Chapter 1
Introduction

The proper conduct of science lies in the pursuit of Nature's puzzles, wherever they may lead.

J.M. Bishop [2]

Abstract Important dates and events in the history of semiconductors are chronologically listed, from the early days (Volta, Seebeck and Faraday) to the latest achievements like the blue and white LED. Many known and not so well known scientists are mentioned. Also a list of semiconductor related Nobel prizes and their winners is given.

The historic development of semiconductor physics and technology began in the second half of the 19th century. Interesting discussions of the history of the physics and chemistry of semiconductors can be found in [3–5]. The development of crystal growth is covered in [6]. The history of semiconductor industry can be followed in [7, 8]. In [9] 141 pioneering papers on semiconductor devices are compiled. In 1947, the commercial realization of the transistor was the impetus to a fast-paced development that created the electronics and photonics industries. Products founded on the basis of semiconductor devices such as computers (CPUs, memories), optical-storage media (lasers for CD, DVD), communication infrastructure (lasers and photodetectors for optical-fiber technology, high frequency electronics for mobile communication), displays (thin film transistors, LEDs), projection (laser diodes) and general lighting (LEDs) are commonplace. Thus, fundamental research on semiconductors and semiconductor physics and its offspring in the form of devices has contributed largely to the development of modern civilization and culture.

1.1 Timetable and Key Achievements

In this section important milestones in semiconductor physics and technology are listed.

1782
A. Volta—coins the phrase 'semicoibente' (semi-insulating) which was translated then into English as 'semiconducting' [10].

M. Grundmann, *The Physics of Semiconductors*, Graduate Texts in Physics,
https://doi.org/10.1007/978-3-030-51569-0_1

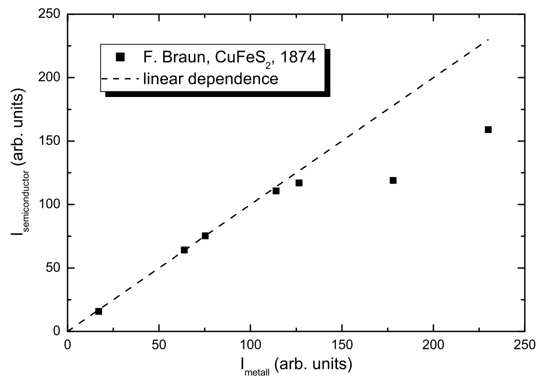

Fig. 1.1 Current through a silver–$CuFeS_2$–silver structure as a function of the current through the metal only, 1874. Data points are for different applied voltages. Experimental data from [24]

1821
T.J. Seebeck—discovery of thermopower (electrical phenomena upon temperature difference) in metals and PbS, FeS_2, $CuFeS_2$ [11, 12].

1833
M. Faraday—discovery of the temperature dependence of the conductivity of Ag_2S (sulphuret of silver, negative $\mathrm{d}R/\mathrm{d}T$) [13].

1839
A.E. Becquerel[1]—photoelectric effect (production of a photocurrent when electrodes covered by copper or silver halides salts (in an electrolyte) were illuminated by solar light) [14–17].

1834
J. Peltier—discovery of the Peltier effect (cooling by current) [18].

1873
W. Smith—discovery of photoconductivity in selenium [19, 20]. Early work on photoconductivity in Se is reviewed in [21, 22].

1874
F. Braun[2]—discovery of rectification in metal–sulfide semiconductor contacts [24], e.g. for $CuFeS_2$ and PbS. The current through a metal–semiconductor contact is nonlinear (as compared to that through a metal, Fig. 1.1), i.e. a deviation from Ohm's law. Braun's structure is similar to a MSM diode.

1876
W.G. Adams and R.E. Day—discovery of the photovoltaic effect in selenium [25].
W. Siemens—large response from selenium photoconductor [26], made by winding two thin platinum wires to the surface of a sheet of mica, and then covering the surface with a thin film of molten selenium. Resistance ratio between dark and illuminated by sunlight was larger than ten [26] and measured to 14.8 in [27].

1879
E.H. Hall—measurement of the transverse potential difference in a thin gold leaf on glass [28, 29]. Experiments were continued by his mentor H.A. Rowland [30]. A detailed account of the discovery of the Hall efect is given in [31, 32].

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[1] This is Edmond Becquerel; his son Henri Becquerel received the Nobel Prize in Physics for the discovery of radioactivity.

[2] F. Braun made his discoveries on metal–semiconductor contacts in Leipzig while a teacher at the Thomasschule zu Leipzig [23]. He conducted his famous work on vacuum tubes later as a professor in Strasbourg, France.

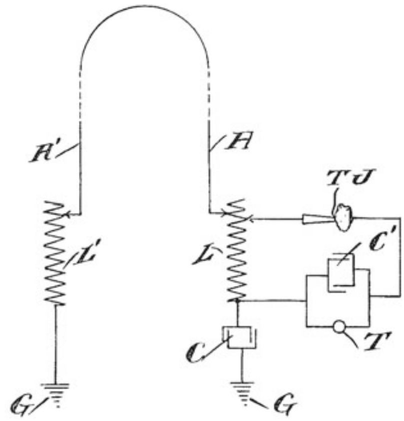

Fig. 1.2 Circuit diagram for a radio receiver with a point-contact diode (TJ). Adapted from [34]

1883
Ch. Fritts—first solar cell, based on an gold/selenium rectifier [27]. The efficiency was below 1%.

1901
J.C. Bose—point contact detector for electromagnetic waves based on galena (PbS) [33]. At the time, the term semiconductor was not introduced yet and Bose speaks about 'substances of a certain class (...) presenting a decreasing resistance to the passage of the electric current with an increasing impressed electromotive force'.

1906
G.W. Pickard—rectifier based on point contact (cat's whisker) diode on silicon [34–36]. Erroneously, the rectifying effect was attributed to a thermal effect, however, the drawing of the 'thermo-junction' (TJ in Fig. 1.2) developed into the circuit symbol for a diode (cmp. Fig. 21.63a).

1907
H.J. Round—discovery of electroluminescence investigating yellow and blue light emission from SiC [37].
K. Bädeker—preparation of metal (e.g. Cd, Cu) oxides and sulfides and also CuI from metal layers using a vapor phase transport method [38][3]. CuI is reported transparent ($\sim$ 200 nm thick films) with a specific resistivity of $\rho = 4.5 \times 10^{-2}\,\Omega$cm, the first transparent conductor.[4] Also CdO (films of thickness 100–200 nm) is reported to be highly conductive, $\rho = 1.2 \times 10^{-3}\,\Omega$cm, and orange-yellow in color, the first reported TCO (transparent conductive oxide).

1909
K. Bädeker—discovery of doping. Controlled variation of the conductivity of CuI by dipping into iodine solutions (e.g. in chloroform) of different concentrations [41].

1910
W.H. Eccles—negative differential resistance of contacts with galena (PbS), construction of crystal oscillators[5] [45].

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[3]This work was conducted as Habilitation in the Physics Institute of Universität Leipzig. Bädeker became subsequently professor in Jena and fell in WW I. His scientific contribution to semiconductor physics is discussed in [39, 40]

[4]CuI is actually a p-type transparent conductor; at that time the positive sign of the Hall effect [41, 42] could not be interpreted as hole conduction yet.

[5]Historical remarks on Eccles' contributions to radio technology can be found in [43, 44]

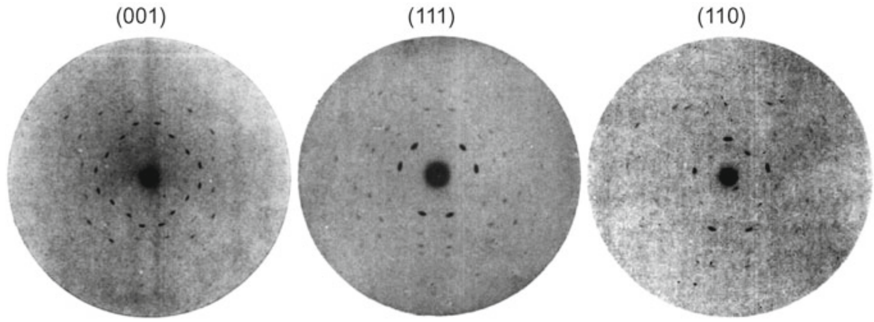

Fig. 1.3 Laue images of 'regular' (cubic) ZnS along three major crystallographic directions, directly visualizing their 4-, 3- and 2-fold symmetry. Adapted from [48]

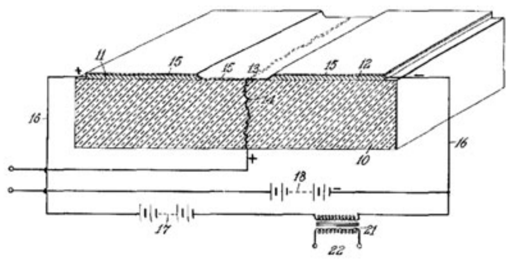

Fig. 1.4 Sketch of a field-effect transistor, 1926. From [53]

1911
The term 'Halbleiter' (semiconductor) is introduced for the first time by J. Weiss [46] and J. Königsberger and J. Weiss [47]. Königsberger preferred the term 'Variabler Leiter' (variable conductor).

1912
M. von Laue—X-ray diffraction of bulk crystals including ZnS (Fig. 1.3) [48, 49].

1925
J.E. Lilienfeld[6]—proposal of the metal-semiconductor field-effect transistor (MESFET) [53], with suggested copper sulfide thin film channel and aluminum gate.[7] (Fig. 1.4). Lilienfeld was also awarded patents for a depletion mode MOSFET [55] with proposed copper sulfide, copper oxide or lead oxide channel and current amplification with nppn- and pnnp-transistors [56]. Due to the lack of other publications of Lilienfeld on transistors, it is under discussion whether Lilienfeld just patented ideas or also build working devices with mounting evidence for the latter [51, 54, 57].

1927
A. Schleede, H. Buggisch—synthesis of pure, stoichiometric PbS, influence of sulphur excess and impurities [58].
A. Schleede, E. Körner—activation of luminescence of ZnS [59, 60].

[6]After obtaining his PhD in 1905 from the Friedrich-Wilhelms-Universität Berlin, Julius Edgar Lilienfeld joined the Physics Department of Universität Leipzig and worked on gas liquefaction and with Lord Zeppelin on hydrogen-filled blimps. In 1910 he became professor at the Universität Leipzig where he mainly researched on X-rays and vacuum tubes [50]. To the surprise of his colleagues he left in 1926 to join a US industrial laboratory [51, 52].

[7]In [51] it is suggested that the device works as a npn transistor, in [54] it is suggested to be a JFET.

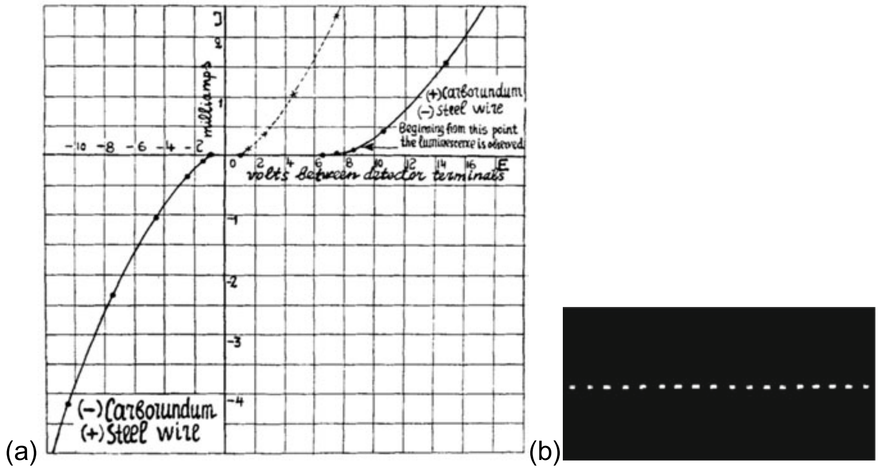

Fig. 1.5 **a** I–V characteristic of SiC/steel wire light emitting diode. The *dotted curve* is the flipped curve for negative voltage (3rd quadrant). **b** Recording of current modulated (at 500 Hz) LED on moving photographic plate. Adapted from [65]

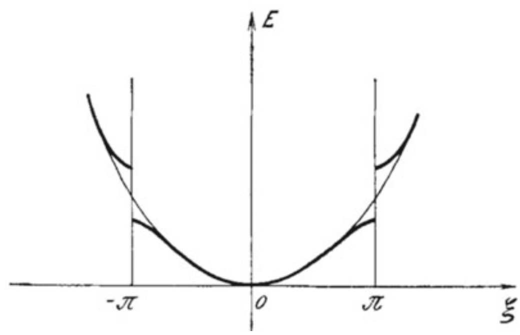

Fig. 1.6 First band structure calculation from Peierls ($\xi = k\,a$). Adapted from [69]

1928
F. Bloch—quantum mechanics of electrons in a crystal lattice, 'Bloch functions' [61].
O.V. Losev—description of the light emitting diode[8] (SiC) [65]; light emission was observed in forward direction and close to breakdown (Fig. 1.5a). Also current modulation of LED light output was reported (Fig. 1.5b) [65].

1929
R. Peierls—explanation of positive (anomalous) Hall effect with unoccupied electron states [66, 67].

1930
R. Peierls—first calculation of a band structure and band gap[9] (Fig. 1.6) [69].

1931
W. Heisenberg—theory of hole ('Löcher') states [70].
R. de L. Kronig and W.G. Penney—properties of periodic potentials in solids [71].

[8]The historic role of Losev regarding the invention of the LED and oscillators is discussed in [62–64].

[9]Peierls performed this work at suggestion of W. Pauli at ETH Zürich. The mathematical problem of Schrödinger's equation with a sinusoidal potential had been already treated by M.J.O Strutt in 1928 [68]

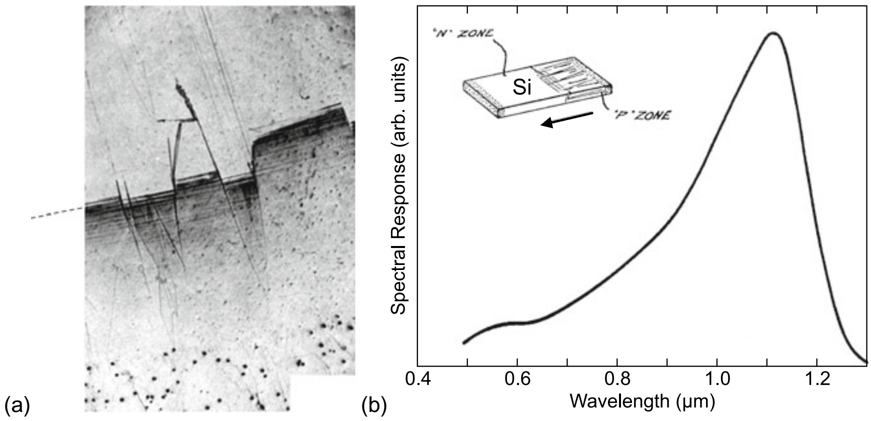

Fig. 1.7 **a** Optical image of directionally solidified silicon. The lower part contains predominantly boron, the upper part contains predominantly phosphorous. First the growth is porous and subsequently columnar. Adapted from [90]. **b** Spectral response of silicon pn-junction photoelement, 1940. The *inset* depicts schematically a Si slab with built-in pn-junction formed during directed solidification as shown in panel (**a**). The *arrow* denotes the direction of solidification (cmp. Fig. 4.6). Adapted from [89]

A.H. Wilson[10]—development of band-structure theory [74, 75].

1933
C. Wagner—excess ('Elektronenüberschuss-Leitung', n-type) and defect ('Elektronen-Defektleitung', p-type) conduction [76–79]. Anion deficiency in ZnO causes conducting behavior [80].

1934
C. Zener—Zener tunneling [81].

1936
J. Frenkel—description of excitons [82].

1938
B. Davydov—theoretical prediction of rectification at pn-junction [83] and in Cu_2O [84].
W. Schottky—theory of the boundary layer in metal–semiconductor contacts [85], being the basis for Schottky contacts and field-effect transistors.
N.F. Mott—metal–semiconductor rectifier theory [86, 87].
R. Hilsch and R.W. Pohl—three-electrode crystal (KBr) [88].

1940
R.S. Ohl—Silicon-based photoeffect (solar cell, Fig. 1.7) [89] from a pn-junction formed within a slab of polycrystalline Si fabricated with directed solidification due to different distribution coefficients of p- and n-dopants (boron and phosphorus, cmp. Fig. 4.6b) (J. Scaff and H. Theurer) [90, 91].

[10]Wilson was theoretical physicist in Cambridge, who spent a sabbatical with Heisenberg in Leipzig and applied the brand new field of quantum mechanics to issues of electrical conduction, first in metals and then in semiconductors. When he returned to Cambridge, Wilson urged that attention be paid to germanium but, as he expressed it long afterward, 'the silence was deafening' in response. He was told that devoting attention to semiconductors, those messy entities, was likely to blight his career among physicists. He ignored these warnings and in 1939 brought out his famous book 'Semiconductors and Metals' [72] which explained semiconductor properties, including the much-doubted phenomenon of intrinsic semiconductivity, in terms of electronic energy bands. His academic career seems indeed to have been blighted, because despite his great intellectual distinction, he was not promoted in Cambridge (he remained an assistant professor year after year) [73]. Compare the remark of W. Pauli (p. 179)

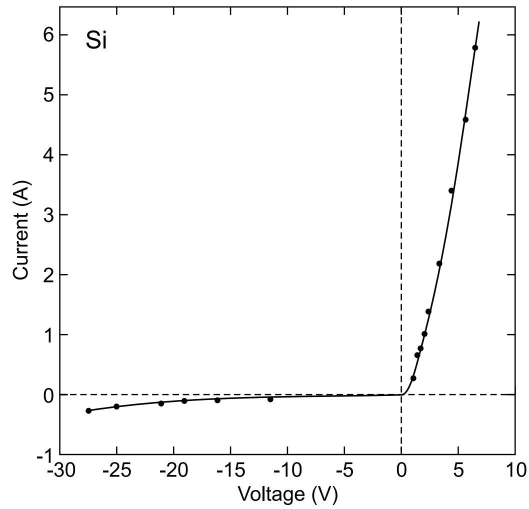

Fig. 1.8 Characteristics of a silicon rectifier, 1941. Adapted from [92]

1941
R.S. Ohl—Silicon rectifier with point contact [92, 93] (Fig. 1.8), building on work from G.W. Pickard (1906) and using metallurgically refined and intentionally doped silicon (J. Scaff and H. Theurer) [90].

1942
K. Clusius, E. Holz and H. Welker—rectification in germanium [94].

1945
H. Welker—patents for JFET and MESFET [95].

1947
W. Shockley, J. Bardeen and W. Brattain fabricate the first transistor in the AT&T Bell Laboratories, Holmdel, NJ in an effort to improve hearing aids [96].[11] Strictly speaking the structure was a point-contact transistor. A 50-µm wide slit was cut with a razor blade into gold foil over a plastic (insulating) triangle and pressed with a spring on n-type germanium (Fig. 1.9a) [97]. The surface region of the germanium is p-type due to surface states and represents an inversion layer. The two gold contacts form emitter and collector, the large-area back contact of the germanium the base contact [98]. For the first time, amplification was observed [99]. Later models use two close point contacts made from wires with their tips cut into wedge shape (Fig. 1.9b) [98].[12] More details about the history and development of the semiconductor transistor can be found in [100], written on the occasion of the 50th anniversary of its invention.

1948
W. Shockley—invention of the bipolar (junction) transistor [101].

1952
H. Welker—fabrication of III–V compound semiconductors[13] [104–107].

[11] Subsequently, AT&T, under pressure from the US Justice Department's antitrust division, licensed the transistor for $25,000. This action initiated the rise of companies like Texas Instruments, Sony and Fairchild.

[12] The setup of Fig. 1.9b represents a common base circuit. In a modern bipolar transistor, current amplification in this case is close to unity (Sect. 24.2.2). In the 1948 germanium transistor, the reversely biased collector contact is influenced by the emitter current such that current amplification $\partial I_C / \partial I_E$ for constant U_C was up to 2–3. Due to the collector voltage being much larger than the emitter voltage, a power gain of $\sim$ 125 was reported [98].

[13] An early concept for III–V semiconductors was developed in [102, 103].

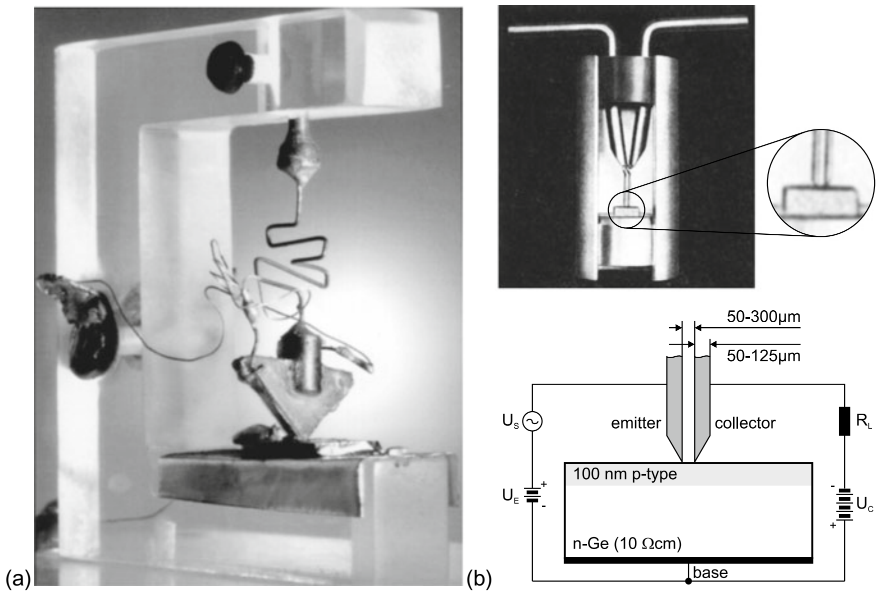

Fig. 1.9 **a** The first transistor, 1947 (length of side of wedge: 32 mm). **b** Cutaway model of a 1948 point contact transistor ('Type A') based on n-type bulk Ge ($n = 5 \times 10^{14}\,\mathrm{cm}^{-3}$) and common base circuit diagram. The surface region ($\sim$ 100 nm depth) of the Ge is p-type due to surface states and represents an inversion layer. The two wires are made from phosphor bronze. Adapted from [98]

W. Shockley—description of today's version of the (J)FET [108].

1953
G.C. Dacey and I.M. Ross—first realization of a JFET [109].
D.M. Chapin, C.S. Fuller and G.L. Pearson—invention of the silicon solar cell at Bell Laboratories [110]. A single $2\,\mathrm{cm}^2$ photovoltaic cell from Si, Si:As with an ultrathin layer of Si:B, with about 6% efficiency generated 5 mW of electrical power.[14] Previously existing solar cells based on selenium had very low efficiency ($< 0.5\%$).

1958
J.S. Kilby made the first integrated circuit at Texas Instruments. The simple 1.3 MHz RC-oscillator consisted of one transistor, three resistors and a capacitor on a $11 \times 1.7\,\mathrm{mm}^2$ Ge platelet (Fig. 1.10a). J.S. Kilby filed in 1959 for a US patent for miniaturized electronic circuits [111]. At practically the same time R.N. Noyce from Fairchild Semiconductors, the predecessor of INTEL, invented the integrated circuit on silicon using planar technology [112]. A detailed and (very) critical view on the invention of the integrated circuit can be found in [113].
Figure 1.10b shows a flip-flop with four bipolar transistors and five resistors. Initially, the invention of the integrated circuit[15] met scepticism because of concerns regarding yield and the achievable quality of the transistors and the other components (such as resistors and capacitors).

[14] A solar cell with 1 W power cost \$300 in 1956 (\$3 in 2004). Initially, 'solar batteries' were only used for toys and were looking for an application. H. Ziegler proposed the use in satellites in the 'space race' of the late 1950s.

[15] The two patents led to a decade-long legal battle between Fairchild Semiconductors and Texas Instruments. Eventually, the US Court of Customs and Patent Appeals upheld R.N. Noyce's claims on interconnection techniques but gave J.S. Kilby and Texas Instruments credit for building the first working integrated circuit.

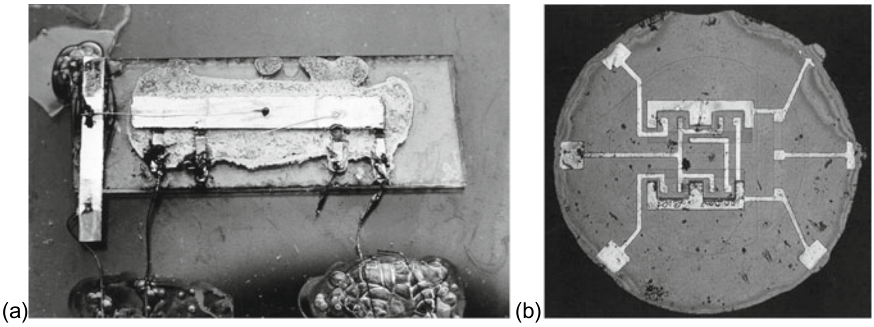

Fig. 1.10 **a** The first integrated circuit, 1958 (germanium, $11 \times 1.7\,\mathrm{mm}^2$). **b** The first planar integrated circuit, 1959 (silicon, diameter: 1.5 mm)

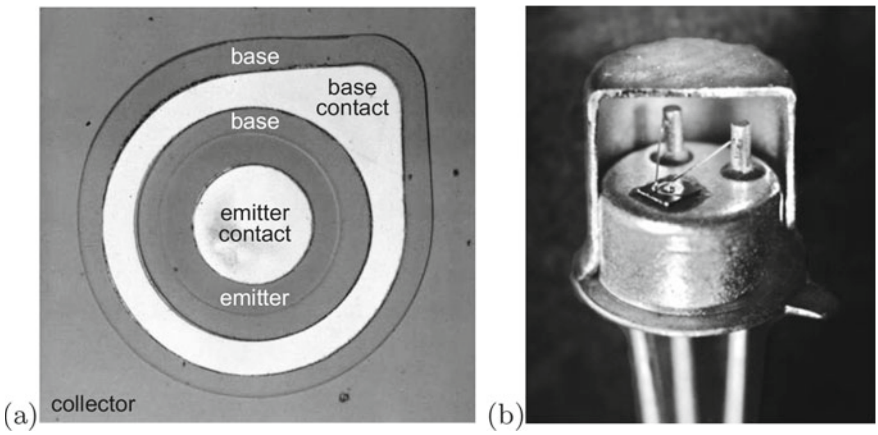

Fig. 1.11 (**a**) Optical image of planar pnp silicon transistor (2N1613 [120]), 1959. The contacts are Al surfaces (not bonded). (**b**) Housing of such transistor cut open

1959
J. Hoerni[16] and R. Noyce—first realization of a planar transistor (in silicon) (Fig. 1.11) [115–119].

1960
D. Kahng and M.M. Atalla—first realization of a MOSFET [121, 122].

1962
The first semiconductor laser on GaAs basis at 77 K at GE [123, 124] (Fig. 1.12) and at IBM [125] and MIT [126].
First visible laser diode [127].[17]

1963
Proposal of a double heterostructure laser (DH laser) by Zh.I. Alferov [130, 131] and H. Kroemer [132, 133].
J.B. Gunn—discovery of the Gunn effect, the spontaneous microwave oscillations in GaAs and InP at sufficiently large applied electric field (due to negative differential resistance) [134].

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[16] The Swiss born Jean Hoerni also contributed $12 000 for the building of the first school in the Karakoram Mountain area in Pakistan and has continued to build schools in Pakistan and Afghanistan as described in [114].

[17] Remarks on the discovery and further development of the laser diode can be found in [128, 129].

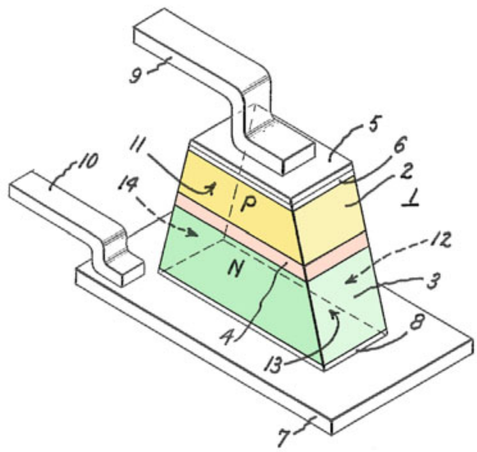

Fig. 1.12 Schematics of GaAs-based laser diode. The active layer is highlighted in *red*. Adapted from [124]

1966
C.A. Mead—proposal of the MESFET ('Schottky Barrier Gate FET') [135].

1967
Zh.I. Alferov—report of the first DH laser on the basis of Ga(As,P) at 77 K [136, 137].
W.W. Hooper and W.I. Lehrer—first realization of a MESFET [138].

1968
DH laser on the basis of GaAs/(Al,Ga)As at room temperature, independently developed by Zh.I. Alferov [139] and I. Hayashi [140].
GaP:N LEDs with yellow-green emission (550 nm) and 0.3% efficiency [141].

1968
SiC blue LED with efficiency of 0.005% [142].

1970
W.S. Boyle and G.E. Smith—invention of the charge coupled device (CCD) [143, 144].

1971
R.F. Kazarinov and R.A. Suris—proposal of the quantum cascade laser [145].

1975
R.S. Pengelly and J.A. Turner—first monolithic microwave integrated circuit (MMIC) (Fig. 1.13) [146]

1992
S. Nakamura—growth of high-quality group-III–nitride thin films [147], blue nitride heterostructure LED with efficiency exceeding 10% (1995) [148] (Fig. 1.14a). Later the white LED was built by combining a blue LED with yellow phosphors (Fig. 1.14b, c).

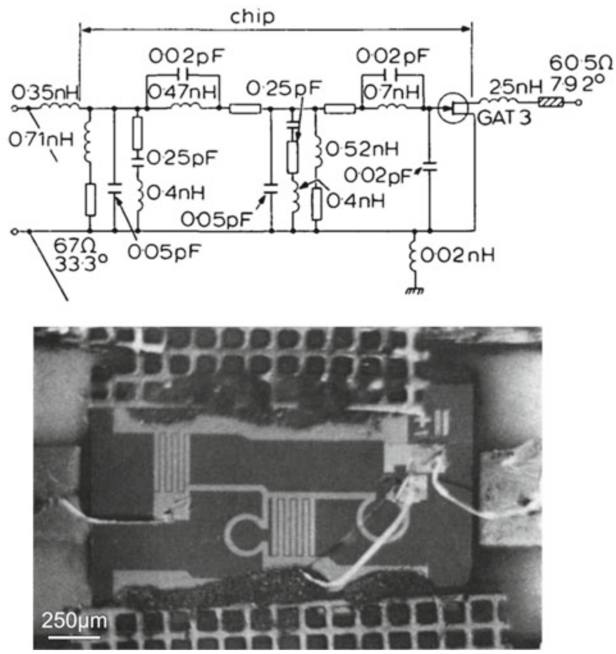

Fig. 1.13 Equivalent circuit and optical image of first monolithic microwave integrated circuit (exhibiting gain (4.5 ± 0.9 dB) in the frequency range 7.0–11.7 GHz). Adapted from [146]

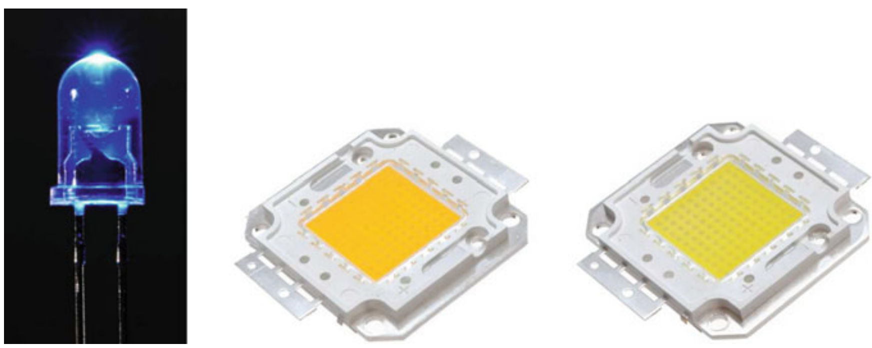

Fig. 1.14 **a** Blue LED (standard housing). 50 W, 4000 lm, **b** warm white and **c** cold white LED (45 × 45 mm^2)

1994

J. Faist and F. Capasso—quantum cascade laser [149].

N. Kirstaedter, N.N. Ledentsov, Zh.I. Alferov and D. Bimberg—quantum dot laser [150].

2004

H. Hosono and T. Kamiya—thin film transistor (TFT) from amorphous oxide semiconductor [151].

1.2 Nobel Prize Winners

Several Nobel Prizes[18] have been awarded for discoveries and inventions in the field of semiconductor physics (Fig. 1.15).

1909
Karl Ferdinand Braun
'in recognition of his contributions to the development of wireless telegraphy'

1914
Max von Laue 'for his discovery of the diffraction of X-rays by crystals'

1915
Sir William Henry Bragg
William Lawrence Bragg
'for their services in the analysis of crystal structure by means of X-rays'

1946
Percy Williams Bridgman
'for the invention of an apparatus to produce extremely high pressures, and for the discoveries he made therewith in the field of high pressure physics'

1953
William Bradford Shockley
John Bardeen
Walter Houser Brattain
'for their researches on semiconductors and their discovery of the transistor effect'

1973
Leo Esaki
'for his experimental discoveries regarding tunneling phenomena in semiconductors'

1985
Klaus von Klitzing
'for the discovery of the quantized Hall effect'

1998
Robert B. Laughlin
Horst L. Störmer
Daniel C. Tsui
'for their discovery of a new form of quantum fluid with fractionally charged excitations'

2000
Zhores I. Alferov
Herbert Kroemer
'for developing semiconductor heterostructures used in high-speed and optoelectronics'
Jack St. Clair Kilby
'for his part in the invention of the integrated circuit'

2009
Willard S. Boyle
George E. Smith
'for the invention of an imaging semiconductor circuit—the CCD sensor'

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[18] www.nobel.se

Fig. 1.15 Winners of Nobel Prize in Physics and year of award with great importance for semiconductor physics

Fig. 1.15 (continued)

2014
Isamu Akasaki
(*1929)

2014
Hiroshi Amano
(*1960)

2014
Shuji Nakamura
(*1954)

2010
Andre Geim
Konstantin Novoselov
'for groundbreaking experiments regarding the two-dimensional material graphene'

2014
Isamu Akasaki
Hiroshi Amano
Shuji Nakamura
'for the invention of efficient blue light-emitting diodes which has enabled bright and energy-saving white light sources'

1.3 General Information

In Fig. 1.16, the periodic table of elements is shown.
In Table 1.1 the physical properties of various semiconductors are summarized. Data on semiconductors can be found in [152–166].

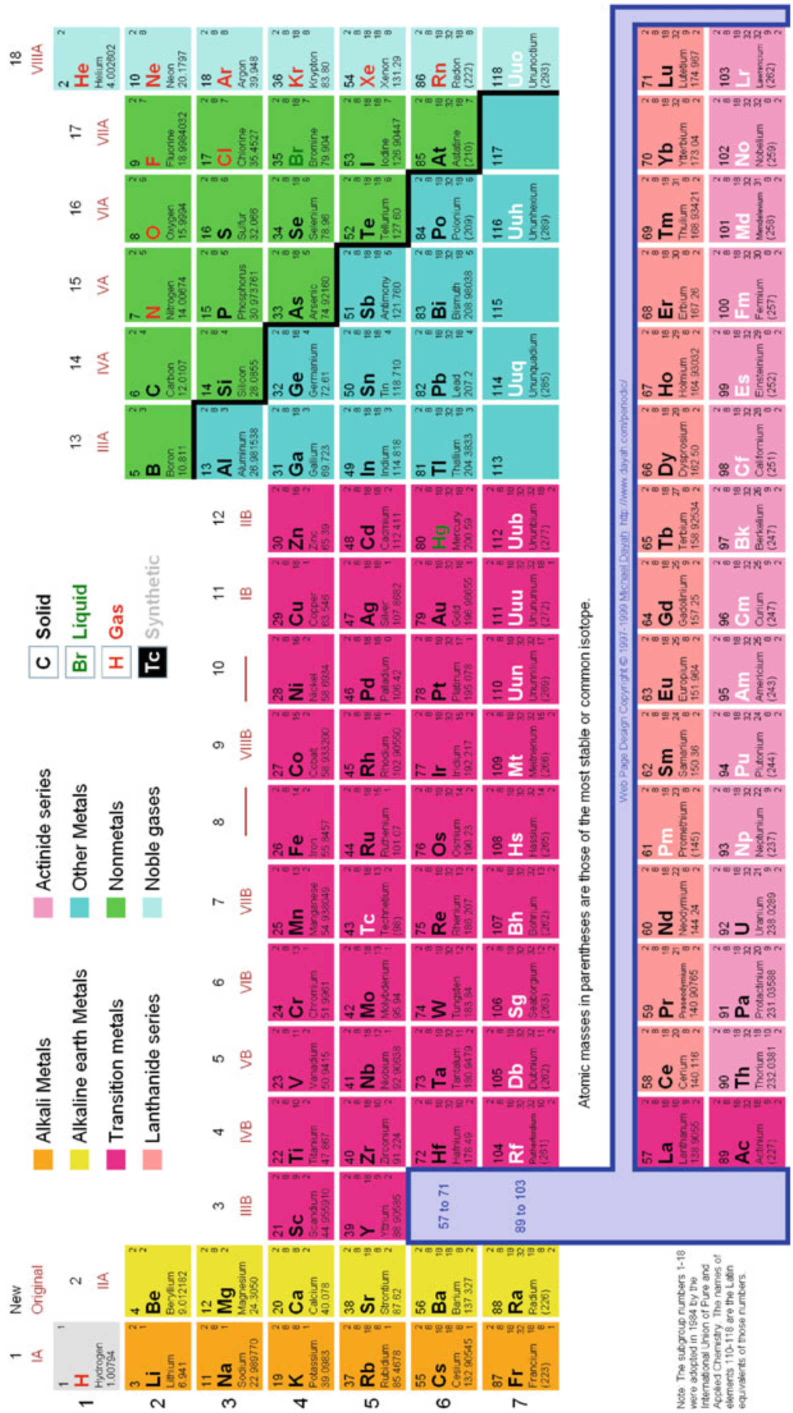

Fig. 1.16 Periodic table of elements. From [167]

Table 1.1 Physical properties of various (bulk) semiconductors at room temperature. 'S' denotes the crystal structure (d: diamond, w: wurtzite, zb: zincblende, ch: chalcopyrite, rs: rocksalt)

	S	a_0 (nm)	E_g (eV)	m_e^*	m_h^*	ϵ_0	n_r	μ_e (cm^2/Vs)	μ_h (cm^2/Vs)
C	d	0.3567	5.45 (Γ)			5.5	2.42	2200	1600
Si	d	0.5431	1.124 (X)	0.98 (m_l) 0.19 (m_t)	0.16 (m_{lh}) 0.5 (m_{hh})	11.7	3.44	1350	480
Ge	d	0.5658	0.67 (L)	1.58 (m_l) 0.08 (m_t)	0.04 (m_{lh}) 0.3 (m_{hh})	16.3	4.00	3900	1900
α-Sn	d	0.64892	0.08 (Γ)	0.02				2000	1000
3C-SiC	zb	0.436	2.4			9.7	2.7	1000	50
4H-SiC	w	0.3073 (a)	3.26			9.6	2.7		120
		1.005 (c)							
6H-SiC	w	0.30806 (a) 1.5117 (c)	3.101			10.2	2.7	1140	850
AlN	w	0.3111 (a) 0.4978 (c)	6.2			8.5	3.32		
AlP	zb	0.54625	2.43 (X)	0.13		9.8	3.0	80	
AlAs	zb	0.56605	2.16 (X)	0.5	0.49 (m_{lh}) 1.06 (m_{hh})	12		1000	80
AlSb	zb	0.61335	1.52 X)	0.11	0.39	11	3.4	200	300
GaN	w	0.3189 (a) 0.5185 (c)	3.4 (Γ)	0.2	0.8	12	2.4	1500	
GaP	zb	0.54506	2.26 (Γ)	0.13	0.67	10	3.37	300	150
GaAs	zb	0.56533	1.42 (Γ)	0.067	0.12 (m_{lh}) 0.5 (m_{hh})	12.5	3.4	8500	400
GaSb	zb	0.60954	0.72 (Γ)	0.045	0.39	15	3.9	5000	1000
InN	w	0.3533 (a)	0.69 (Γ)						
		0.5693 (c)							
InP	zb	0.58686	1.35 (Γ)	0.07	0.4	12.1	3.37	4000	600
InAs	zb	0.60584	0.36 (Γ)	0.028	0.33	12.5	3.42	22 600	200
InSb	zb	0.64788	0.18 (Γ)	0.013	0.18	18	3.75	100 000	1700
ZnO	w	0.325 (a)	3.4 (Γ)	0.24	0.59	6.5	2.2	220	
		0.5206 (c)							
ZnS	zb	0.54109	3.6 (Γ)	0.3		8.3	2.4	110	
ZnSe	zb	0.56686	2.58 (Γ)	0.17		8.1	2.89	600	
ZnTe	zb	0.61037	2.25 (Γ)	0.15		9.7	3.56		
CdO	rs	0.47	2.16						

(continued)

Table 1.1 (continued)

	S	a_0 (nm)	E_g (eV)	m_e^*	m_h^*	ϵ_0	n_r	μ_e (cm^2/Vs)	μ_h (cm^2/Vs)
CdS	w	0.416 (a) 0.6756 (c)	2.42 (Γ)	0.2	0.7	8.9	2.5	250	
CdSe	zb	0.650	1.73 (Γ)	0.13	0.4	10.6		650	
CdTe	zb	0.64816	1.50 (Γ)	0.11	0.35	10.9	2.75	1050	100
	S	a_0 (nm)	E_g (eV)	m_e^*	m_h^*	ϵ_0	n_r	μ_e (cm^2/Vs)	μ_h (cm^2/Vs)
MgO	rs	0.421	7.3						
HgS	zb	0.5852	2.0 (Γ)					50	
HgSe	zb	0.6084	−0.15 (Γ)	0.045		25		18 500	
HgTe	zb	0.64616	−0.15 (Γ)	0.029	0.3	20	3.7	22 000	100
PbS	rs	0.5936	0.37 (L)	0.1	0.1	170	3.7	500	600
PbSe	rs	0.6147	0.26 (L)	0.07 (m_{lh})	0.06 (m_{lh})	250		1800	930
				0.039 (m_{hh})	0.03 (m_{hh})				
PbTe	rs	0.645	0.29 (L)	0.24 (m_{lh}) 0.02 (m_{hh})	0.3 (m_{lh}) 0.02 (m_{hh})	412		1400	1100
$ZnSiP_2$	ch	0.54 (a)	2.96 (Γ)	0.07					
		1.0441 (c)							
$ZnGeP_2$	ch	0.5465 (a) 1.0771 (c)	2.34 (Γ)		0.5				
$ZnSnP_2$	ch	0.5651 (a) 1.1302 (c)	1.66 (Γ)						
$CuInS_2$	ch	0.523 (a) 1.113 (c)	1.53 (Γ)						
$CuGaS_2$	ch	0.5347 (a) 1.0474 (c)	2.5 (Γ)						
$CuInSe_2$	ch	0.5784 (a) 1.162 (c)	1.0 (Γ)						
$CuGaSe_2$	ch	0.5614 (a) 1.103 (c)	1.7 (Γ)						