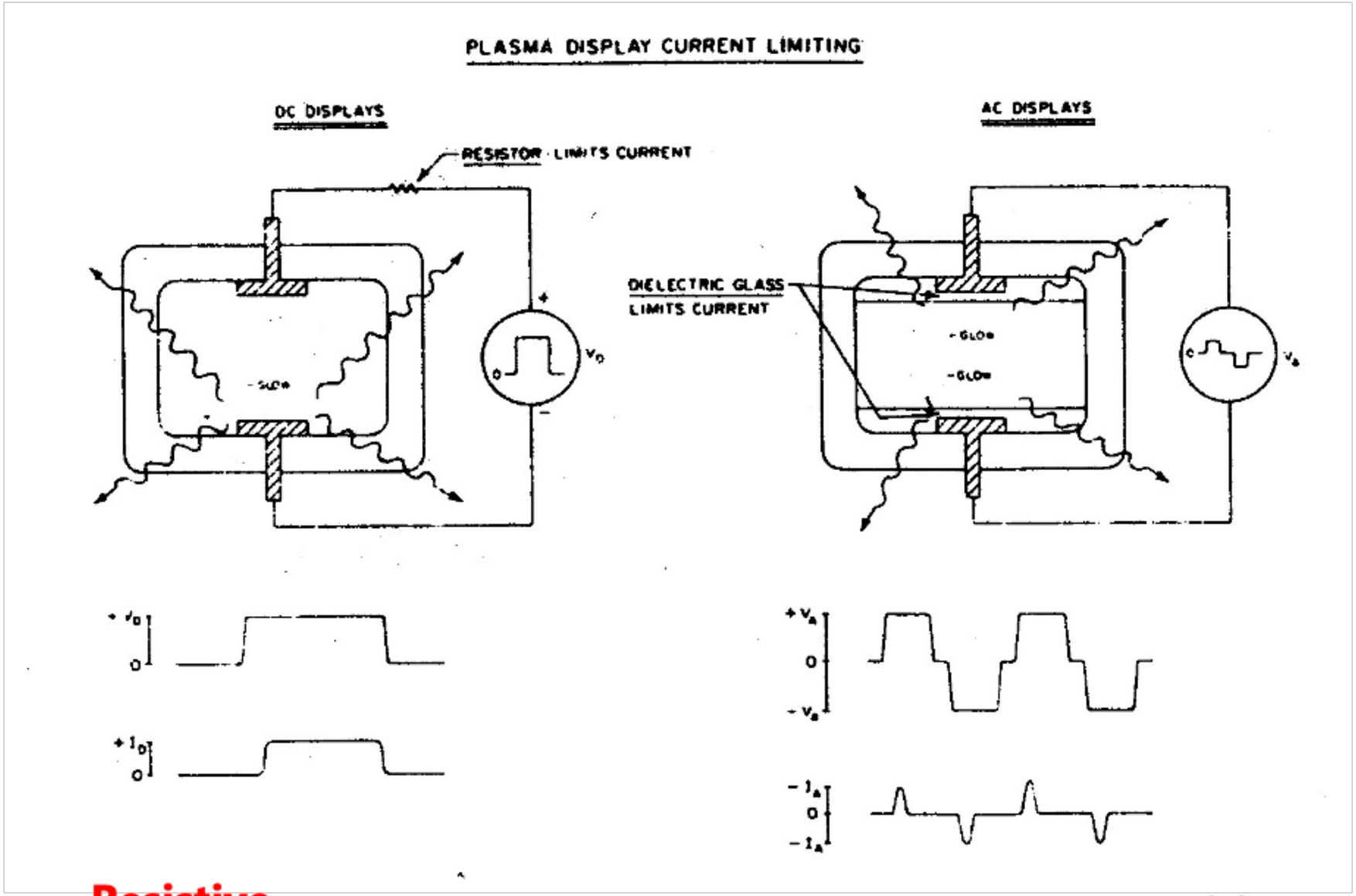
Mikoshiba, SID Seminar Notes, 2000

Voltage Priming

Breakdown voltage depends on priming…



Current Limiting Techniques



Resistive

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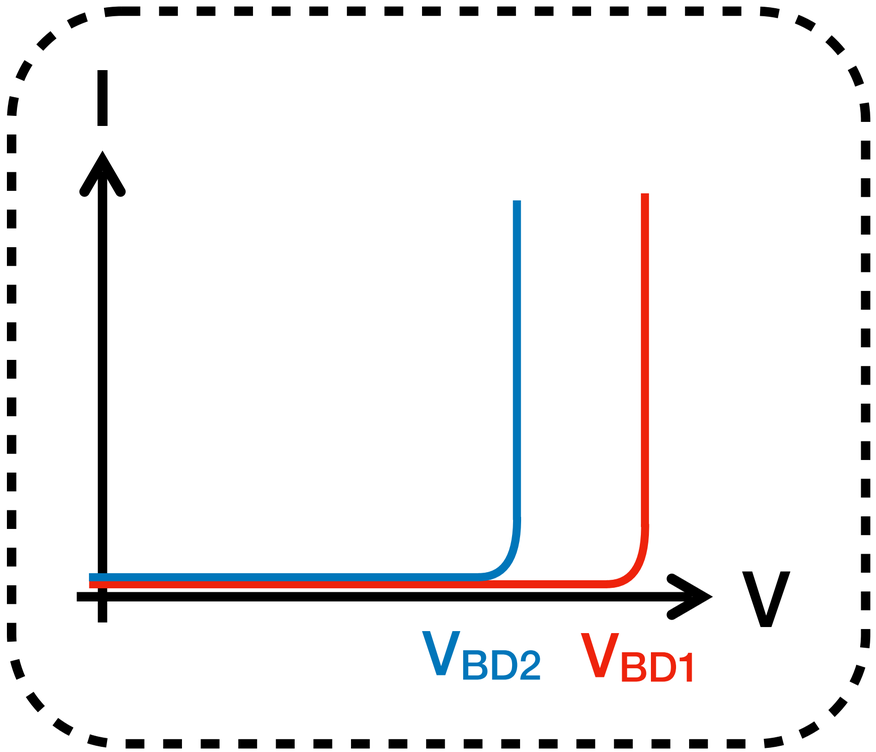
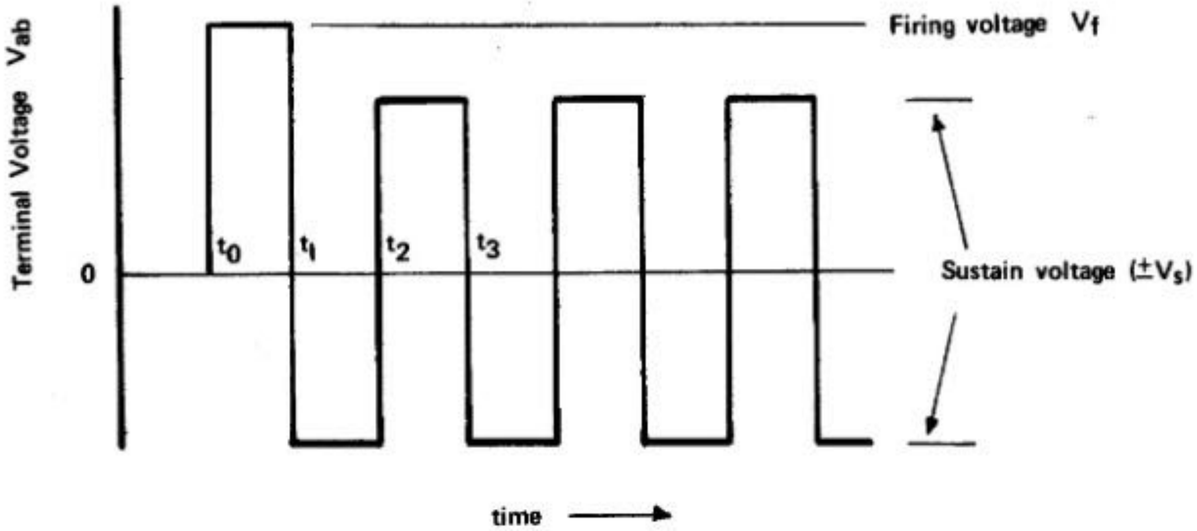
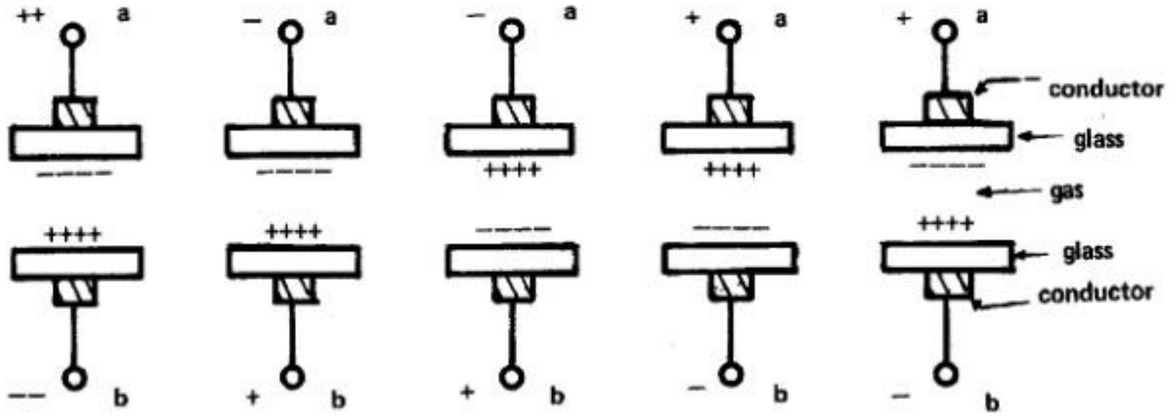
Capacitive

AC Plasma Cell Operation

Recall:







Firing of cell at t_0 and resultant wall charge

Polarity reversal at t_1

Wall charge after firing at t_1

Polarity reversal at t_2

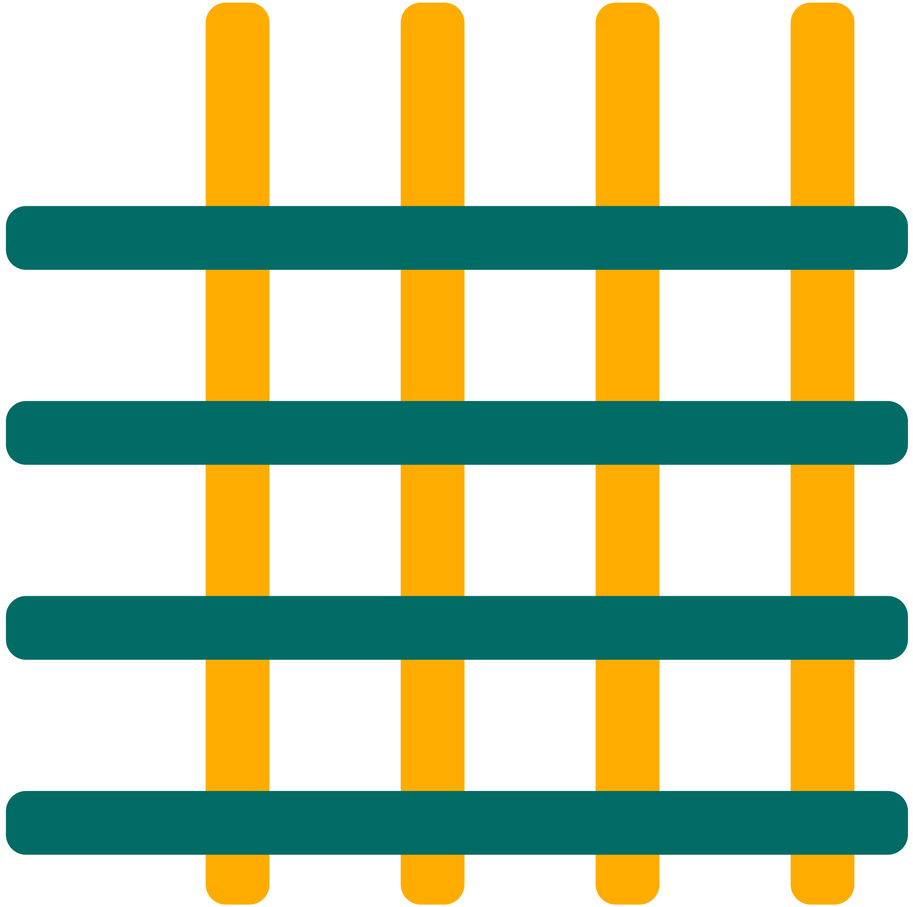
Wall charge after firing at t_2

Fig. 3.5. correspon

Credit: Peter Pleshko

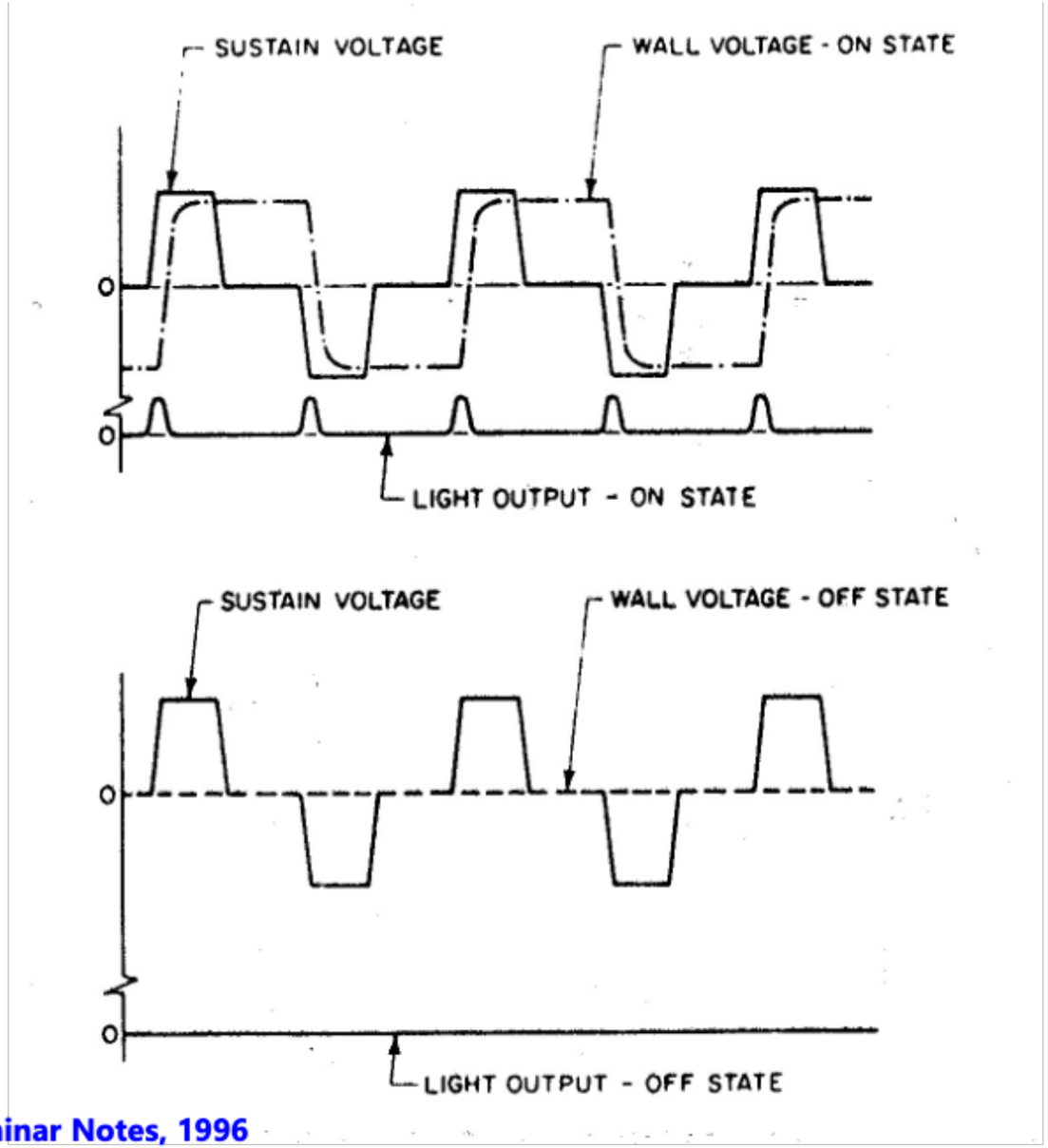
Plasma Display Addressing

- The plasma is non-linear
- Priming reduces the breakdown voltage
- These two facts allow us to create a really simple display



Light Output vs. Applied Voltage

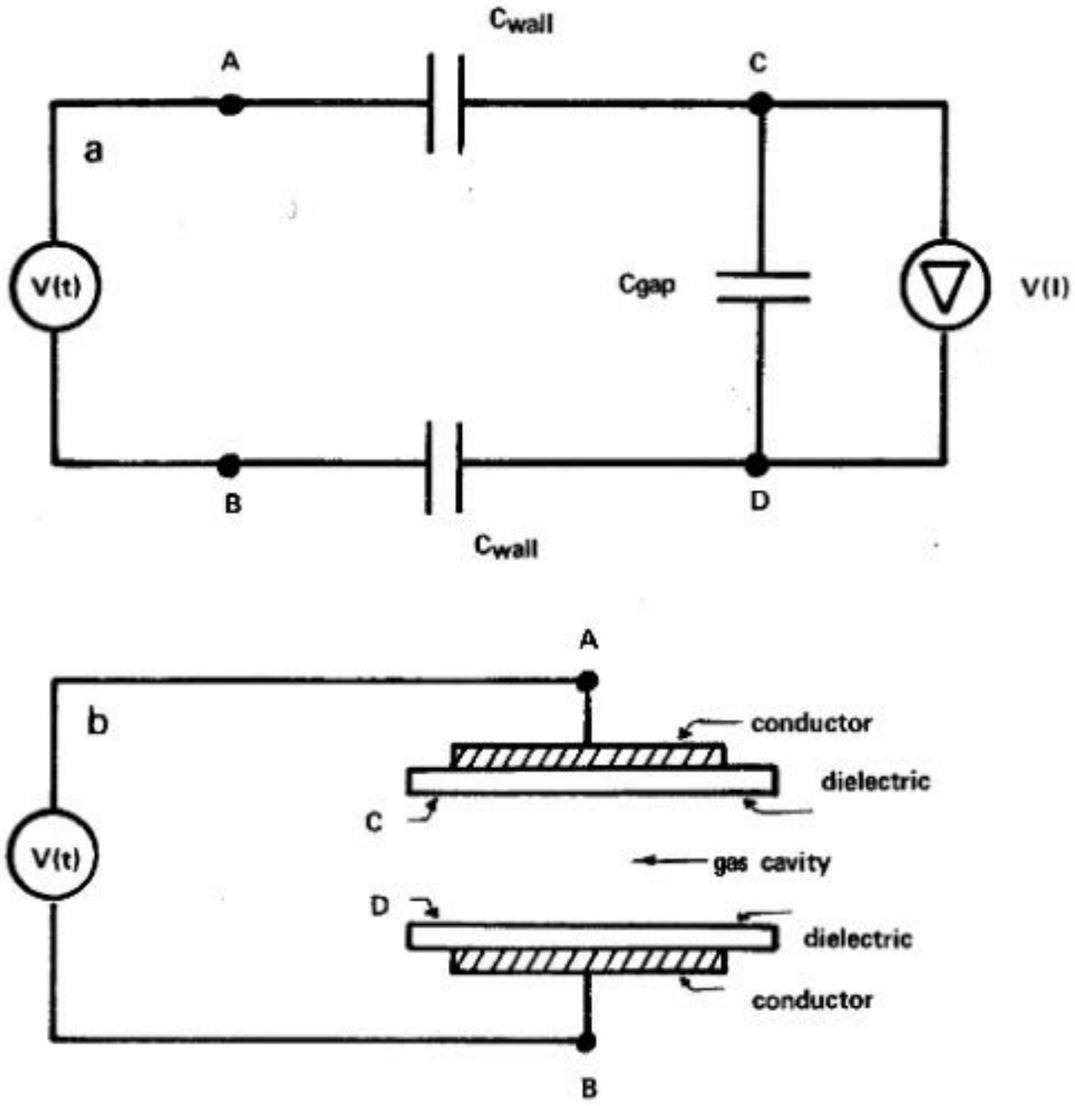
- Light output flashes briefly when voltage polarity inverts
- The device is essentially a giant RC network…
- The speed at which we can operate is determined by RC time constant of the passive, not physics of the plasma



Weber, SID Seminar Notes, 1996

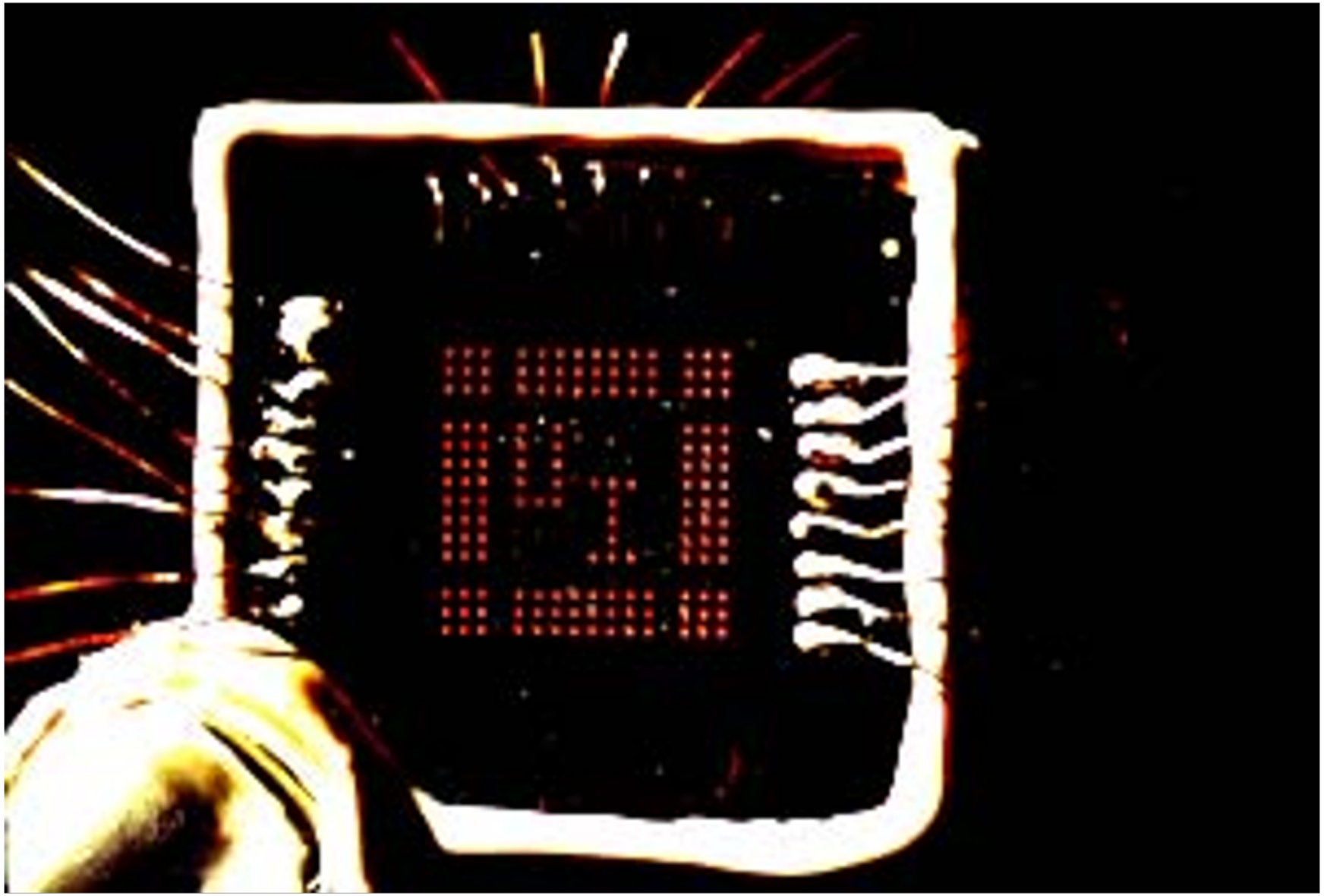
AC Plasma Cell Circuit Model

- This is the circuit model
- Capacitive coupling to the plasma
- Plasma represented as capacitor in parallel with zener diode for breakdown



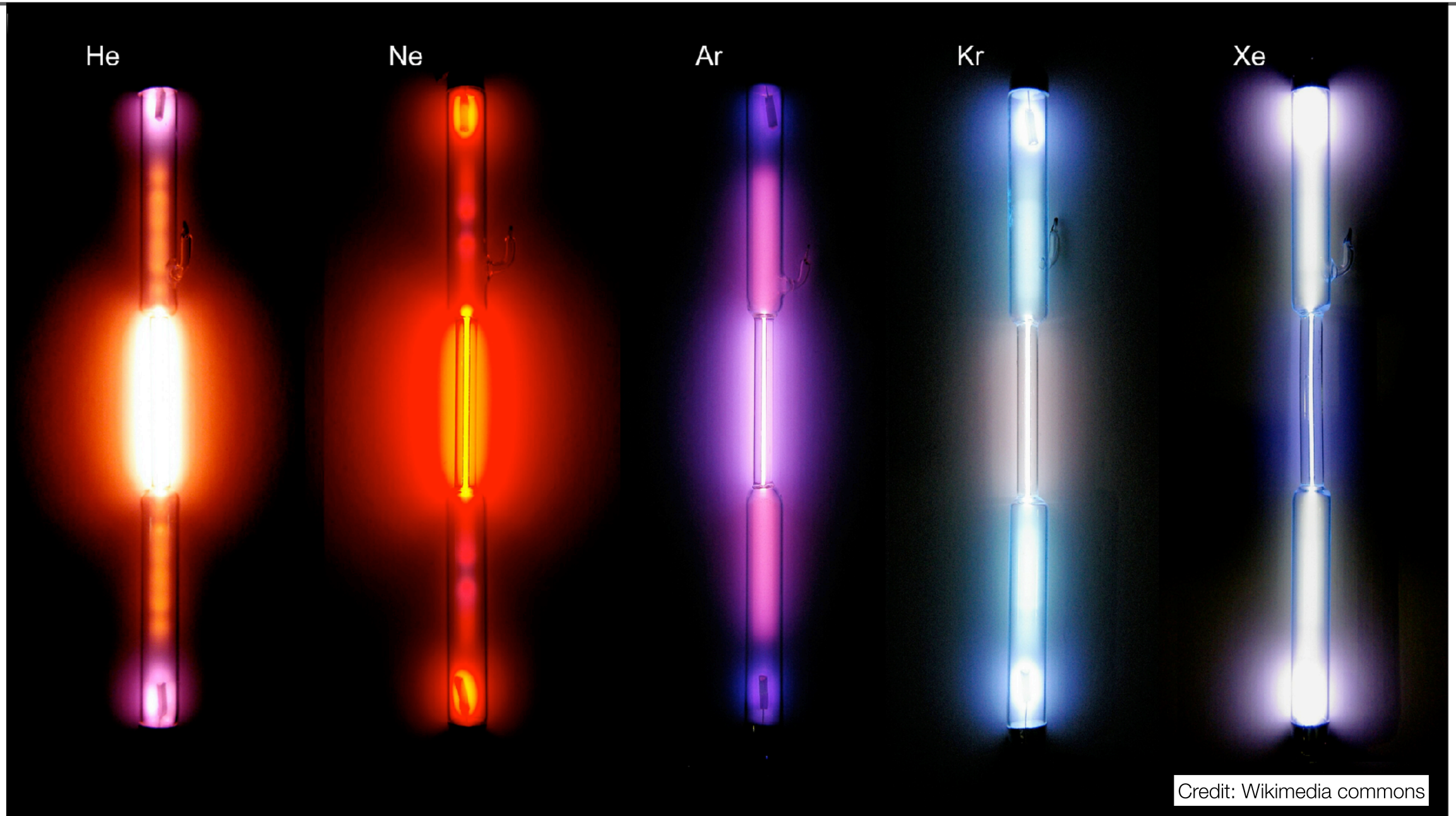
Credit: Peter Pleshko

The First Plasma Display (1967)



Credit: plasmatvscience.org

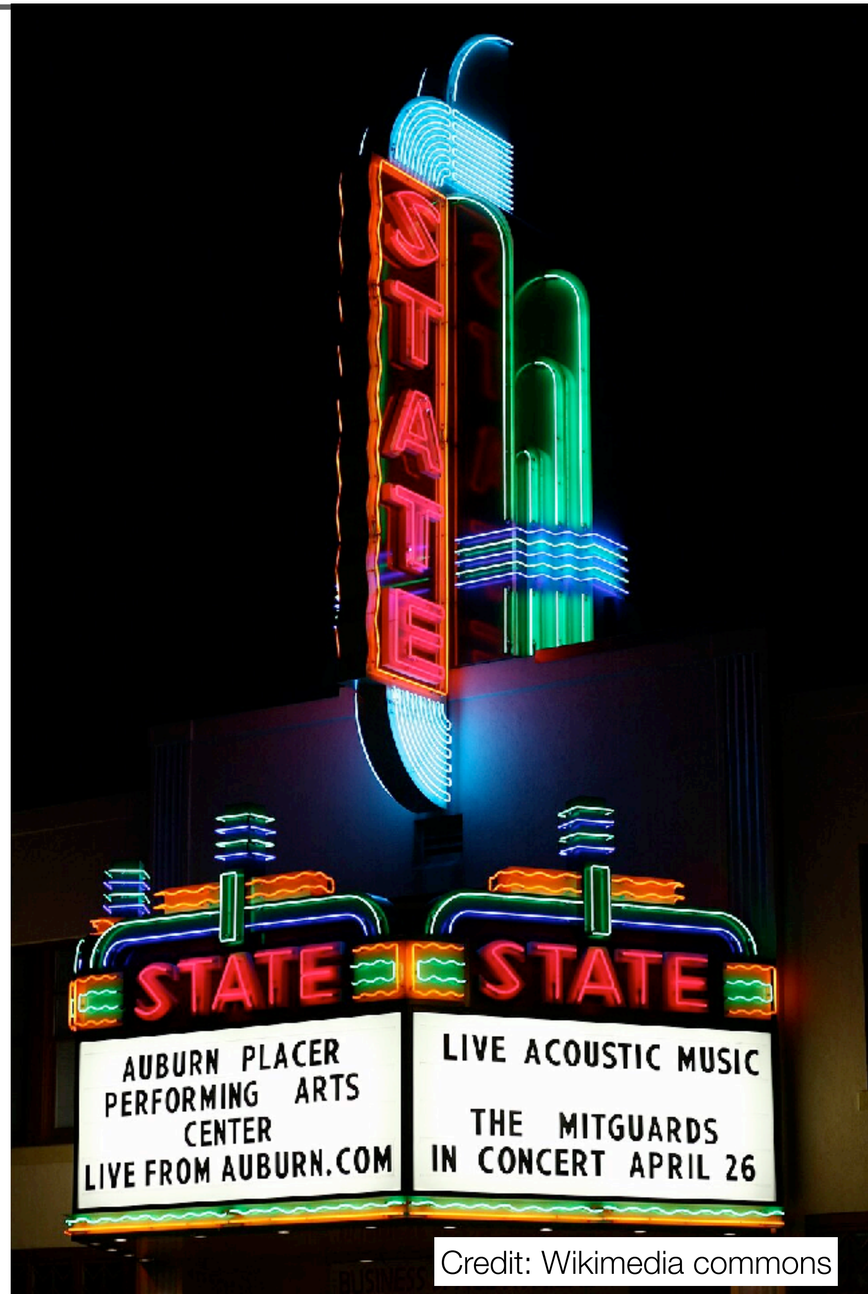
Noble Gas Plasma Discharge



Credit: Wikimedia commons

Color Plasma

- Neon emits is mostly red, but there are other options
- Different energy level structures in other gases allow for emission of different colors
- We can segment these into different sections



Credit: Wikimedia commons

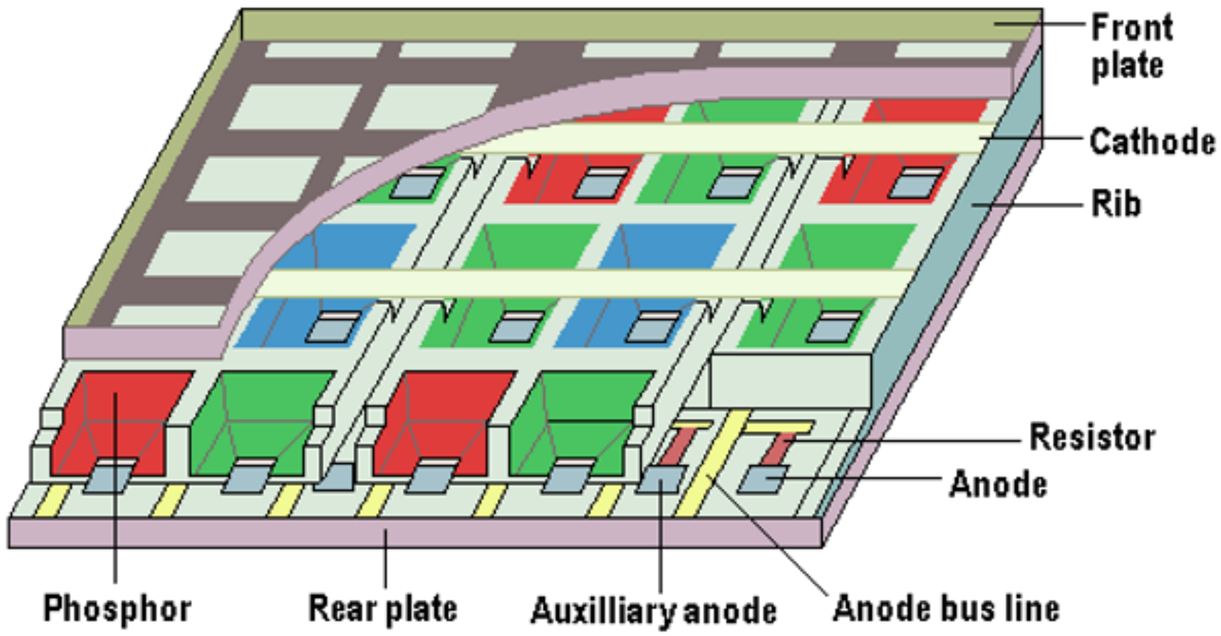
Color Plasma

Credit: CNN

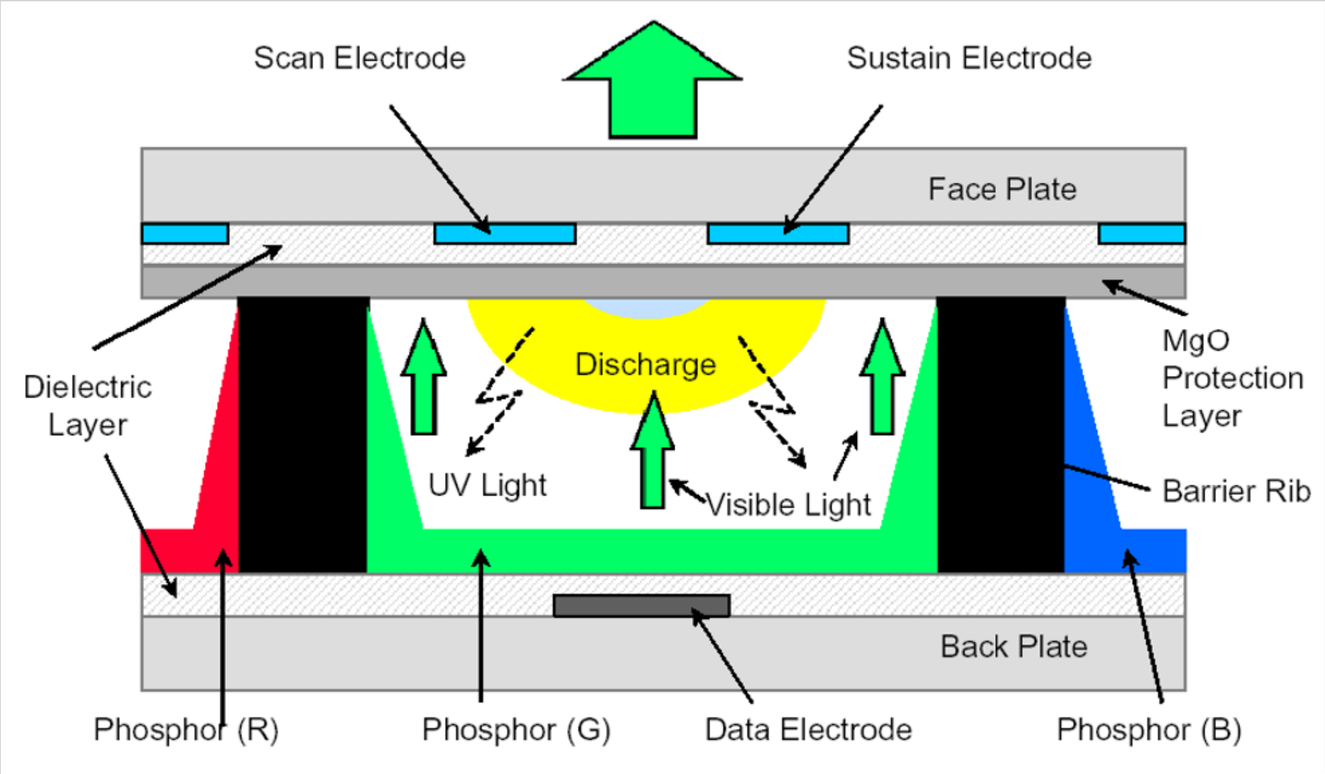
Full Color Plasma

- Neon orange is fine… but people want full color
- Filling each cavity with a different gas is troublesome… and the primaries aren't even that good
- The solution is to make a UV display and and cover each sub pixel in a different photoluminescent material

Basic Device Structure



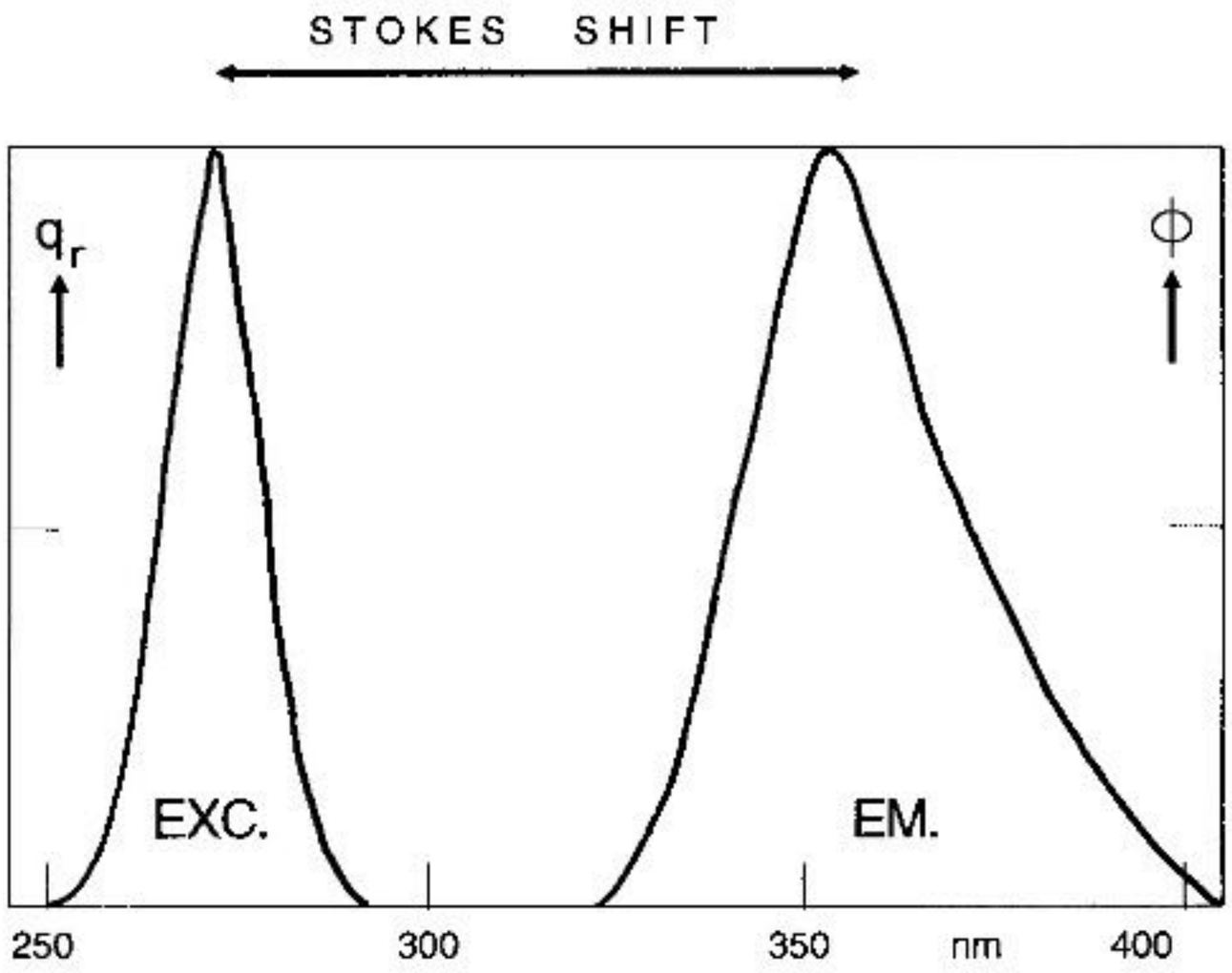
Plasma display cross section - Credit: pctechguide.com



Weber, SID '00 Digest p. 402

Does something about this scare you?

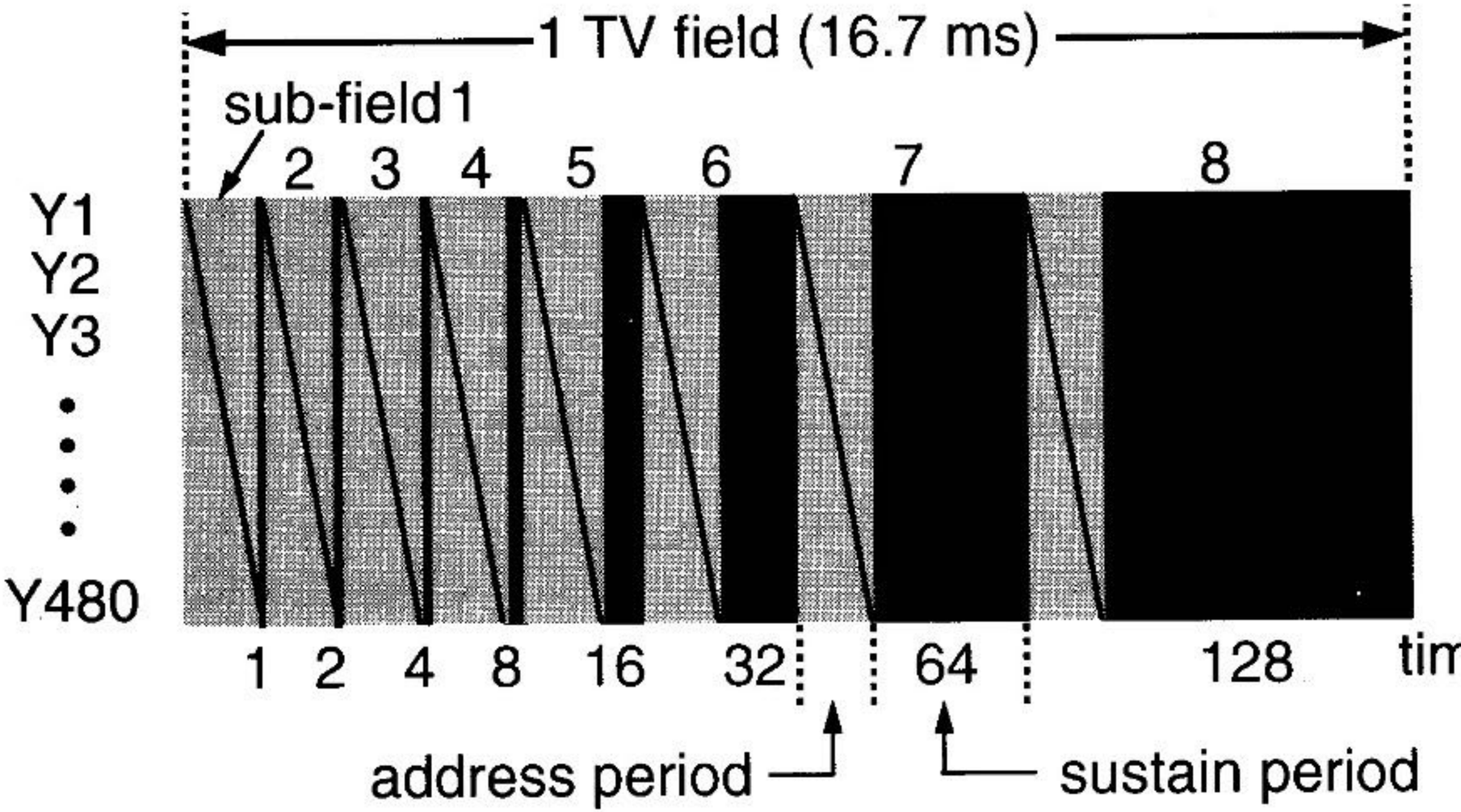
Phosphor Down-Conversion Concept



Blasse

Gray Scale Control with Plasma

- There's no halfway with plasma
- It either sparks or it doesn't
- To achieve grey scale, we need use a PWM-like technique
- This example demonstrates 8-bit gray scale via sub-field encoding



Mikoshiba, SID Seminar Notes, 2000

Efficiency Comparison

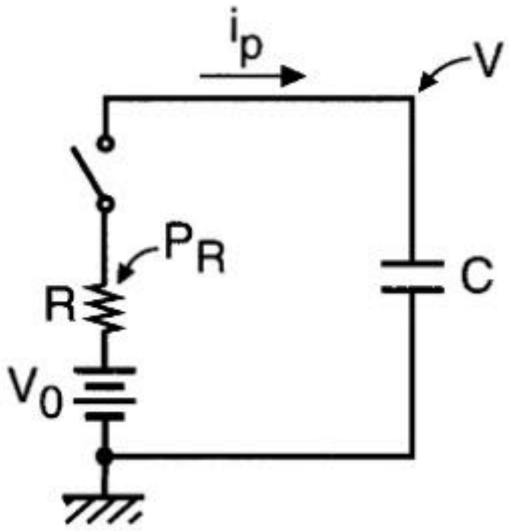
- As early as 2000, it was pointed out that PDP efficiency leaves a lot to be desired…
- Energy efficiency becomes a key focus for R&D departments

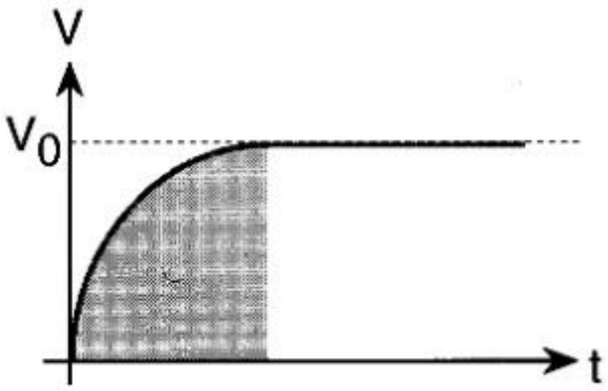
	PDP cell	fluorescent lamp
discharge eff. [%]	6	60
UV structure eff. [%]	40	90
phosphor eff. [%]	25	40
visible light stuct eff. [%]	40	90
global efficiency		
in energy units [%]	0.25	20
in photometry units [lm/W]	1.2 (for green)	60 (for white)

Mikoshiba, SID Seminar Notes, 2000

Power Dissipation

- **Problem:** PDP is a giant array of capacitors
- We have to charge/discharge all of them at 60 Hz
- Firing/sustain voltages for the plasma are ≈100 V
- Result: PDP power consumption is enormous.
- Electricity cost of running it was not insignificant





$$P_R(R\text{–}C) = \frac{CV_0^2}{2}$$

$$i_p(R\text{–}C) = \frac{V_0}{R}$$

Stray Capacitance, C = 1 μF
Drive Voltage, V= 100 V
Data Rate, f=100kHz

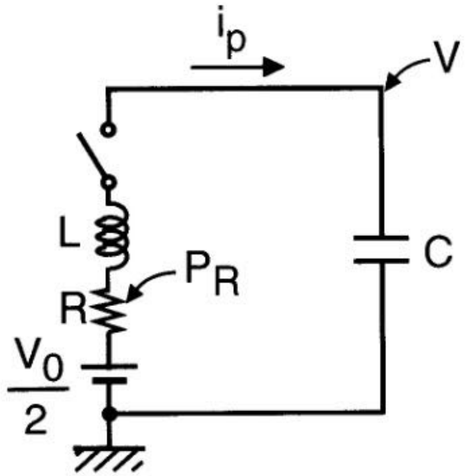
$$\mathbf{P_D = fCV^2 = 1\,kW}$$

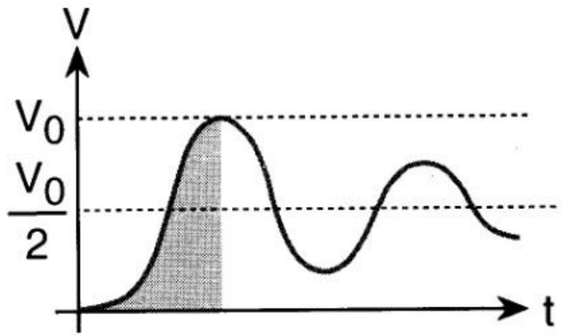
For a 40 inch, 1080p display

Mikoshiba, SID Seminar Notes, 2000

RLC Resonant Circuit

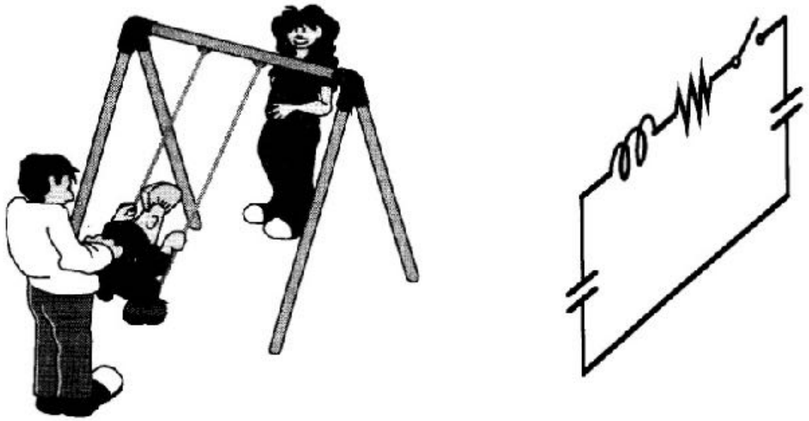
- One way to mitigate this is to introduce some regenerative energy storage
- We can do this by adding an inductor to the circuit
- Creates and RLC resonant circuit where the energy is stored in the inductor when the capacitor discharges
- About 2x power efficiency benefit compared to discharging to ground
- Allowed PDP power to decrease to around 300W





$$\frac{P_R(R\text{–}L\text{–}C)}{P_R(R\text{–}C)} = \frac{\pi R}{4}\sqrt{\frac{C}{L}} \approx \frac{1}{40}$$

$$\frac{i_p(R\text{–}L\text{–}C)}{i_p(R\text{–}C)} = \frac{R}{2}\sqrt{\frac{C}{L}} \approx \frac{1}{60}$$

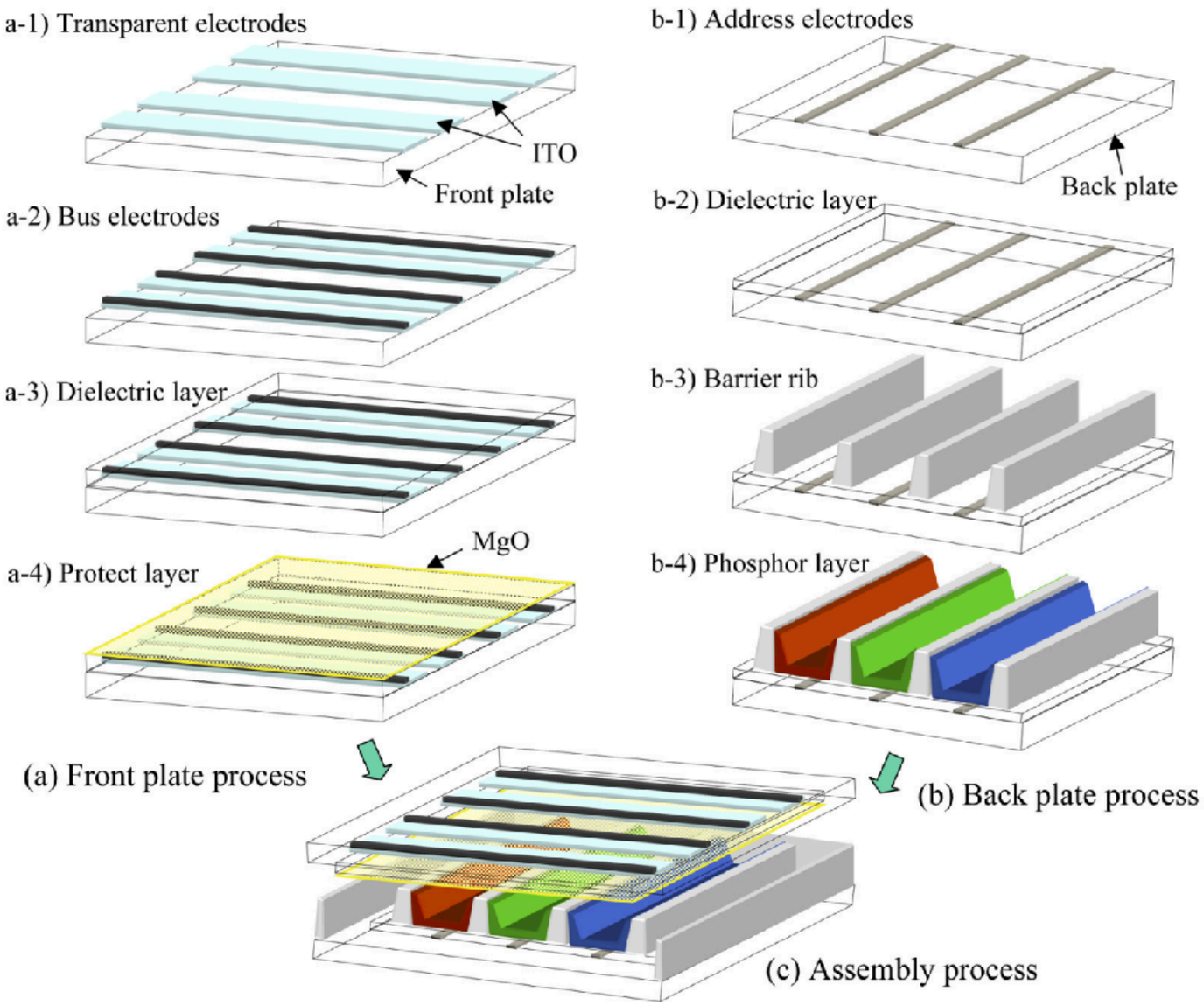


potential energy ⟷ electrostatic energy

kinetic energy ⟷ electromagnetic energy

Fabrication

- Plasma display fabrication is more similar to a PCB process than a semiconductor process
- Take two glass plates
- Pattern electrodes on each
- Sandblast rib shape onto one
- Evacuate the atmosphere, refill with Xe, then seal plates together
- This scaled really well



Credit: Shinoda et al. in *IEEE Transactions on Plasma Science* 2006

What Were Plasma Displays Like?

Credit: Wikimedia Commons

Credit: NBC News

What Were Plasma Displays Like?

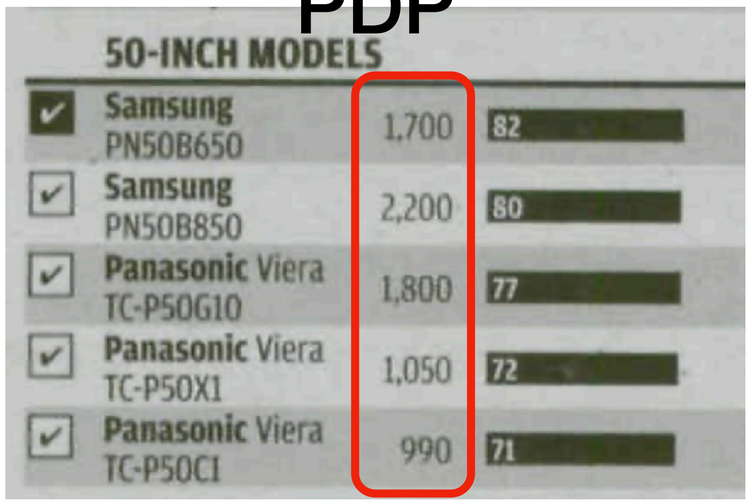
Source unknown…

World Record Largest PDP

- This was plasma's claim to fame → First display technology to achieve this scale
- 150 inches diagonal
- 7 kW
- 1700 lbs or 770 kg
- Motherglass of 9 50" panels
- Rumor has it that only 6 were ever manufactured…

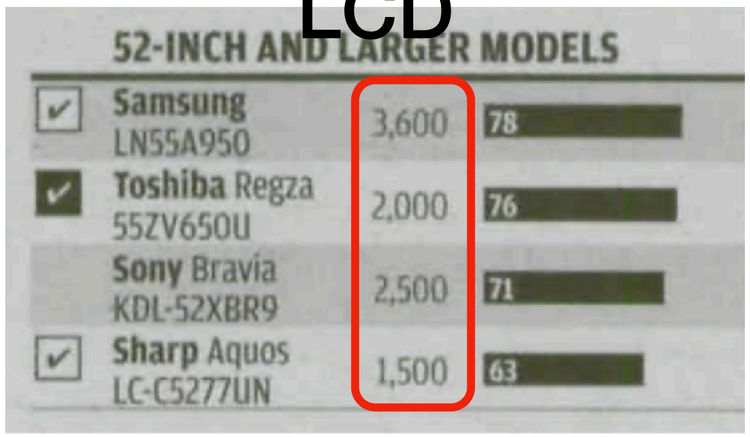
PDP vs. LCD Cost

PDP



50-INCH MODELS		
✔ Samsung PN50B650	1,700	82
✔ Samsung PN50B850	2,200	80
✔ Panasonic Viera TC-P50G10	1,800	77
✔ Panasonic Viera TC-P50X1	1,050	72
✔ Panasonic Viera TC-P50C1	990	71

LCD



52-INCH AND LARGER MODELS		
✔ Samsung LN55A950	3,600	78
✔ Toshiba Regza 55ZV650U	2,000	76
Sony Bravia KDL-52XBR9	2,500	71
✔ Sharp Aquos LC-C5277UN	1,500	63

Credit: Consumer Reports, 2010

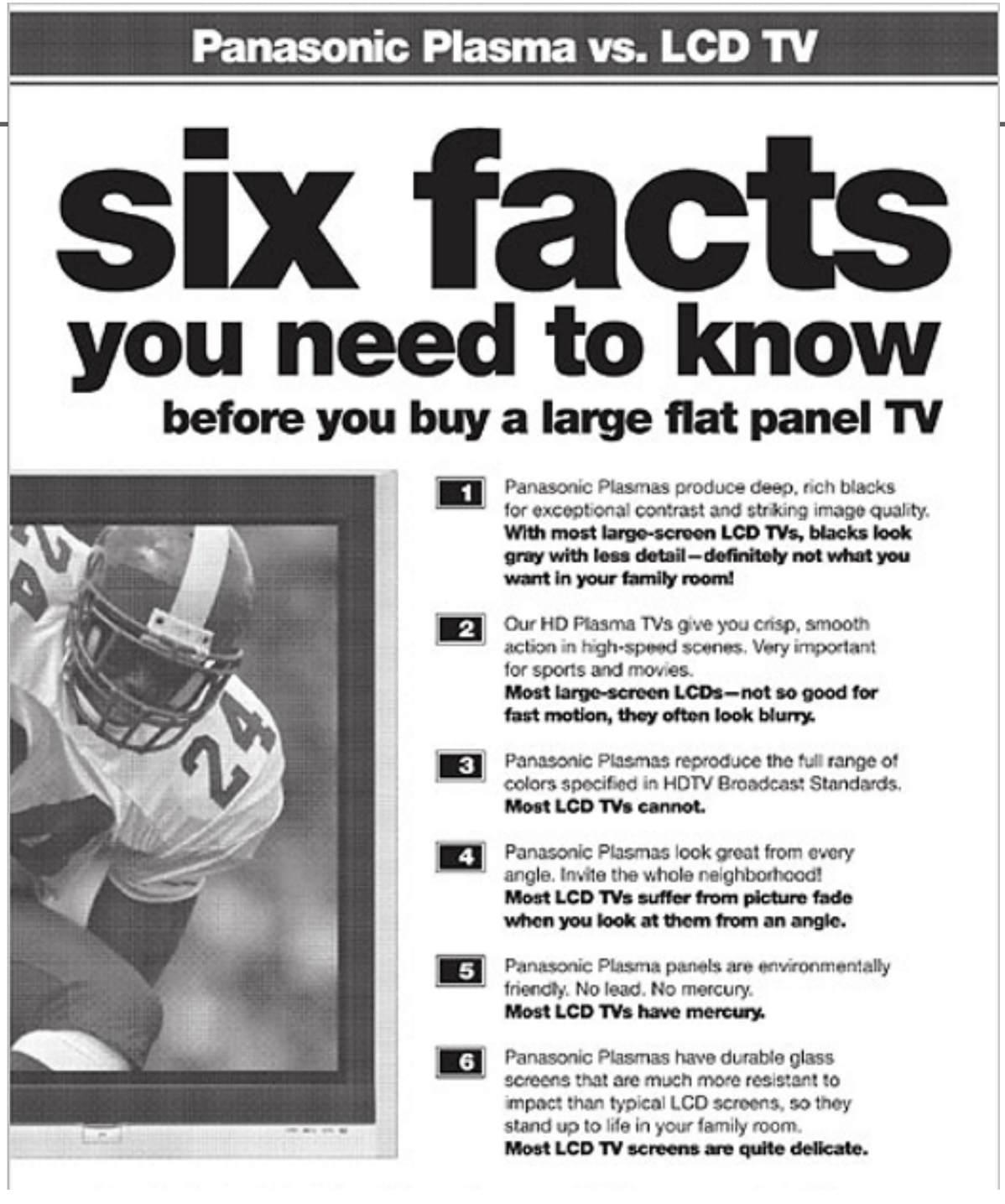
2010 → 2016

As LCD manufacturing matured, it got a lot cheaper….

Credit: Walmart Black Friday Brochure 2016

PDP vs. LCD Performance

- LCD price was falling faster than plasma
- PDP manufacturers start releasing this kind of ad
- LCD slowly chipped away at these advantages


Panasonic Plasma vs. LCD TV

six facts you need to know

before you buy a large flat panel TV

1 Panasonic Plasmas produce deep, rich blacks for exceptional contrast and striking image quality. **With most large-screen LCD TVs, blacks look gray with less detail—definitely not what you want in your family room!**

2 Our HD Plasma TVs give you crisp, smooth action in high-speed scenes. Very important for sports and movies. **Most large-screen LCDs—not so good for fast motion, they often look blurry.**

3 Panasonic Plasmas reproduce the full range of colors specified in HDTV Broadcast Standards. **Most LCD TVs cannot.**

4 Panasonic Plasmas look great from every angle. Invite the whole neighborhood! **Most LCD TVs suffer from picture fade when you look at them from an angle.**

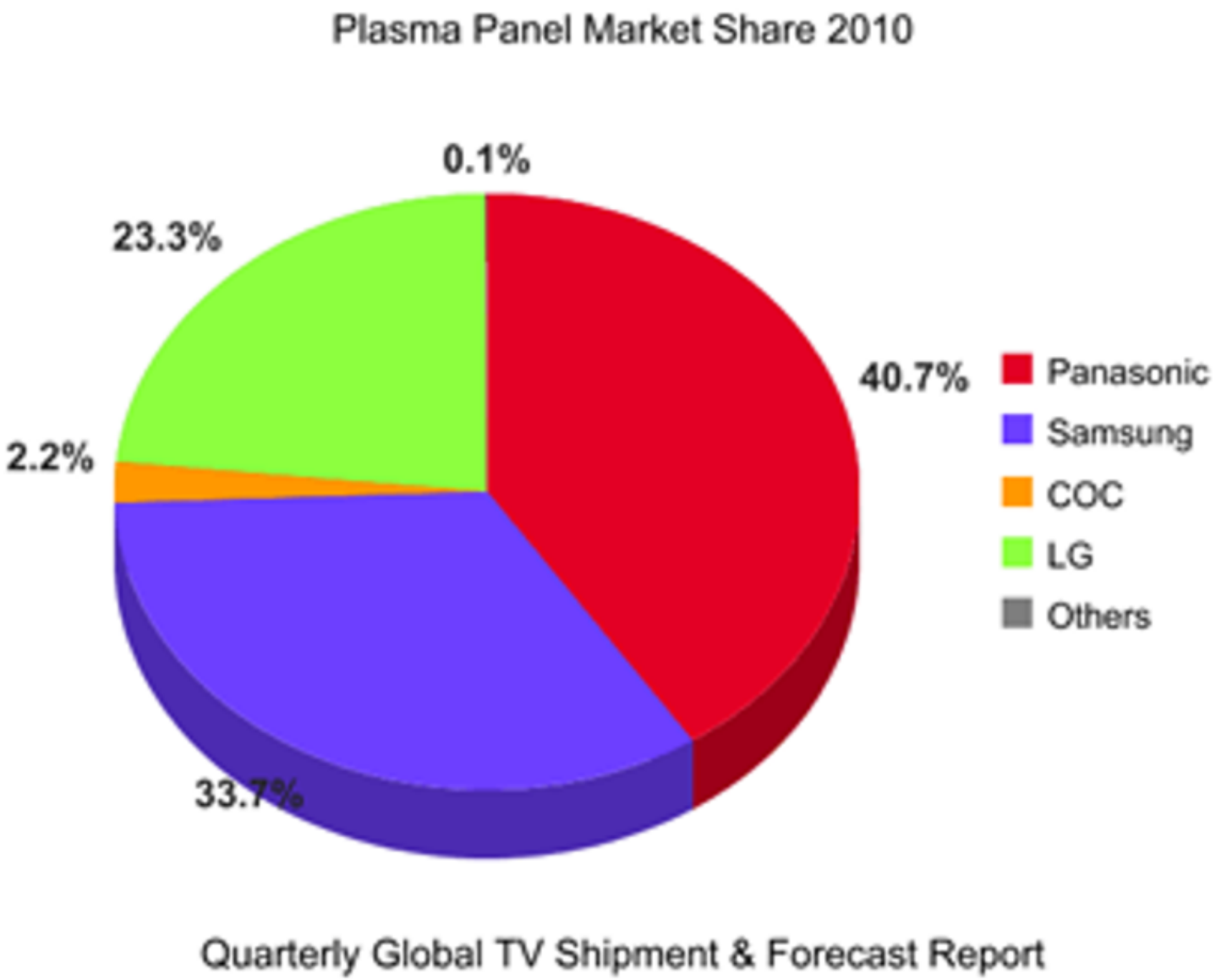
5 Panasonic Plasma panels are environmentally friendly. No lead. No mercury. **Most LCD TVs have mercury.**

6 Panasonic Plasmas have durable glass screens that are much more resistant to impact than typical LCD screens, so they stand up to life in your family room. **Most LCD TV screens are quite delicate.**

Credit: The New York Times

State of The PDP Industry - 2010

- Panasonic (Japan) was the largest manufacturer of PDPs
- Samsung and LG (South Korea) were also very large suppliers
- COC (China) was also significant



State of The PDP Industry - 2014

Display Daily

Empowering display industry professionals with cutting-edge insights and analysis

LG to End PDP Production This Month

November 2, 2013

Forbes

LIFESTYLE > TRAVEL

Panasonic To Exit The Plasma HDTV Business

By Geoffrey Morrison, Former Contributor. ⓘ Geoffrey Morrison is a travel writer and digital nomad.

Published Oct 31, 2013, 01:46pm EDT, Updated Oct 31, 2013, 06:44pm EDT

Samsung to end plasma TV production this year

Following in the footsteps of Panasonic, Samsung says it will end production of plasma display panels by the end of this year.

David Katzmaier

July 1, 2014 12:19 p.m. PT

2 min read

By 2014, Panasonic, LG, and Samsung are all out of the game

Briefly, The Market Leader…

虹欧 Creator Of Colourful Lives | Sichuan COC Display Devices Co., Ltd.

"While two dogs fight for a bone, a third dog can run away with it"

鹬蚌相争，渔人得利

The Race to Zero…

Credit: displaysearch.com

A Very Brief History…

Tsutae Shinoda

Larry Weber

Summary

- Color plasma display panels (PDPs) are photoluminescent
- Generate UV light using an array of miniature plasma discharge cells
- Color is achieved through photoluminescent phosphors
- The nonlinearity of the plasma cell I-V characteristic allows for simple addressing and memory affects
- These advantages briefly led PDPs to being the dominant high-end display technology
- However, they could never solve problems with power efficiency, weight, white point shift
- LCD now dominates low-cost segments, OLED dominates the premium segments