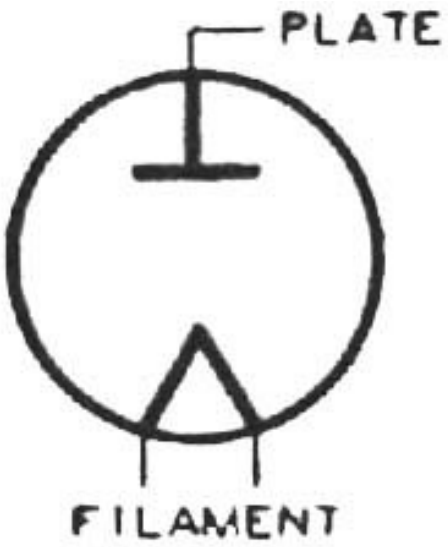
Diode in historisch perspectief

Hans Wallinga
Emeritus Universiteit Twente

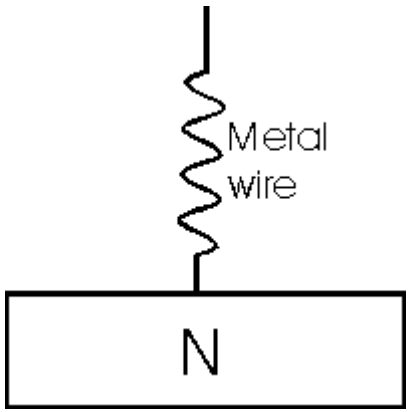
Vacuüm Diode



Gepatenteerd in 1904

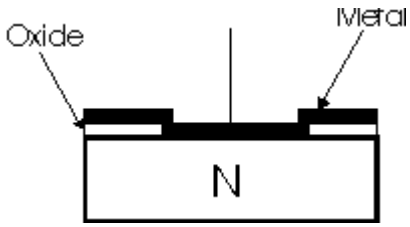
John Ambrose Fleming
(1848-1945)

Schottky diode



Gepatenteerd in 1938

Walter Schottky (1886-1976)



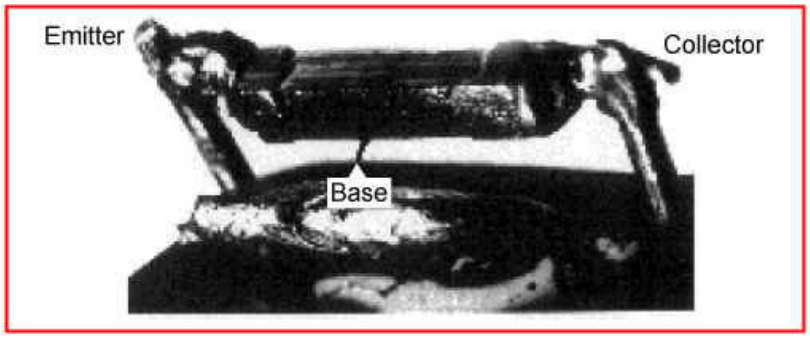
Nobelprijs 1911

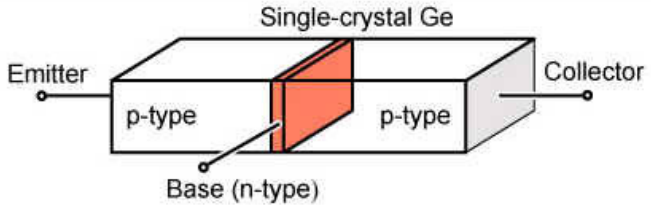
pn-overgang

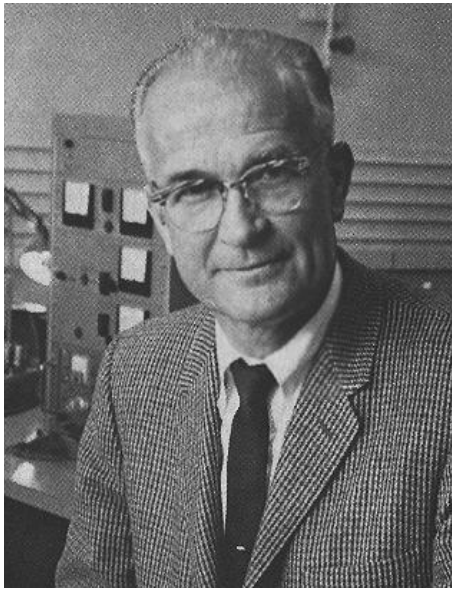
Gepatenteerd in 1951

William Bradford Shockley (1910 - 1989)

Nobelprijs 1956



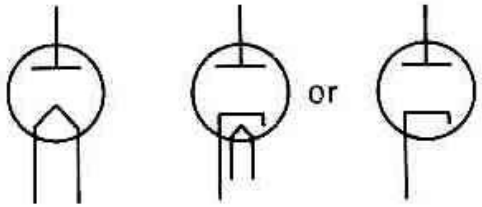




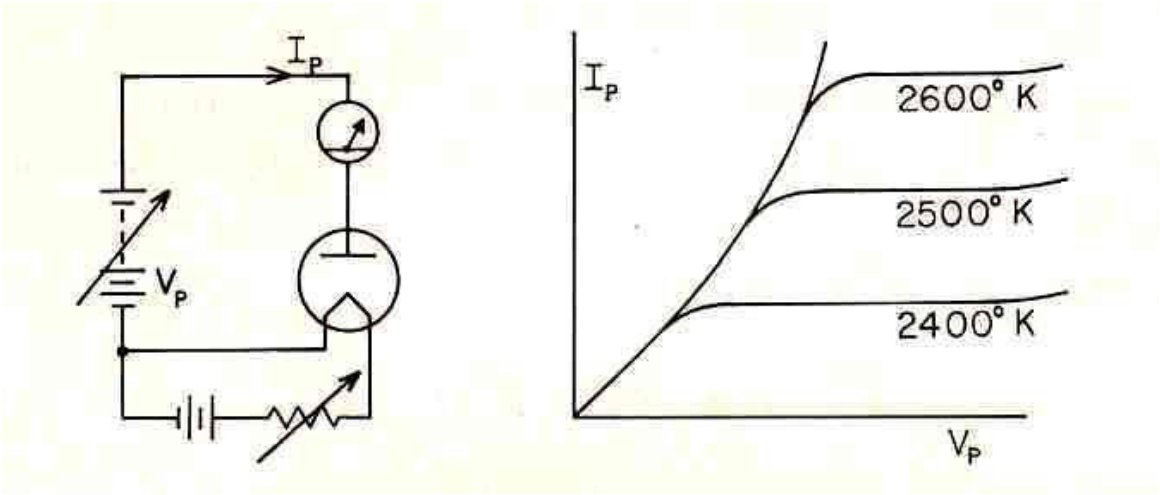
Fysische werking vacuüm diode

Thermische emissie: $J = A_0 T^2 e^{-W/kT}$

Diode stroom: $I = KV_p^{3/2}$

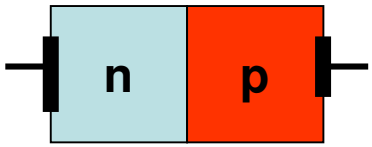


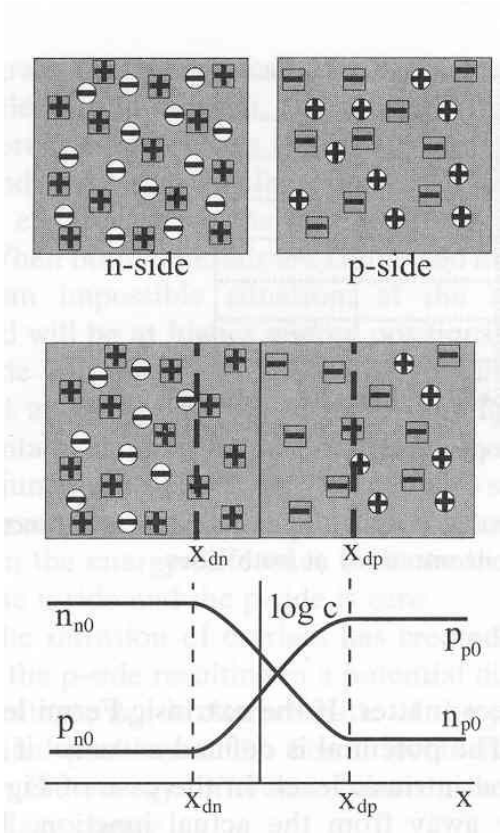
Diode symbolen

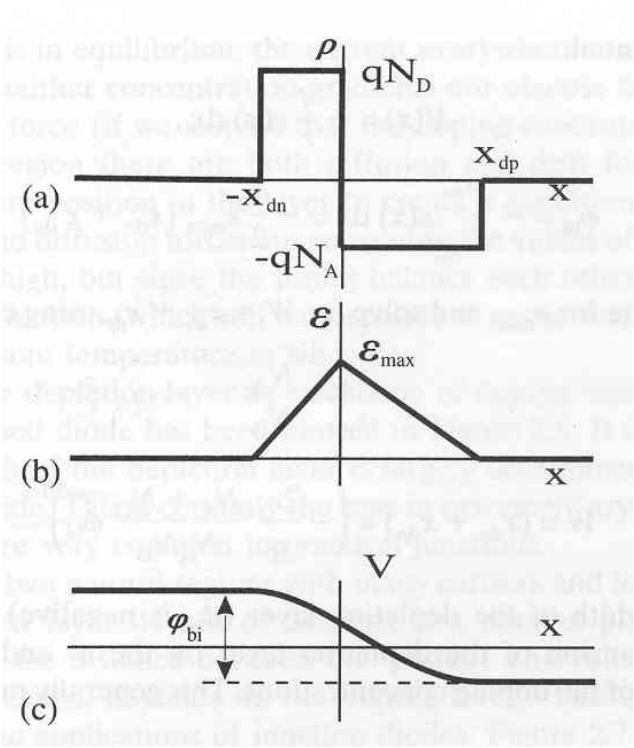


Diode karakterisieken

Fysische werking pn-junctie (1)

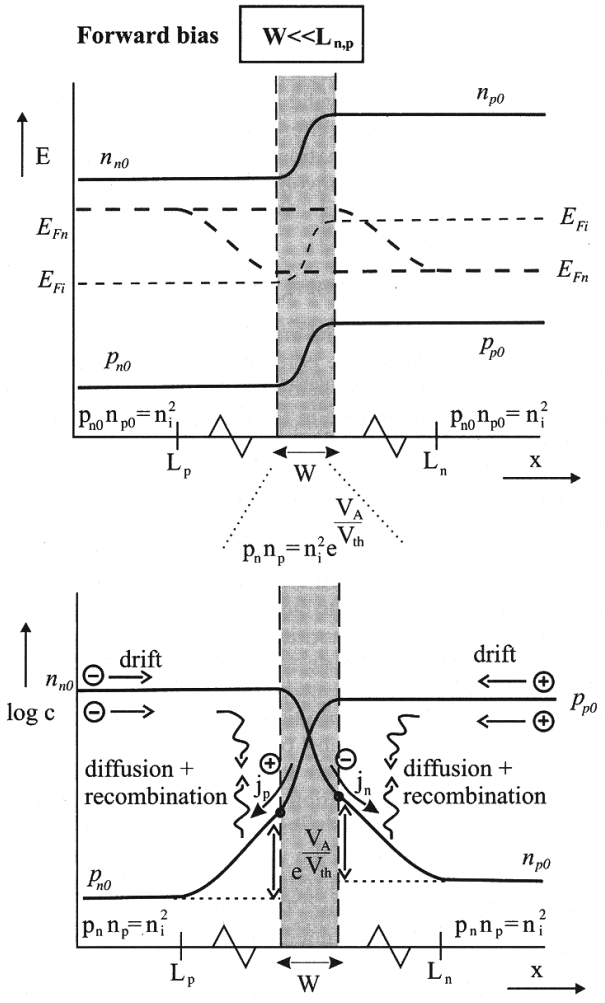






$$j_n = qD_n \frac{dn_p}{dx} + qn\mu_n E$$

Fysische werking pn-junctie (2)

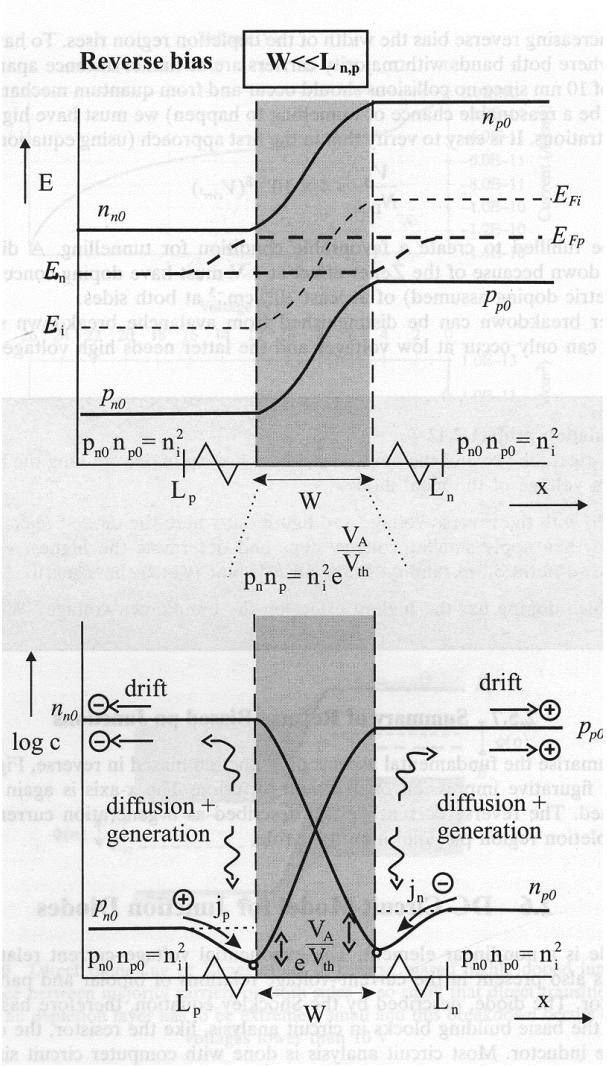


Voorwaartsstroom:

$$j = j_n + j_p = qn_i^2\left[\frac{1}{N_A}\frac{D_n}{L_n} + \frac{1}{N_D}\frac{D_p}{L_p}\right]\left[\exp\left(\frac{qV_A}{kT}\right) - 1\right]$$

$$j = j_0\left[\exp\left(\frac{V_A}{V_{th}}\right) - 1\right]$$

Fysische werking pn-junctie (3)



sperstroom

$$j = -j_0$$

$$j_0 = qn_i^2\left[\frac{1}{N_A}\frac{D_n}{L_n} + \frac{1}{N_D}\frac{D_p}{L_p}\right]$$

Fleming Valve

Elektriciteit

Vacuum

No. 803,684. PATENTED NOV. 7, 1905.

J. A. FLEMING.

INSTRUMENT FOR CONVERTING ALTERNATING ELECTRIC CURRENTS INTO CONTINUOUS CURRENTS.

APPLICATION FILED APR. 19, 1905.

Fig.1.

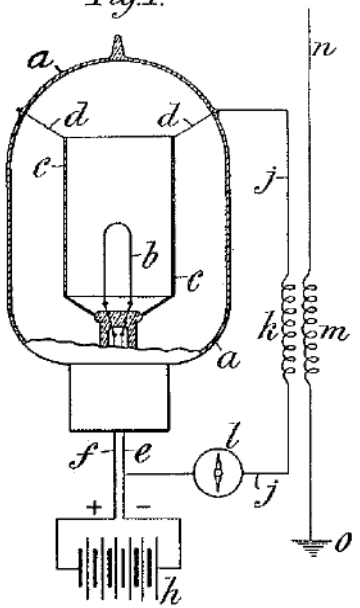


Fig.2.

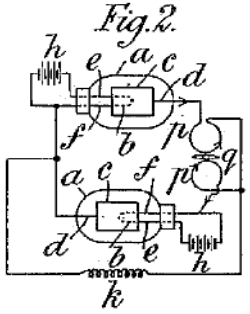
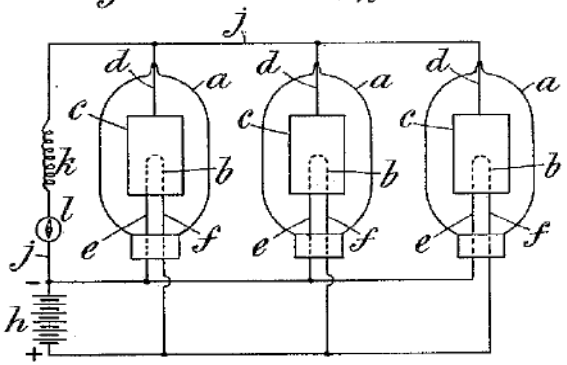


Fig.3.



Witnesses

William H. Davis.

James J. Boyce

Inventor

John Ambrose Fleming

by his attorneys

Betts Betts Sheffield & Betts

Octrooi van Fleming: 1906, ingediend in 1904

Principe: Edison effect, beschreven in 1880

Vervolg: Lee de Forest, Audion, de triode (1908)

No. 879,532. PATENTED FEB. 18, 1908.

L. DE FOREST.

SPACE TELEGRAPHY.

APPLICATION FILED JAN. 29, 1907.

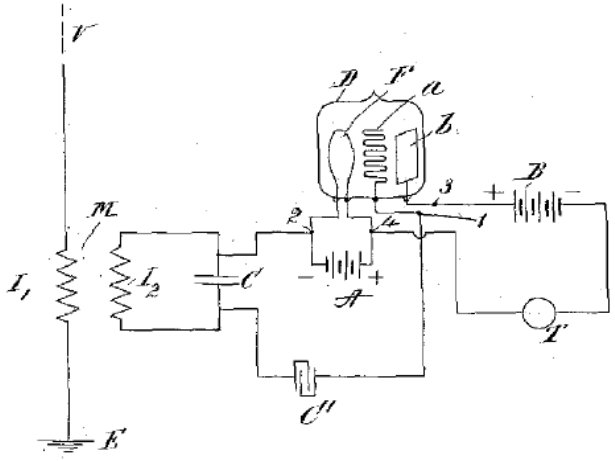
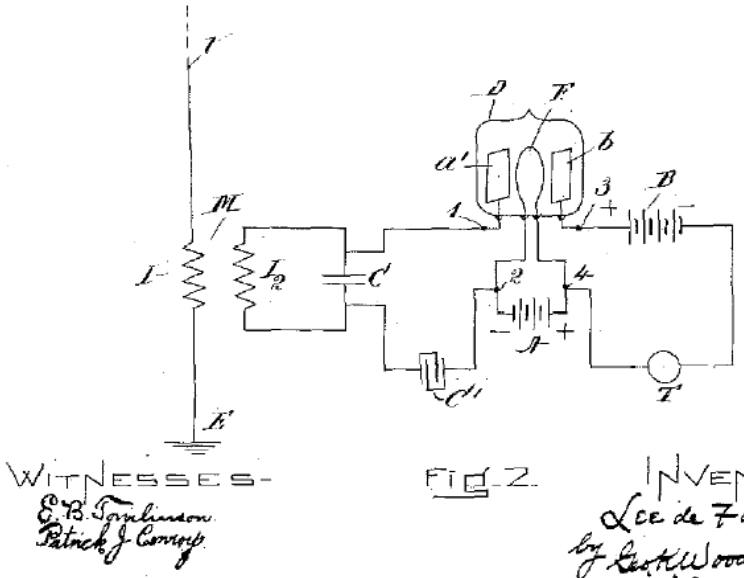


Fig. 1.



WITNESSES-
E. B. Tomlinson
Patrick J. Conroy

Fig. 2.

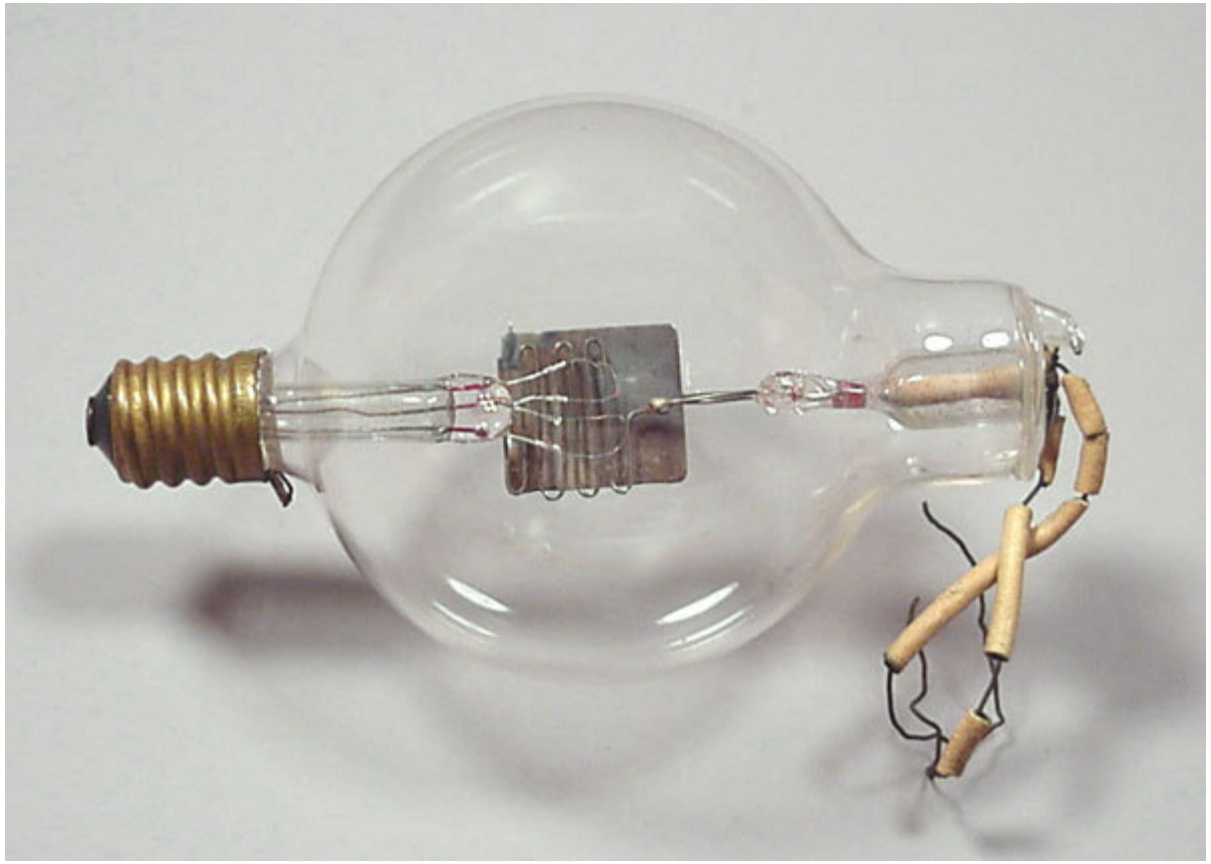
INVENTOR:
Lee de Forest
by Geo. K. Woodworth,
Atty.

Lee de Forest 1906 (gefiled)

Met een stuurelektrode werd versterking mogelijk en kon de elektronica ontwikkeld worden

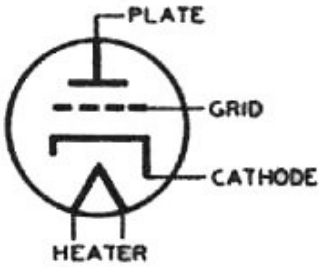
DeForest Spherical Audion

- DeForest Single Wing Audion c.1912 Tantalum Filaments

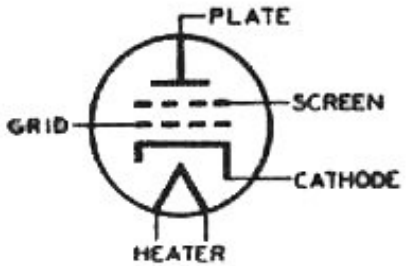


“How does this blamed thingy work?”

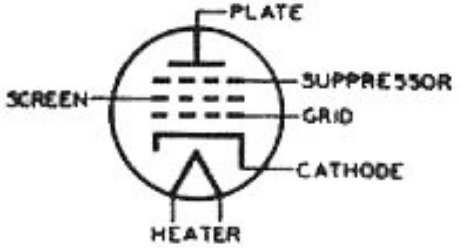
Vervolg vacuüm buizen



1907



1926



1929

Kathodestraalbuis: Karl Ferdinand Braun 1897
Televisie 1923

Natuurkunde vóór 1900

Gilbert	**1544-1603**	**benoemt elektrostatische kracht (ηλετρον = barnsteen)**	
Coulomb	**1736-1806**	**elektrische lading kwantificeerbaar (eenheid van lading) Coulombkracht**	
Watt	**1736-1819**	**Stoommachine**	
Volta	**1745-1827**	**depositie van lading bij elektrolyse, Voltacel**	
Ampère	**1775-1836**	**onderlinge kracht stroomvoerende draden**	
Ørsted	**1777-1851**	**wisselwerking tussen magneet en stroom (1820)**	
Ohm	**1789-1854**	**eenheid van weerstand**	
Faraday	**1791-1867**	**Materietransport bij elektrolyse (eenheid van capaciteit). Inductie (1831), elektrische en magnetische veldlijnen**	
Joule	**1818-1889**	**stroomvoerende draad ontwikkelt warmte**	
Kirchhoff	**1824-1887**	**serie en parallel stroomwetten**	
Maxwell	**1831-1879**	**wiskundige formulering veldtheorie**	
Röntgen	**1845-1923**	**Röntgenstralen, kristalstructuren**	**(1901)**
Lorentz	**1853-1928**	**Lorentzkracht; verwevenheid deeltjes-golven**	**(1902)**

Natuurkunde na 1900

Planck	**1858-1947**	**kwantumtheorie**	**1920**
Rutherford	**1871-1937**	**atoommodel;radioactieve straling**	**1908**
Einstein	**1879-1955**	**relativiteitstheorie**	**1921**
Bohr	**1885-1962**	**atoommodel**	**1922**
Debije	**1884-1966**	**molecuul- en kristalstructuren**	**1936**
Schrödinger	**1887-1961**	**kwantummechanica**	**1933**
Heisenberg	**1901-1976**	**kwantummechanica; onzekerheidsprincipe**	**1932**
Dirac	**1902-1982**	**Kwantummechanica; golfvergelijking**	**1933**

Octrooien 19e eeuw

1837	Thomas Davenport	Electric motor
1839	Samuel Colt	Revolver
1840	Samuel F.B. Morse	Telegraph
1855	Isaac Singer	Sewing Machine
1869	Leigh Burton	Elec. resistance heater
1872	William Robinson	Elec. train signaling
1873	Louis Pasteur	Pasteurization
1873	Thomas Edison	Improved telegraph
1873	Louis Pasteur	Yeast process
1876	Alexander Graham Bell	Telephone
1879	Charles Brush	Carbon arc light
1880	Thomas Edison	Electric light

Octrooien eind 19e eeuw

1876	Alexander Graham Bell	Telephone
1880	Thomas Edison	Electric light
1884	George Eastman	Photographic film
1886	Elihu Thomson	Electric welding
1887	Carl Gassner	Dry cell battery
1888	Nikola Tesla	AC synchronous motor
1888	Nikola Tesla	Alternating current transmission
1888	Nikola Tesla	Electric distribution
1890	Nikola Tesla	Electric generator
1895	Rudolf Diesel	Diesel engine
1897	Guglielmo Marconi	Wireless telegraph
1900	Nikola Tesla	Wireless transmission of electric power

Octrooien begin 20e eeuw

Nov. 13,1900	Valdemar Poulsen	Magnetic tape recording
June 4, 1901	Guglielmo Marconi	Wireless telegraphy
Nov. 5, 1901	Henry Ford	Automobile
Sept. 30,1902	Thomas Edison	Motion picture camera
June 28,1904	Guglielmo Marconi	Wireless telegraph equip.
Nov. 15,1904	King Gillette	Gillette safety blade & razor
Nov. 7,1905	John Fleming	Two element vacuum tube
Dec. 6,1906	Denwoody	Wireless telegraphy system
May 22,1906	O. & W. Wright	Airplane
Nov. 13,1906	Lee de Forest	Radio tube detector
Jan. 15,1907	Lee de Forest	Radio amplifier tube
Feb. 18,1908	Lee de Forest	Triode
Dec. 7,1909	Leo Baekeland	Bakelite plastic

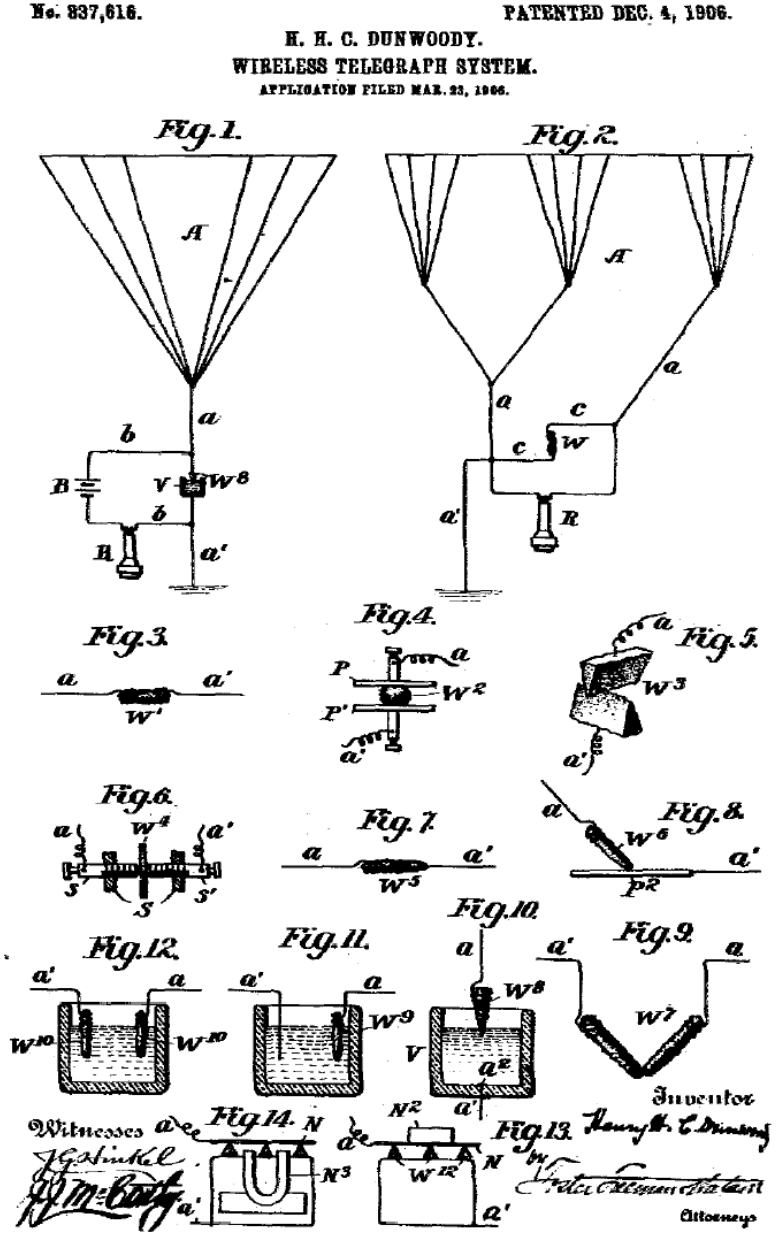
Vroege detector devices

galeniet

Cats-whisker:
een metaaldraad contact op een mineraal zoals bijv. galeniet (PbS).

Voorlopers van de Schottky diode of de puntcontact diode. De werking werd niet begrepen

Kristalradio's


No. 837,616. PATENTED DEC. 4, 1906.

H. H. C. DUNWOODY.

WIRELESS TELEGRAPH SYSTEM.

APPLICATION FILED MAR. 23, 1906.

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.

Fig. 5.

Fig. 6.

Fig. 7.

Fig. 8.

Fig. 9.

Fig. 10.

Fig. 11.

Fig. 12.

Fig. 13.

Fig. 14.

Witnesses

Inventor

Attorneys

Denwoody, 1906
Draadloos telegrafie systeem

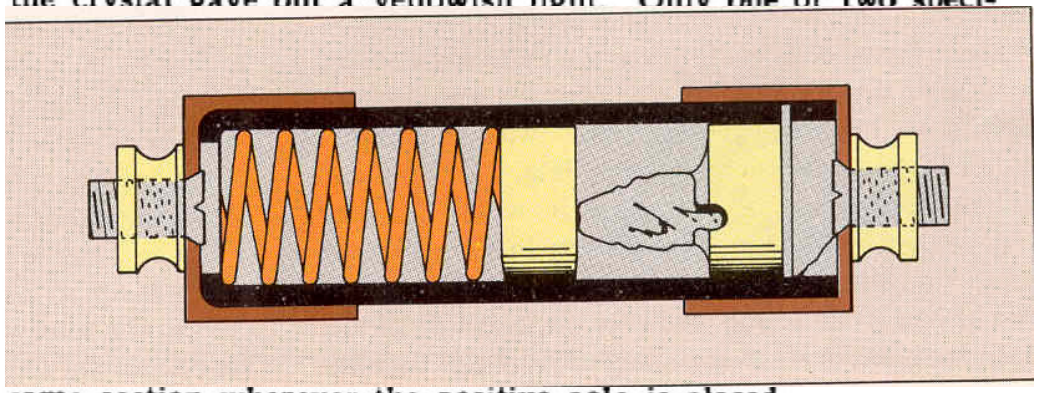
In Fig. 5 the wave-responsive device W^3 comprises two pieces or bodies of the crystalline material or carborundum having at least one relatively sharp edge, and the edges of the two pieces are placed in contact and may be supported in this relation in any suitable way, and are included in the circuit as before.

Cambridge University Press
0521823307 - Light-Emitting Diodes
E. Fred Schubert

A Note on Carborundum.

To the Editors of Electrical World:

SIRS:—During an investigation of the unsymmetrical passage of current through a contact of carborundum and other substances a curious phenomenon was noted. On applying a potential of 10 volts between two points on a crystal of carborundum, the crystal gave out a yellowish light. Only one or two speci-

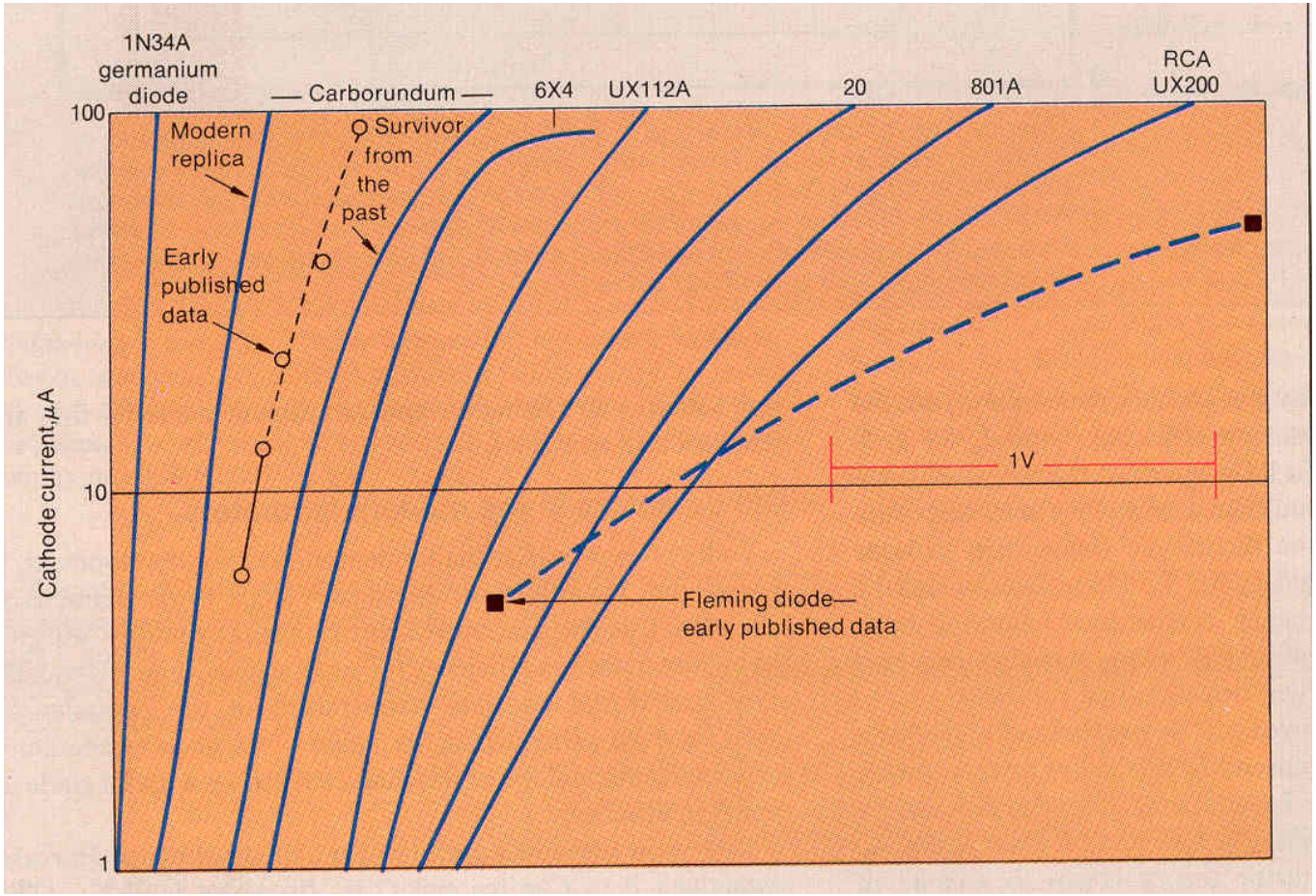


same section wherever the positive pole is placed.

There seems to be some connection between the above effect and the e.m.f. produced by a junction of carborundum and another conductor when heated by a direct or alternating current; but the connection may be only secondary as an obvious explanation of the e.m.f. effect is the thermoelectric one. The writer would be glad of references to any published account of an investigation of this or any allied phenomena.

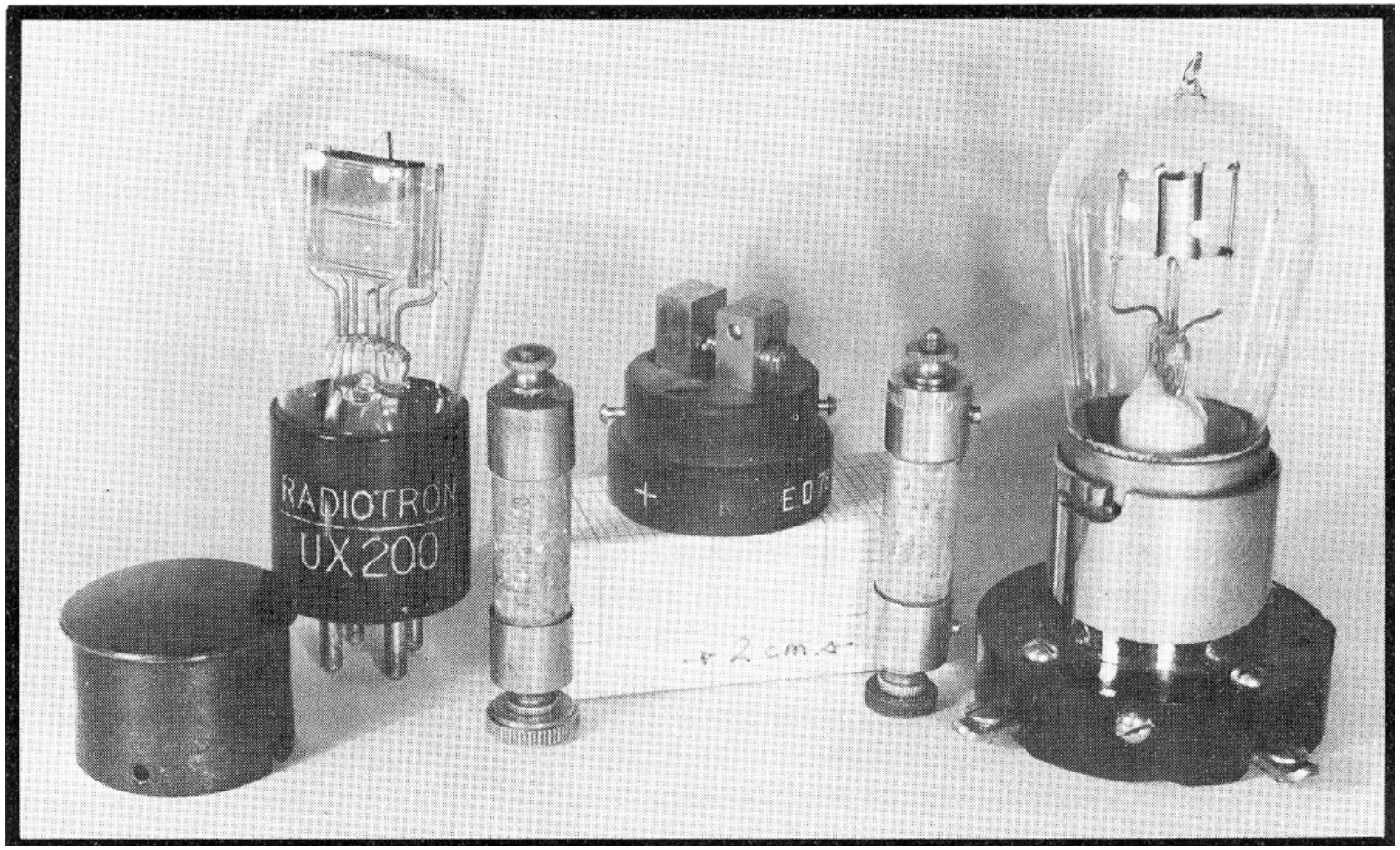
NEW YORK, N. Y. H. J. ROUND.

Fig. 1.1. Publication reporting on a "curious phenomenon", namely the first observation of electroluminescence from a SiC (carborundum) light-emitting diode. The article indicates that the first LED was a Schottky diode rather than a p-n-junction diode (after H. J. Round, *Electrical World* **49**, 309, 1907).



Koolstof diodes waren in feite beter dan vacuum diode

Thackeray, When tubes beat crystals: early radio detectors ;IEEE Spectrum March 1983



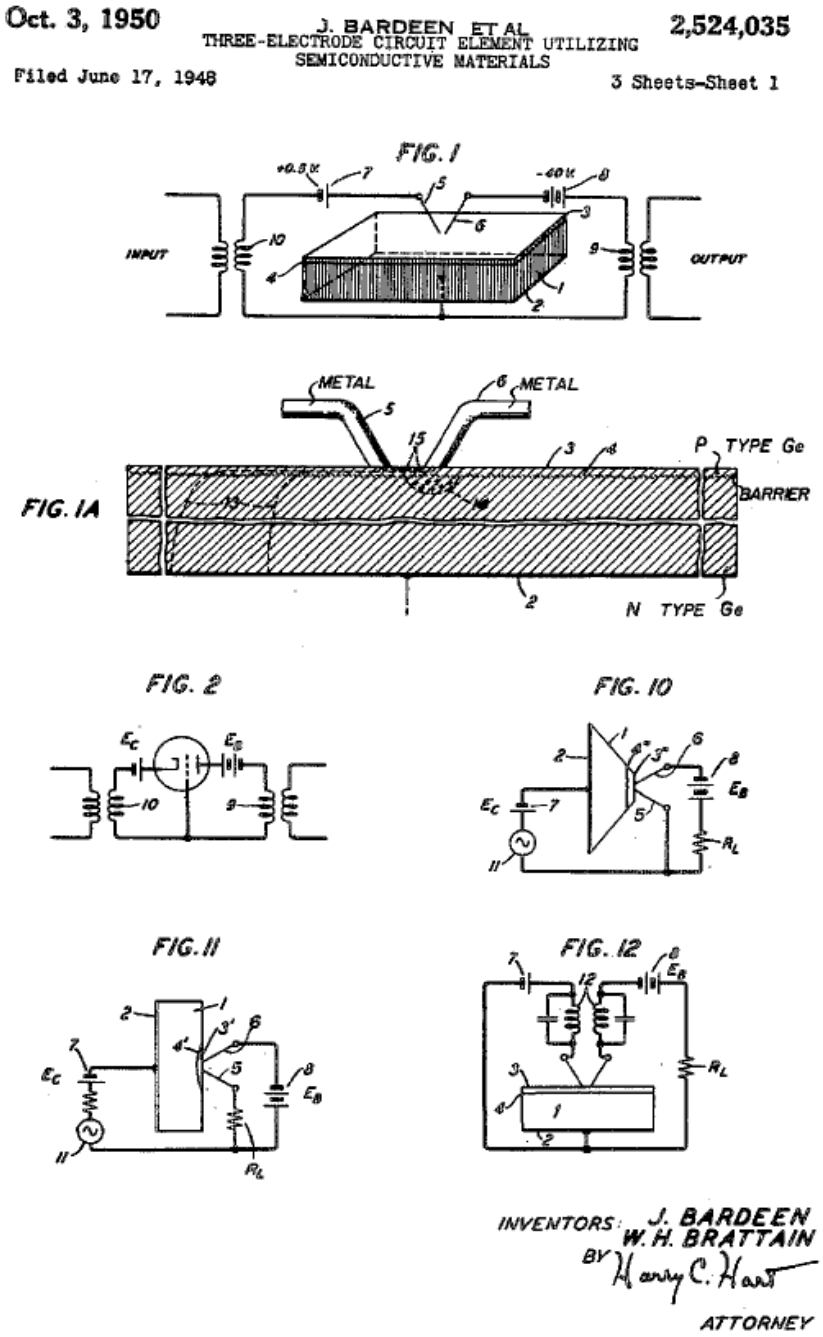
Thackeray, When tubes beat crystals: early radio detectors ;IEEE Spectrum March 1983

A detector chronology

Date	Event	Frequency*
1874–83	Braun's crystal experiments	DC
1884	Edison's lamp diode	DC
1894	Elster and Geitel's phototube detector	Very high frequency
1899	Pupin's electrolytic detector	Up to 25 kHz
1903	Mercury-pool rectifier, Cooper-Hewitt	Power frequency
1903	Wehnelt's oxide-coated filament	No limit
1904	Fleming's "oscillation" valve	DC and high frequency
1905 1906 1906 1906	De Forest's "Audion" Braun's psilomelan detector Dunwoody's carborundum detector Pickard's silicon detector	100 kHz
1906	Brandes's theory of detection	
. . . . 1945†	. . . . The IN34 germanium diode and its successors	

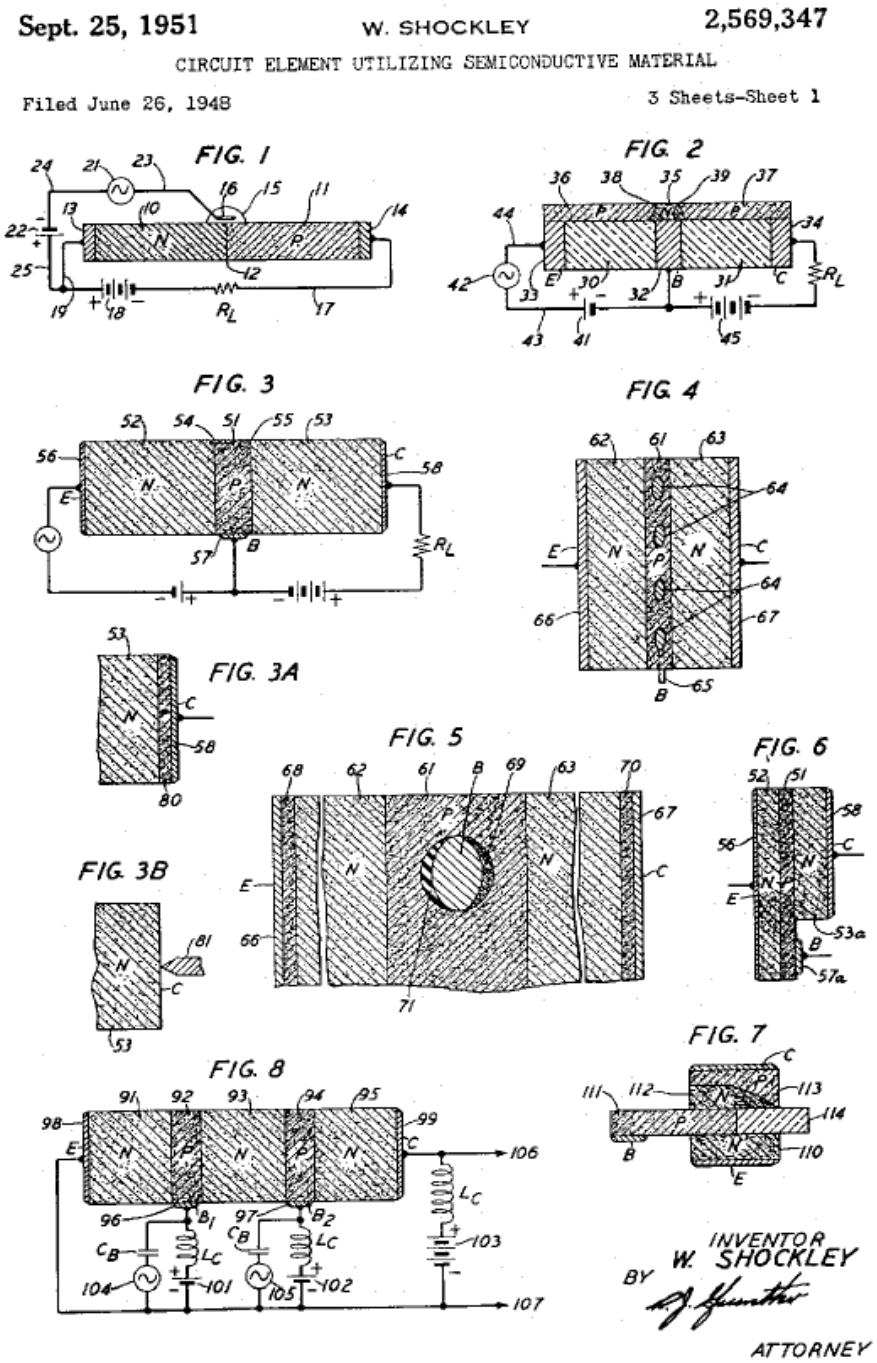
*Estimated
† In the preceding 40 years, progress was slow but more scientific, and steady engineering advances led to this milestone of the 1940s.

Thackeray, When tubes beat crystals: early radio detectors ;IEEE Spectrum March 1983


Oct. 3, 1950 J. BARDEEN ET AL 2,524,035
THREE-ELECTRODE CIRCUIT ELEMENT UTILIZING SEMICONDUCTIVE MATERIALS
Filed June 17, 1948 3 Sheets-Sheet 1
FIG. 1
INPUT
OUTPUT
FIG. 1A
METAL
METAL
P TYPE Ge
BARRIER
N TYPE Ge
FIG. 2
FIG. 10
FIG. 11
FIG. 12
INVENTORS: J. BARDEEN
W. H. BRATTAIN
BY Harry C. Hart
ATTORNEY

17 Juni 1948

Bardeen en Brattain octrooieren separaat van Shockley


Sept. 25, 1951 W. SHOCKLEY 2,569,347

CIRCUIT ELEMENT UTILIZING SEMICONDUCTIVE MATERIAL

Filed June 26, 1948 3 Sheets-Sheet 1

FIG. 1

FIG. 2

FIG. 3

FIG. 4

FIG. 3A

FIG. 5

FIG. 6

FIG. 3B

FIG. 7

FIG. 8

INVENTOR W. SHOCKLEY

BY

ATTORNEY

26 juni 1948

William Shockley octrooieert als eenling de junctietransistor

Another feature pertains to a semiconductive body comprising successive zones of material of opposite conductivity type each separated from the other by an electrical barrier, means for making external connection respectively to two of said zones, and means for making other connections intermediate to the two for controlling the flow of current across one or more of the electrical barriers.

Fig. 1 shows in section one embodiment of the invention with an appropriate circuit;

Dec. 23, 1952 W. SHOCKLEY ET AL 2,623,105

SEMICONDUCTOR TRANSLATING DEVICE
HAVING CONTROLLED GAIN
Filed Sept. 21, 1951

FIG. 1

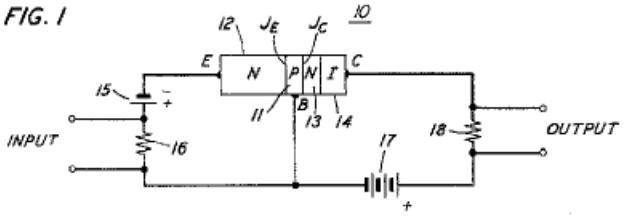


FIG. 2

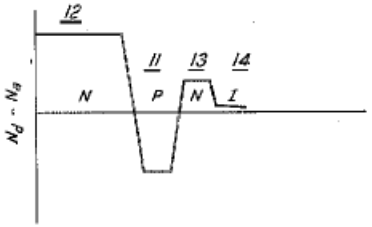


FIG. 3

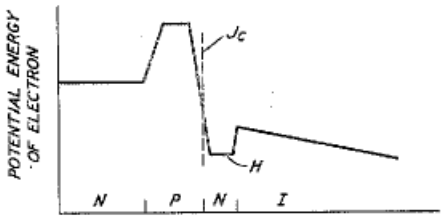
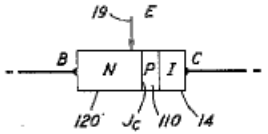


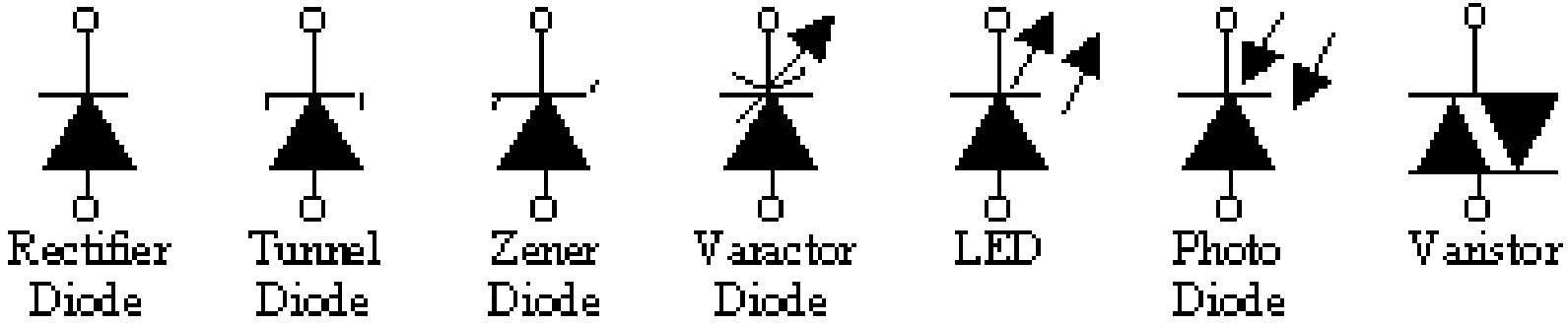
FIG. 4

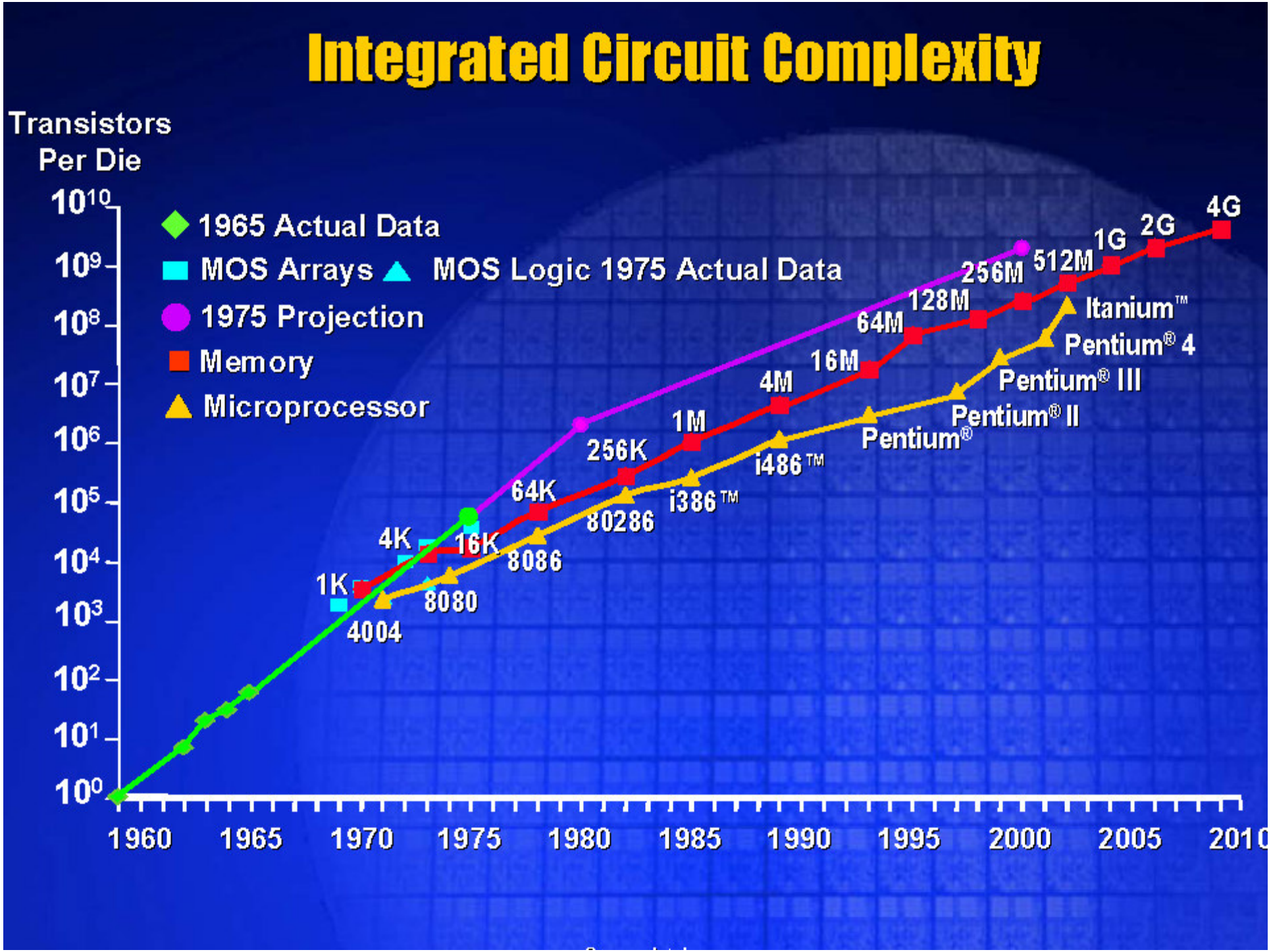


INVENTORS: W. SHOCKLEY
M. SPARKS
BY
ATTORNEY

Shockley octrooieert diverse constructies (1951)

Diverse specialisaties




Integrated Circuit Complexity
Transistors Per Die
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
1965 Actual Data
MOS Arrays
MOS Logic 1975 Actual Data
1975 Projection
Memory
Microprocessor
1K
4K
16K
64K
256K
1M
4M
16M
64M
128M
256M
512M
1G
2G
4G
4004
8080
8086
80286
i386™
i486™
Pentium®
Pentium® II
Pentium® III
Pentium® 4
Itanium™
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010

Halfgeleiderproductie in 2004:

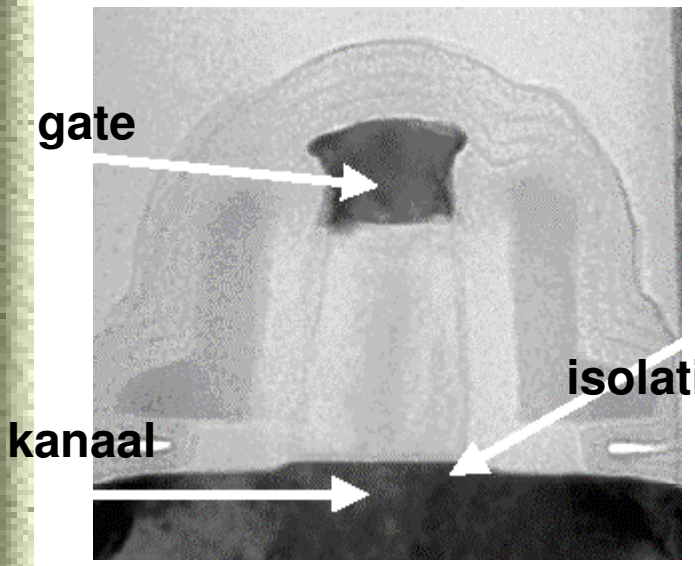
Omzet: 150 miljard $

10^{18} (1 miljard x 1 miljard) transistoren / jaar

150 miljoen transistoren / persoon.jaar

5 transistoren per seconde / persoon

In 100 jaar
van buis naar nanotechnologie



45 nm MOST