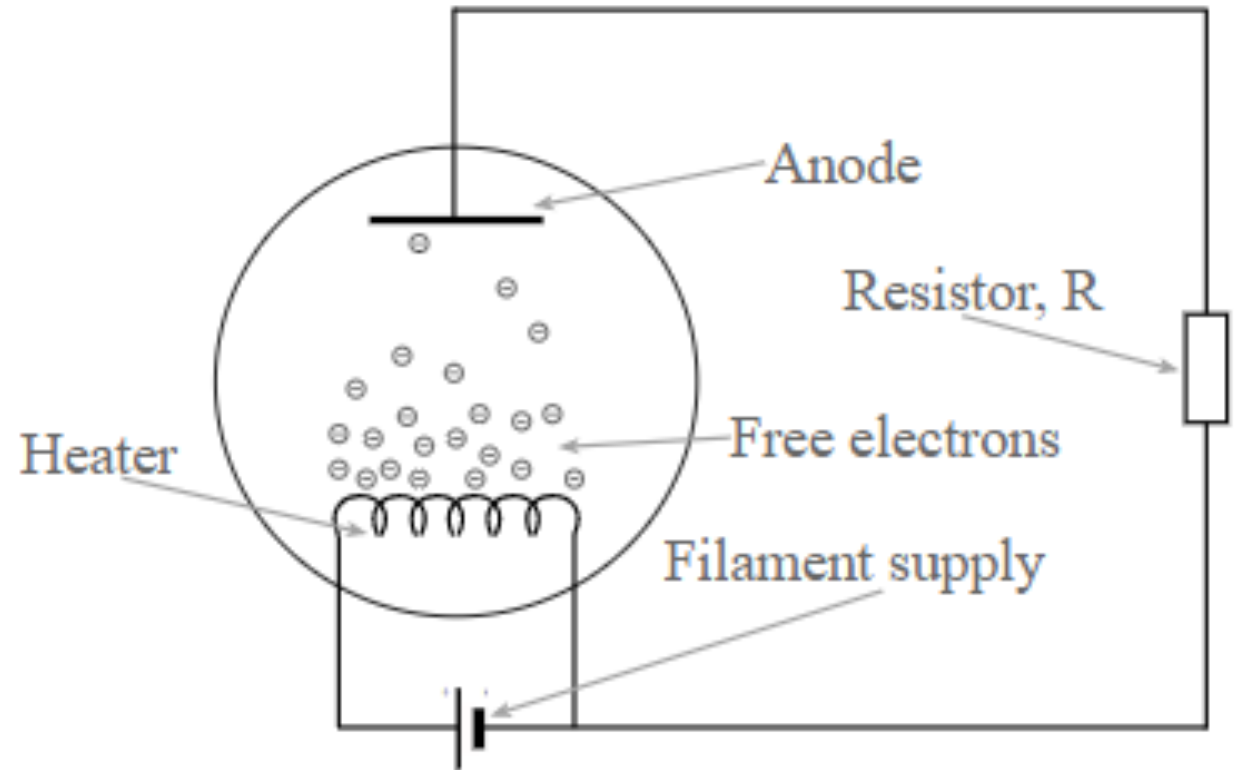


Light Emitting Diodes (LED)

MARC BERNHARDT

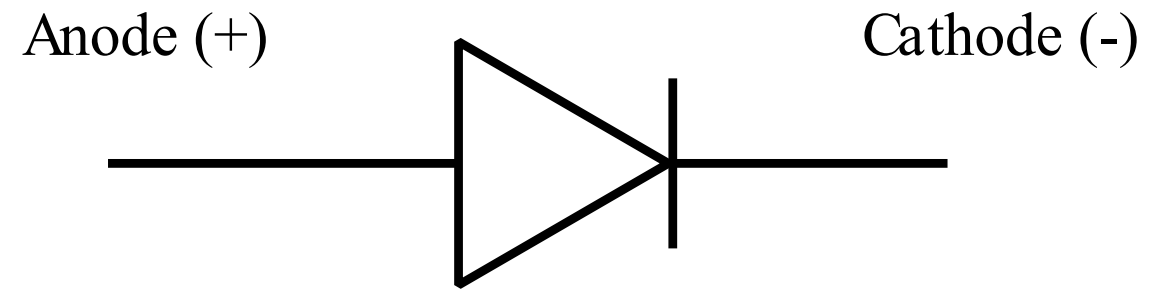
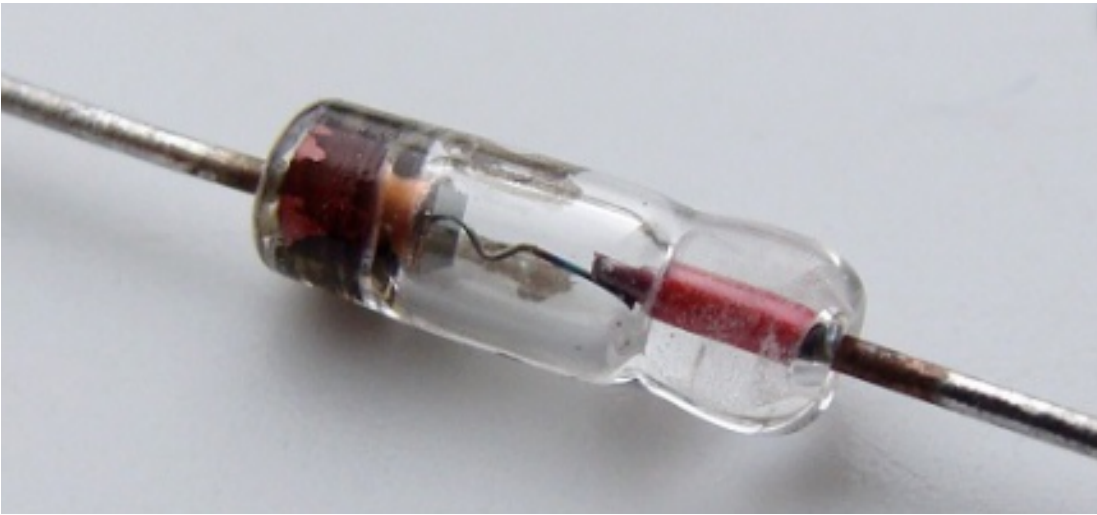
Vacuum Tube Diode



Electrons “boil off” from the heater (cathode) and flow to the anode.

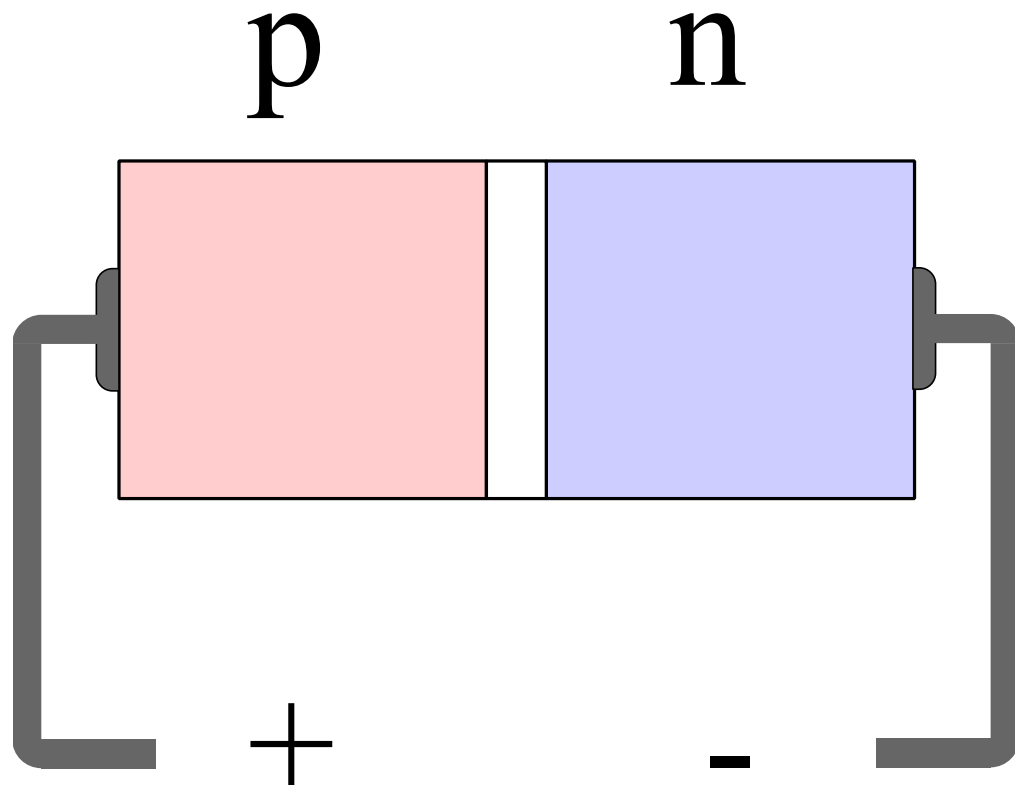
Current can only flow from the anode to the cathode.

Semiconductor Diode

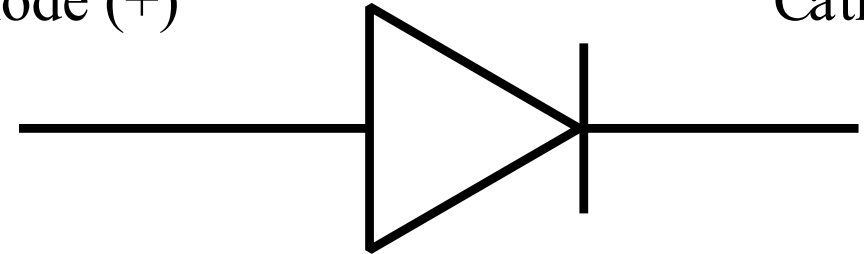


Current can only flow from the anode to the cathode.

Semiconductor Diode



Anode (+)

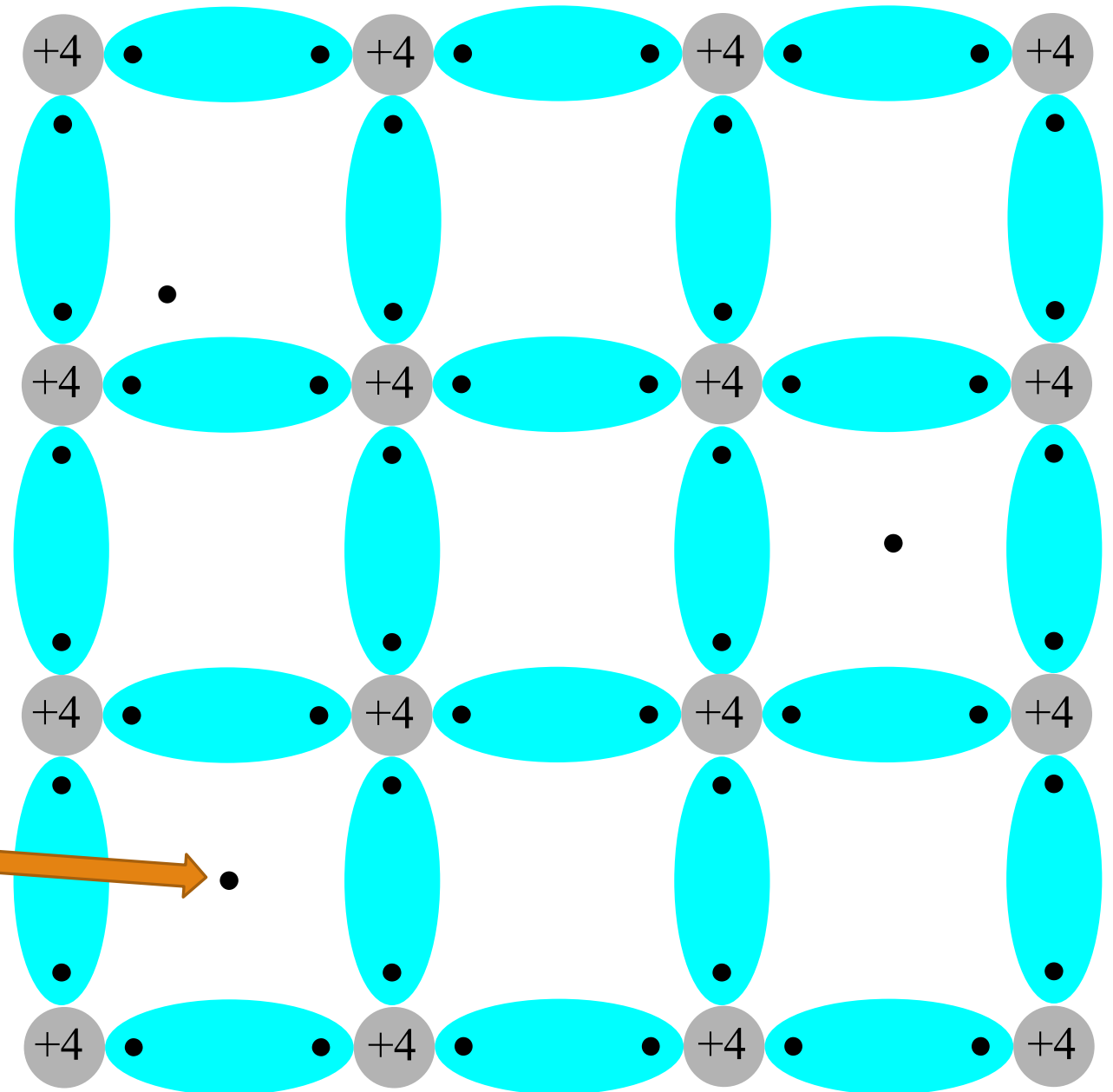


Cathode (-)

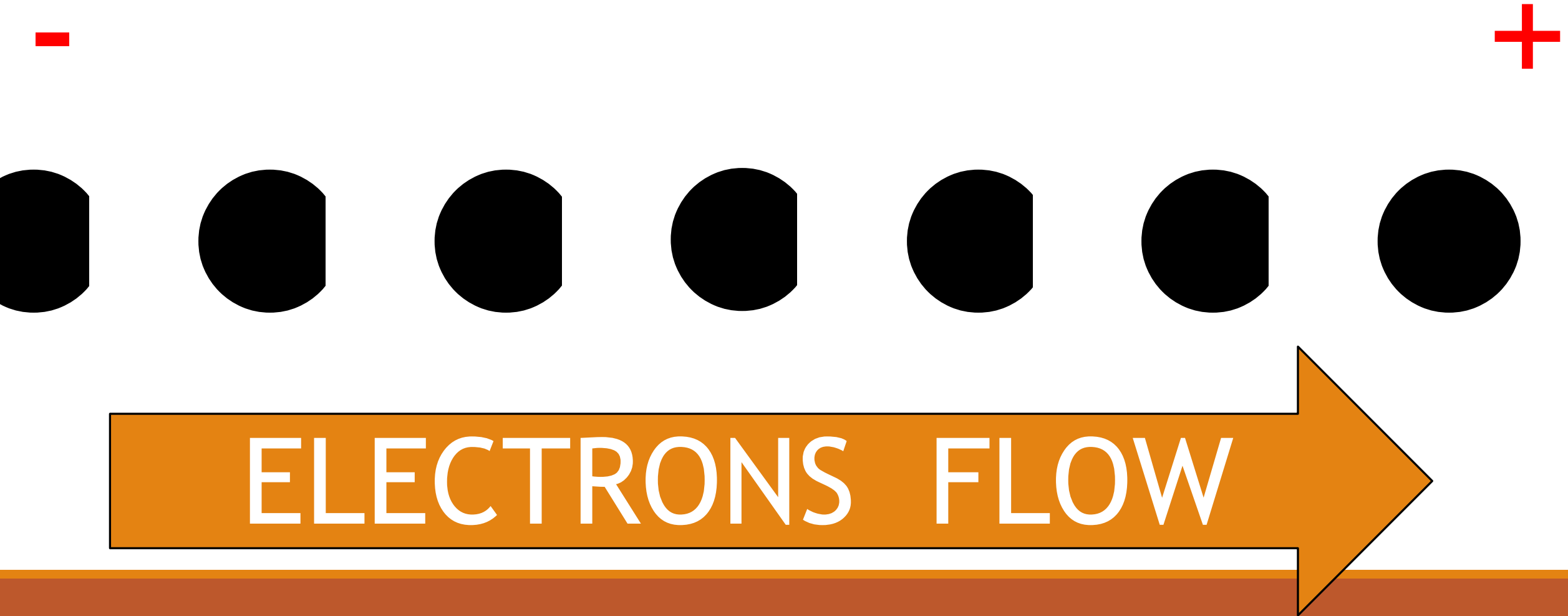
Current can only flow from the anode to the cathode.

Silicon Lattice

Free Electron



Apply Voltage to Silicon Lattice



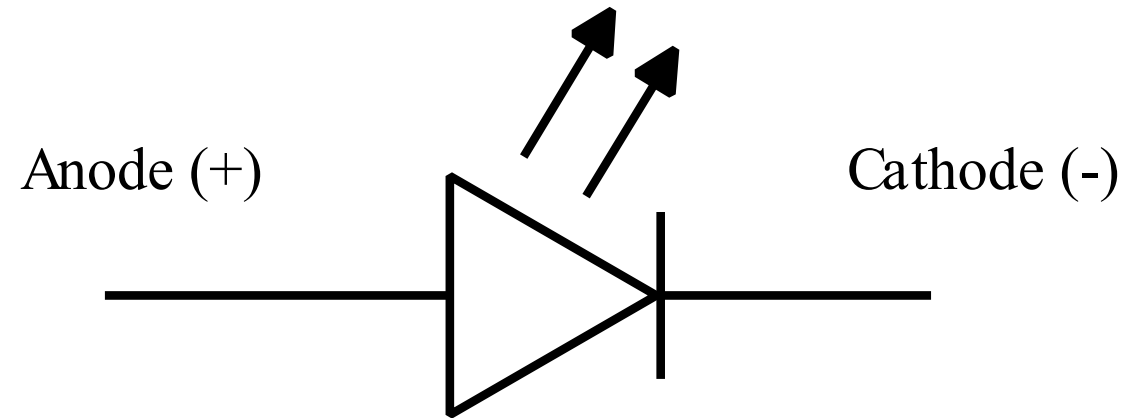
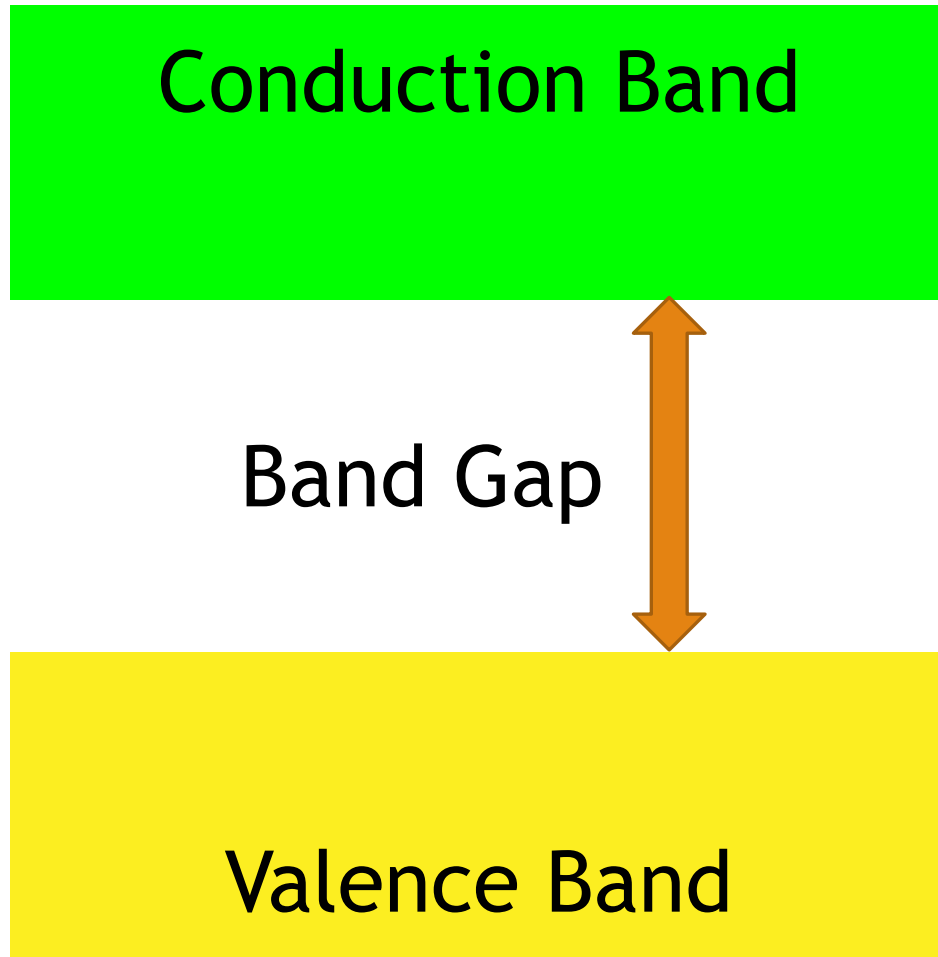
Apply Voltage to Silicon Lattice

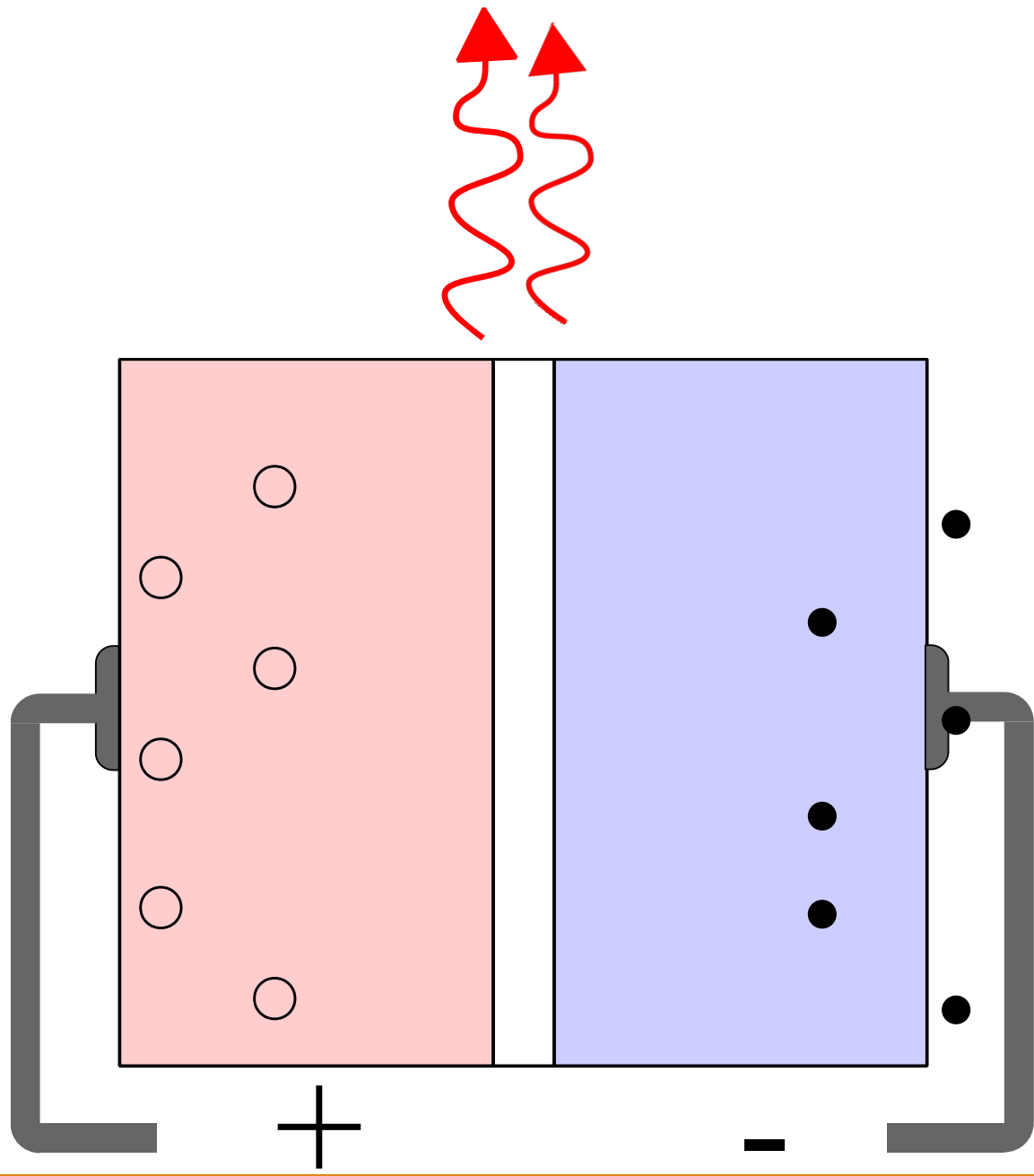


Periodic Table of the Elements



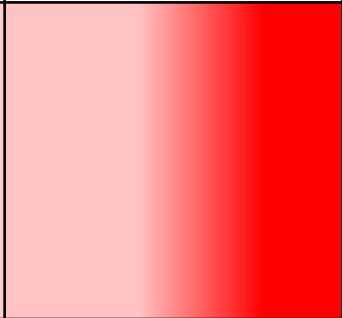

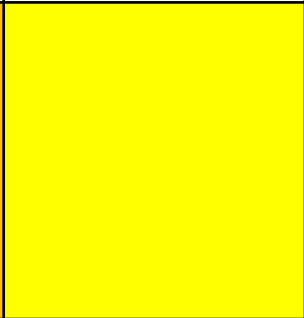
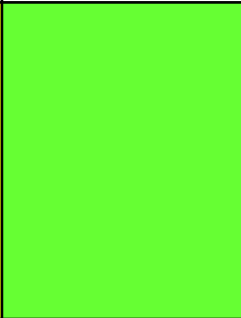
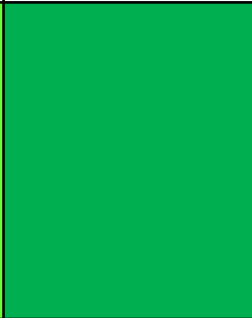

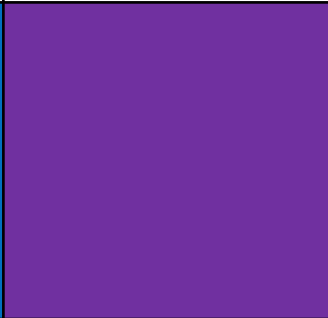
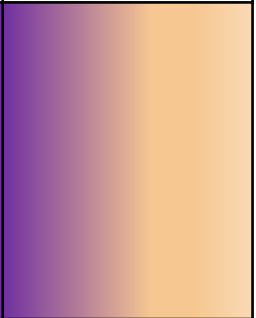
1 IA H Hydrogen 1.008 1																	18 VIIIA He Helium 4.003 2																														
3 Li Lithium 6.94 3	4 Be Beryllium 9.012 4																	19 Na Sodium 22.990 11	20 Mg Magnesium 24.3 12	35 Br Bromine 79.904 35	36 Kr Krypton 83.798 36																										
11 Na Sodium 22.990 11	12 Mg Magnesium 24.3 12	13 Al Aluminum 26.982 13	14 Si Silicon 28.086 14	15 P Phosphorus 30.974 15	16 S Sulfur 32.06 16	17 Cl Chlorine 35.45 17	18 Ar Argon 39.948 18	37 Rb Rubidium 85.468 37	38 Sr Strontium 87.62 38	39 Y Yttrium 88.906 39	40 Zr Zirconium 91.224 40	41 Nb Niobium 92.906 41	42 Mo Molybdenum 95.94 42	43 Tc Technetium 98 43	44 Ru Ruthenium 101.07 44	45 Rh Rhodium 102.91 45	46 Pd Palladium 106.42 46	47 Ag Silver 107.87 47	48 Cd Cadmium 112.41 48	49 In Indium 114.82 49	50 Sn Tin 118.71 50	51 Sb Antimony 121.76 51	52 Te Tellurium 127.6 52	53 I Iodine 126.91 53	54 Xe Xenon 131.29 54																						
19 K Potassium 39.098 19	20 Ca Calcium 40.078 20	21 Sc Scandium 44.956 21	22 Ti Titanium 47.88 22	23 V Vanadium 50.942 23	24 Cr Chromium 51.996 24	25 Mn Manganese 54.938 25	26 Fe Iron 55.845 26	27 Co Cobalt 58.933 27	28 Ni Nickel 58.693 28	29 Cu Copper 63.546 29	30 Zn Zinc 65.38 30	31 Ga Gallium 69.723 31	32 Ge Germanium 72.630 32	33 As Arsenic 74.922 33	34 Se Selenium 78.96 34	35 Br Bromine 79.904 35	36 Kr Krypton 83.798 36	44 Pd Palladium 106.42 44	45 Rh Rhodium 102.91 45	46 Pt Platinum 195.08 46	47 Ag Silver 107.87 47	48 Cd Cadmium 112.41 48	49 In Indium 114.82 49	50 Sn Tin 118.71 50	51 Sb Antimony 121.76 51	52 Te Tellurium 127.6 52	53 I Iodine 126.91 53	54 Xe Xenon 131.29 54																			
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87 Fr Francium 223 87	88 Ra Radium 226 88	89-103 Actinides	104 Rf Rutherfordium 261 104	105 Db Dubnium 262 105	106 Sg Seaborgium 266 106	107 Bh Bohrium 264 107	108 Hs Hassium 277 108	109 Mt Meitnerium 268 109	110 Ds Darmstadtium 271 110	111 Rg Roentgenium 272 111	112 Cn Copernicium 285 112	113 Nh Nihonium 284 113	114 Fl Flerovium 289 114	115 Mc Moscovium 288 115	116 Lv Livermorium 293 116	117 Ts Tennessine 294 117	118 Og Oganesson 294 118	57 La Lanthanum 138.91 57	58 Ce Cerium 140.12 58	59 Pr Praseodymium 140.91 59	60 Nd Neodymium 144.24 60	61 Pm Promethium 145 61	62 Sm Samarium 150.36 62	63 Eu Europium 151.96 63	64 Gd Gadolinium 157.25 64	65 Tb Terbium 158.93 65	66 Dy Dysprosium 162.50 66	67 Ho Holmium 164.93 67	68 Er Erbium 167.26 68	69 Tm Thulium 168.93 69	70 Yb Ytterbium 173.05 70	71 Lu Lutetium 174.967 71	89 Ac Actinium 227 89	90 Th Thorium 232.04 90	91 Pa Protactinium 231.04 91	92 U Uranium 238.03 92	93 Np Neptunium 237 93	94 Pu Plutonium 244 94	95 Am Americium 243 95	96 Cm Curium 247 96	97 Bk Berkelium 247 97	98 Cf Californium 251 98	99 Es Einsteinium 252 99	100 Fm Fermium 257 100	101 Md Mendelevium 258 101	102 No Nobelium 259 102	103 Lr Lawrencium 262 103

Semiconductor Electron States





The Chemistry Determines the Wavelength

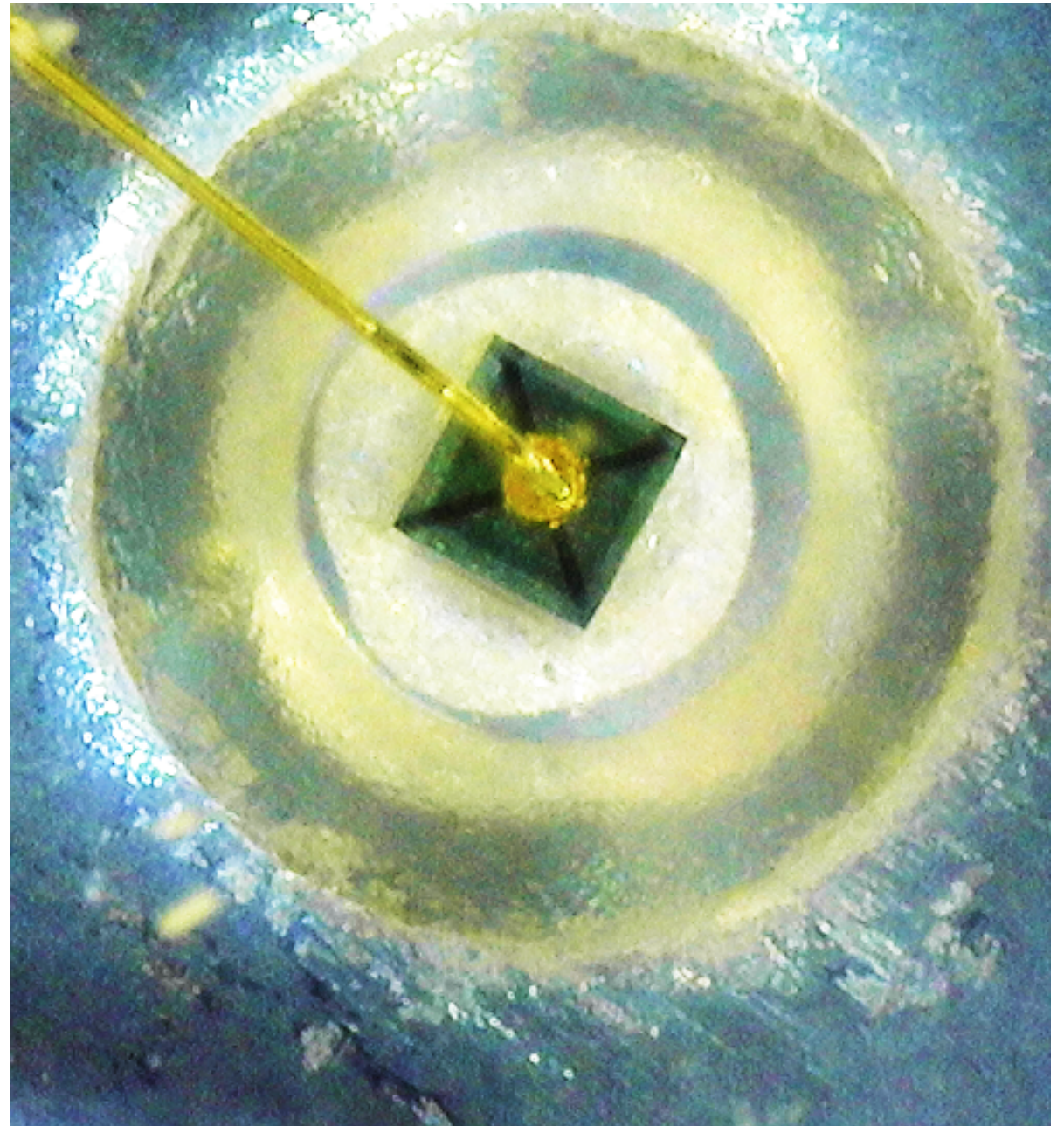
Ge	Si	AlGaAs	InP	GaAsP	GaAs	GaP	ZnSe	InGaN	ZnS
0.7	1.1	1.7	2.1	2.13	2.2	2.3	2.7	3.4	3.9
									

$$\text{Wavelength (nm)} = \frac{1241}{\text{Band Gap (eV)}}$$

Blue LED

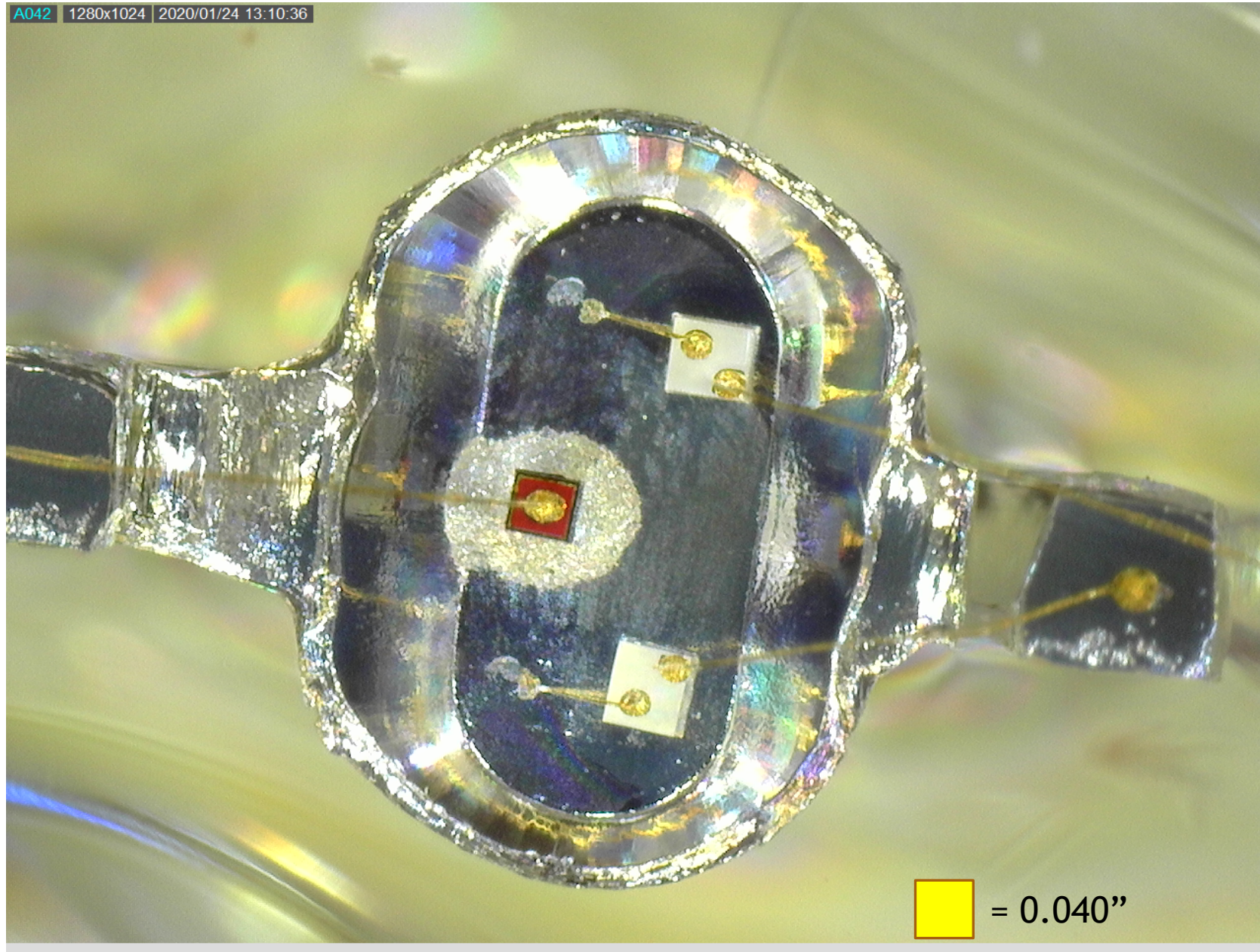
Au wire is ultrasonically bonded to the die.

Nobel Prize 2014.



RGB LED

Three individual LED dice are combined to produce any color light, including white.

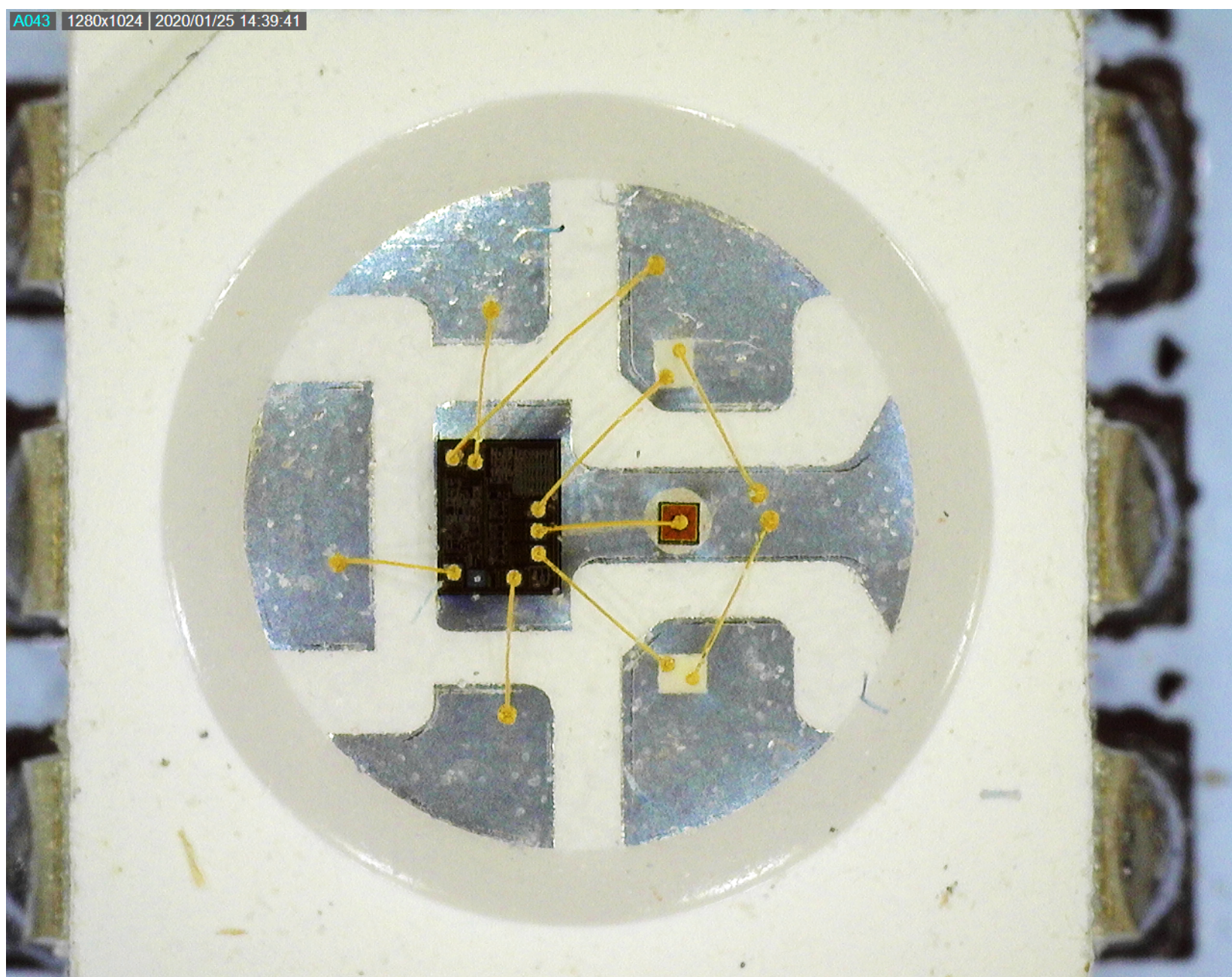


RGB LED



RGB LED

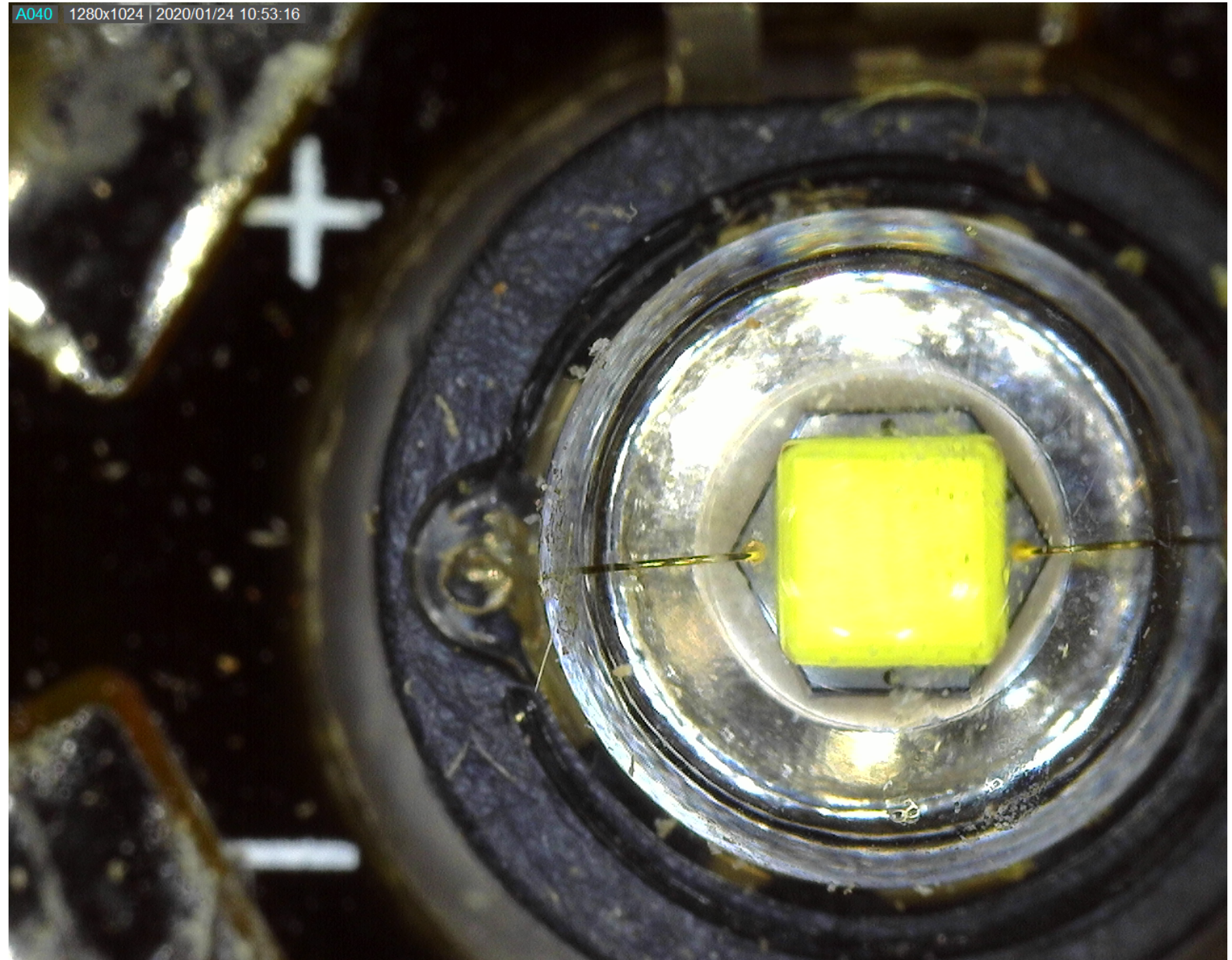
Three individual LED dice are connected to an integrated circuit.



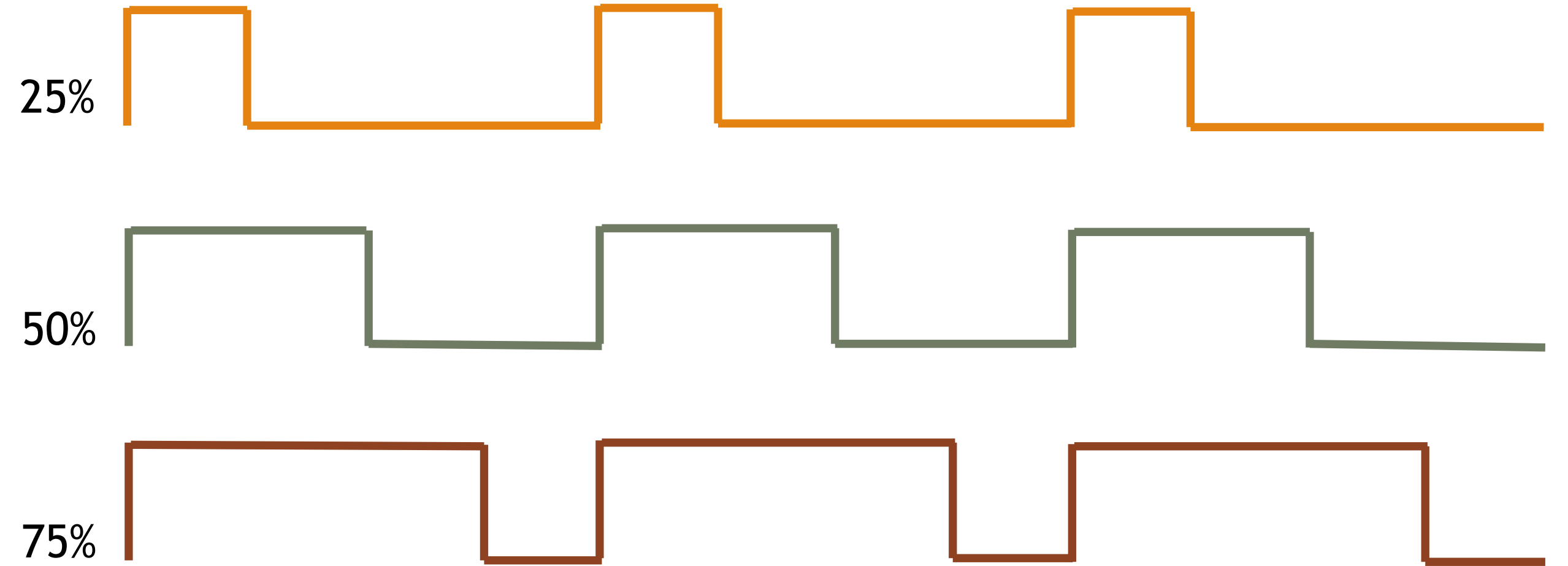
White LED

Note the yellow phosphor coating on the die.

The color temperature of a “white” LED is determined by the emission spectrum.



Dimming LED's with Pulse Width Modulation

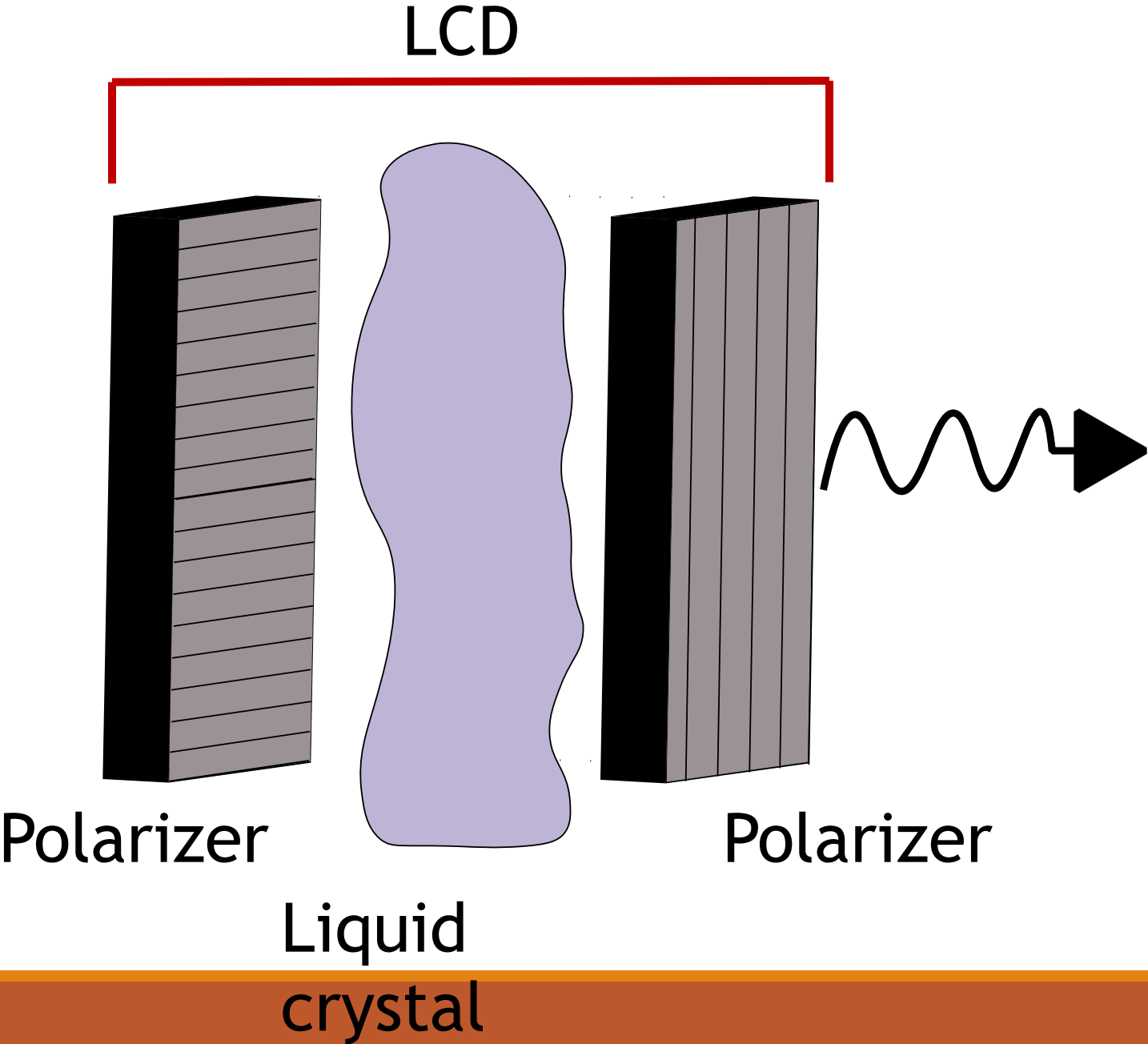
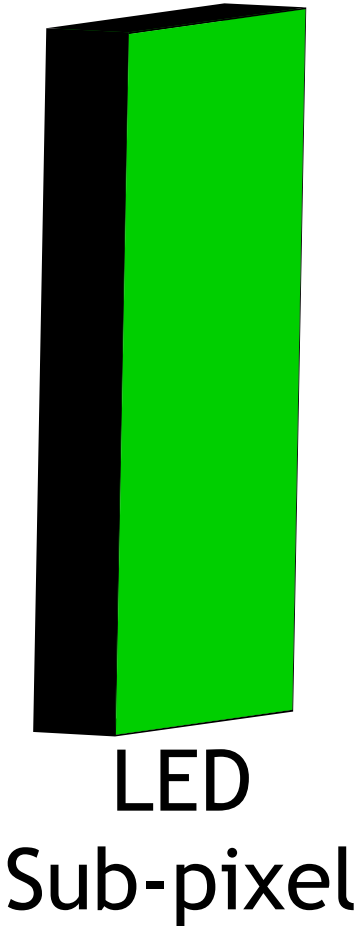


LCD's

Note 3 Sub-pixels (Red, Green and Blue) per pixel.

LED TV Screen

Each pixel has 3 sub-pixels.



8 Bit Digital Color

Example: 11111111 (bright white)

8 bit color = $2^8 = 256$ unique light levels.

Each sub-pixel has 256 unique light levels.

Each pixel can have = $256 \times 256 \times 256$
 $= 2^{24}$

= 16,777,216 colors

TV Screen: How many images can a TV display?

4K TV Screen is 4096 x 2160 pixels = 8,847,360 pixels

Total images possible on a TV screen is:

$$16,777,216^{8,847,360}$$

Using Wolfram Alpha,
this is a number with more
than **116 million digits**.

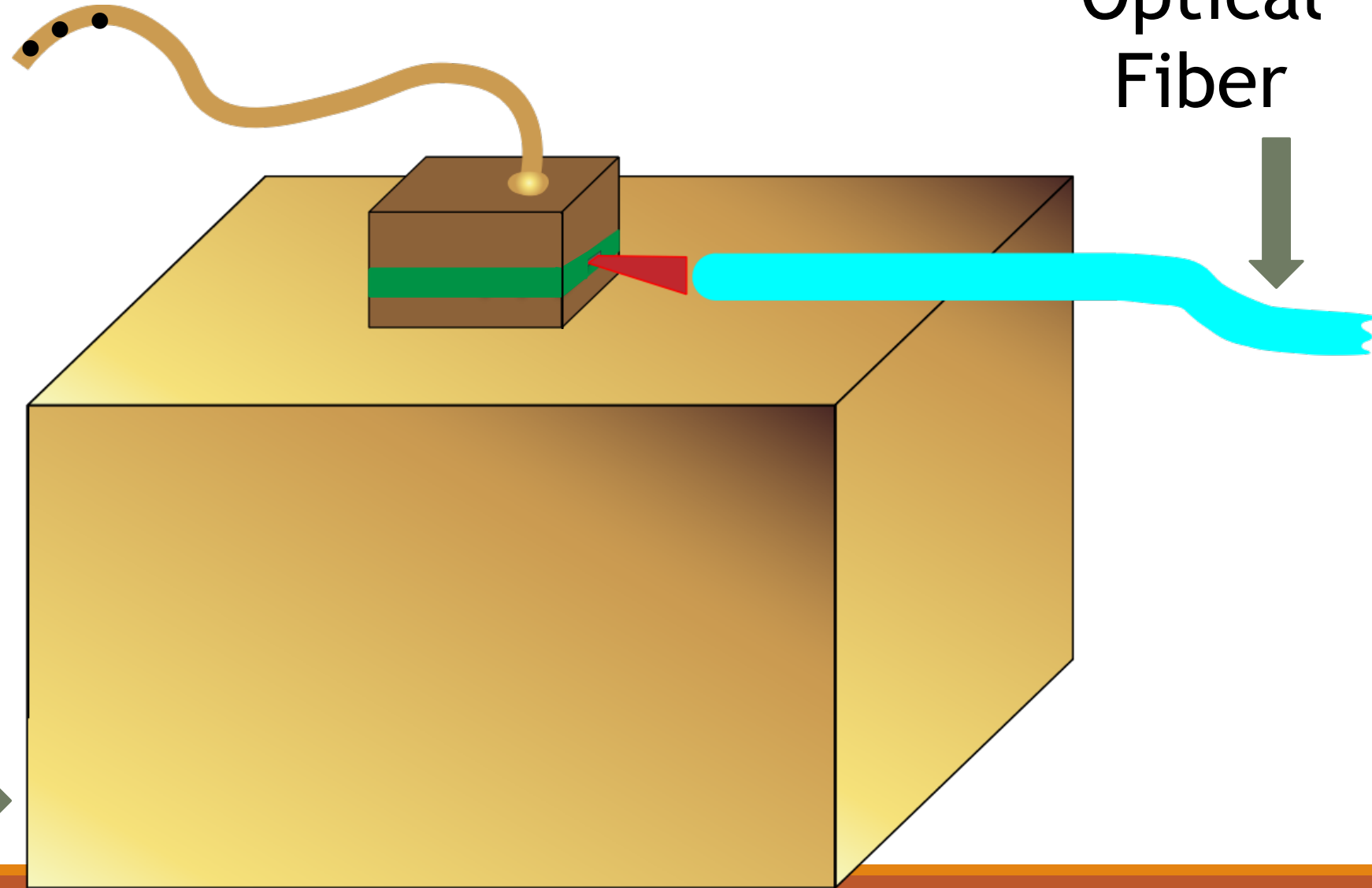


Input:
$8847360^{16777216}$
Decimal approximation:
$8.747290049748879764348081548459742652955730034048... \times 10^{116548193}$
Power of 10 representation:
$10^{10^{8.066505547979670}}$
Number length:
116548194 decimal digits
$\approx 1.16548 \times 10^8$ decimal digits

Laser Diode

Optical
Fiber

Be Cu Heatsink



Thank You!