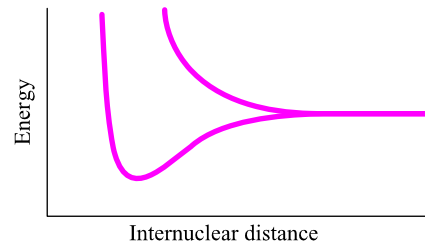
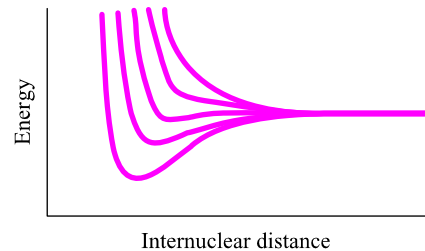




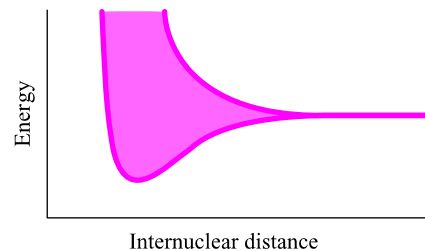
Band Theory of Solids



(a)



(b)



(c)

그림 10.19 나트륨 원자 바닥상태에서 채워진 준위들 중 가장 높은 준위는 3s 준위이다. (a) 나트륨원자가 서로 접근함에 따라, 전자 파동함수의 겹침에 의해 처음에는 같았던 3s 준위들이 두 준위로 갈라지게 된다. (b) 새로 생기는 준위들의 수는 상호작용을 하는 원자 수와 같다. 여기서는 5개이다. (c) 고체 나트륨과 같이 상호작용을 하는 원자 수가 많아지면, 준위들의 간격이 매우 조밀한 에너지 띠로 된다.



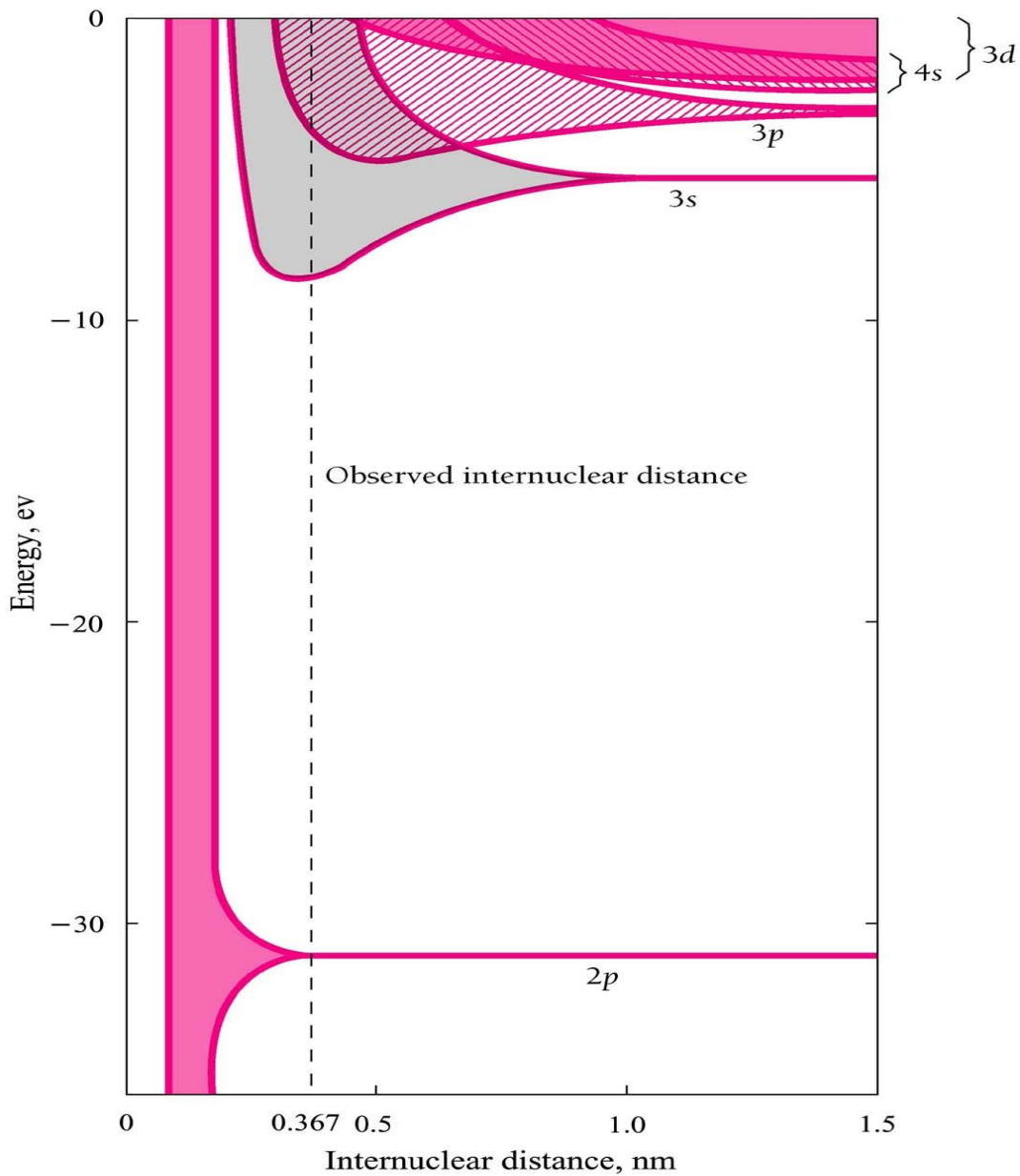
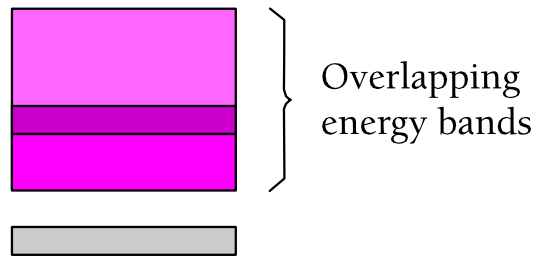
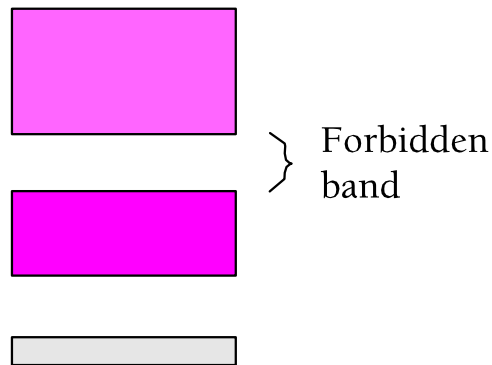


그림 10.20 핵간 거리가 줄어들면서 나트륨 원자의 에너지 준위들은 따로 된다. 고체 나트륨에서 관찰된 핵간의 거리는 0.367nm이다.





(a)



(b)

그림 10.21 (a) 어떤 고체에서는 에너지 띠가 서로 겹쳐져서 연속적인 띠를 형성한다.
(b) 다른 고체에서는, 금지된 띠가 서로 겹치지 않은 에너지 띠를 분리시킨다.



Conductors

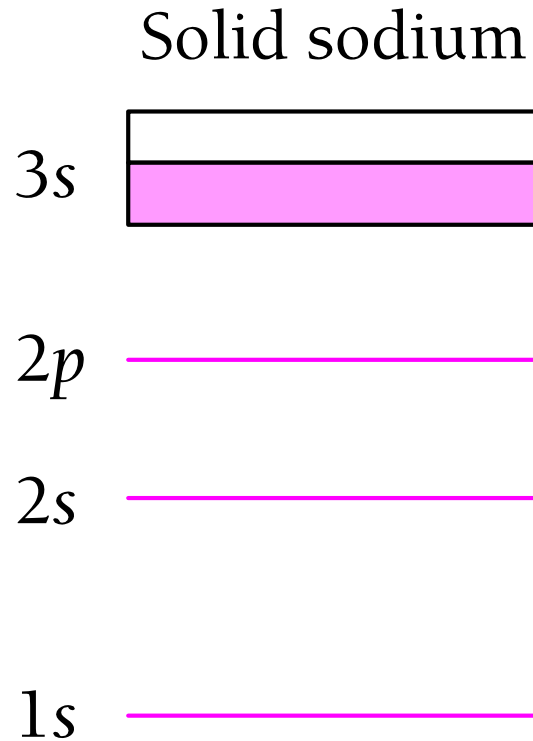
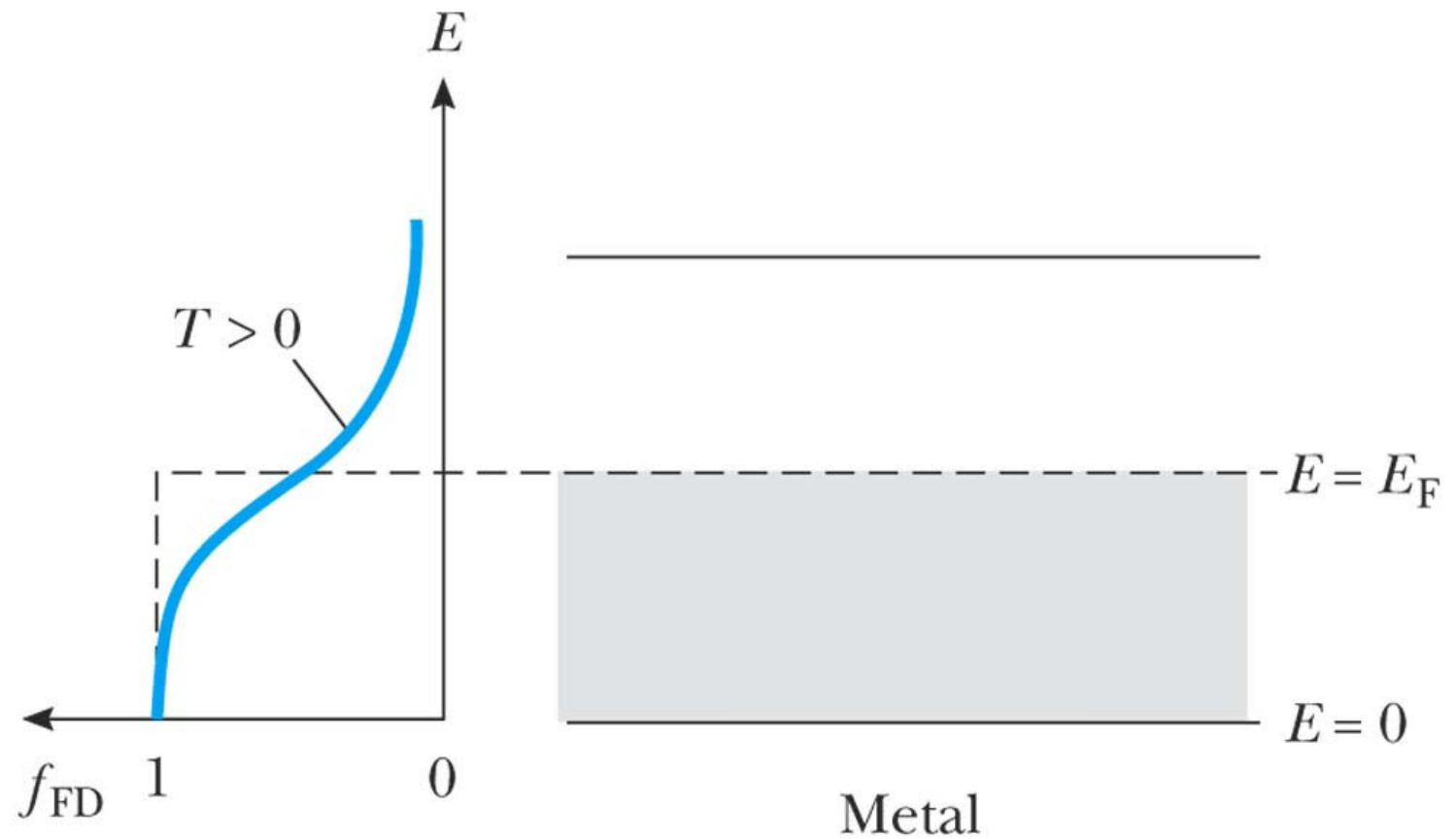


그림 10.22 고체 나트륨의 3s 에너지 띠는 절반만이 전자들로 차 있다. 페르미(Fermi)에너지는 띠의 중간에 있다.



Conductors



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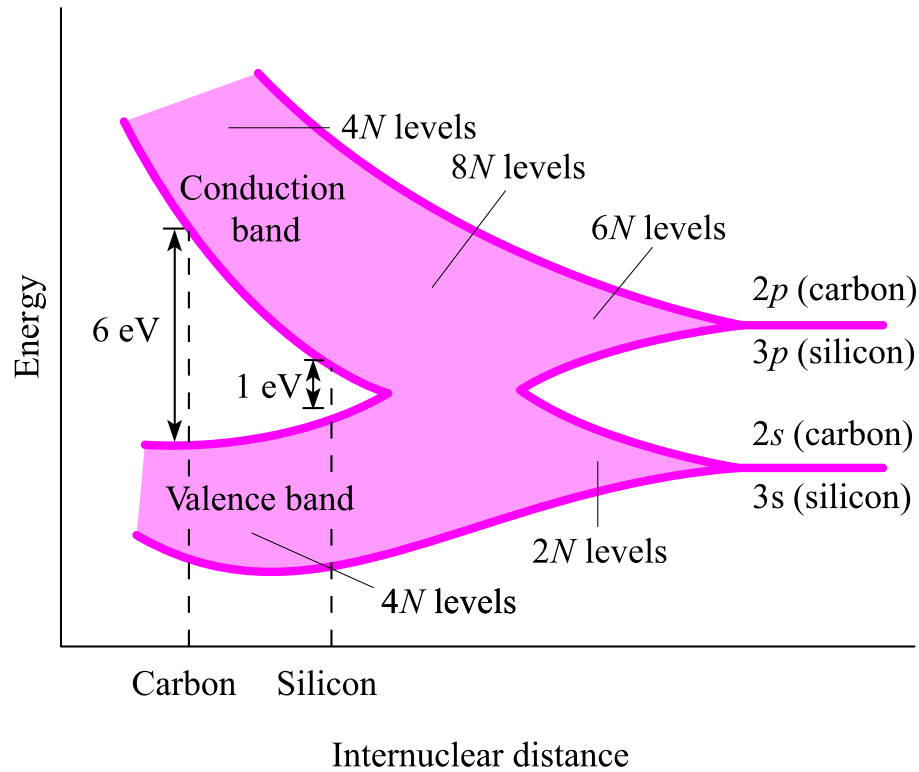


그림 10.23 탄소와 실리콘의 에너지 띠의 기원. 탄소는 2s와 2p 준위가 그리고 실리콘에서는 3s와 3p 준위가 에너지 띠로 펼쳐진다. 원자간 거리가 좁아짐에 따라서, 처음에는 겹쳐지다가 다음에는 갈라져 나가는 두 띠로 분리된다. 아래 띠는 원자가 전자들로 채워지고 위 전도 띠는 비어 있다. 두 띠 사이의 에너지 간격은 원자간 간격에 따라 달라지며, 실리콘에서보다 탄소에서 그 간격이 더 크다.



Insulators

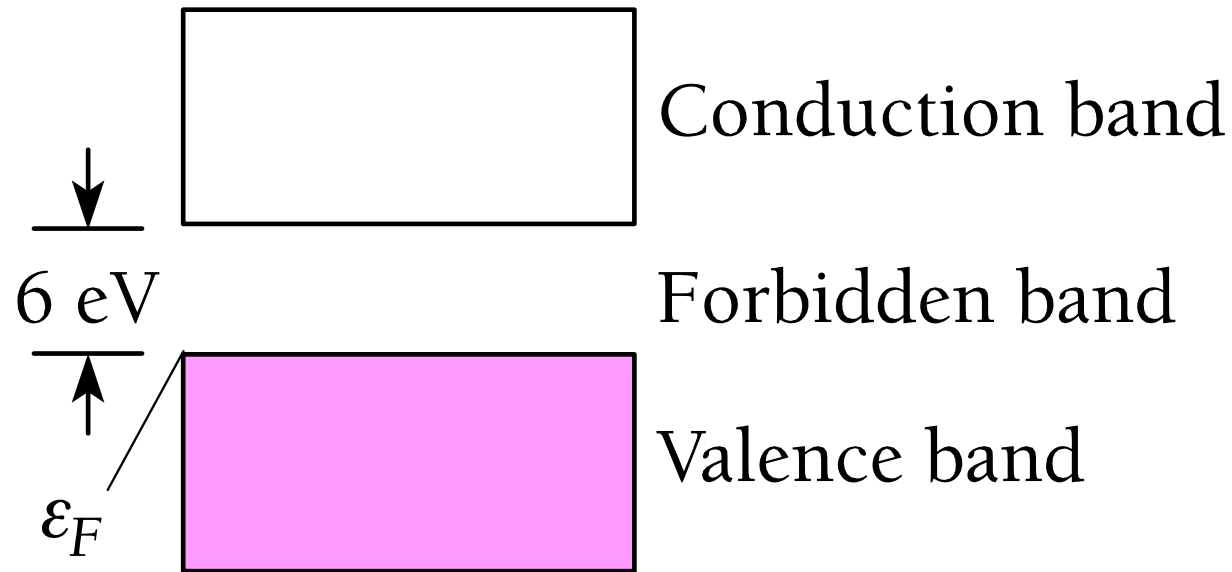
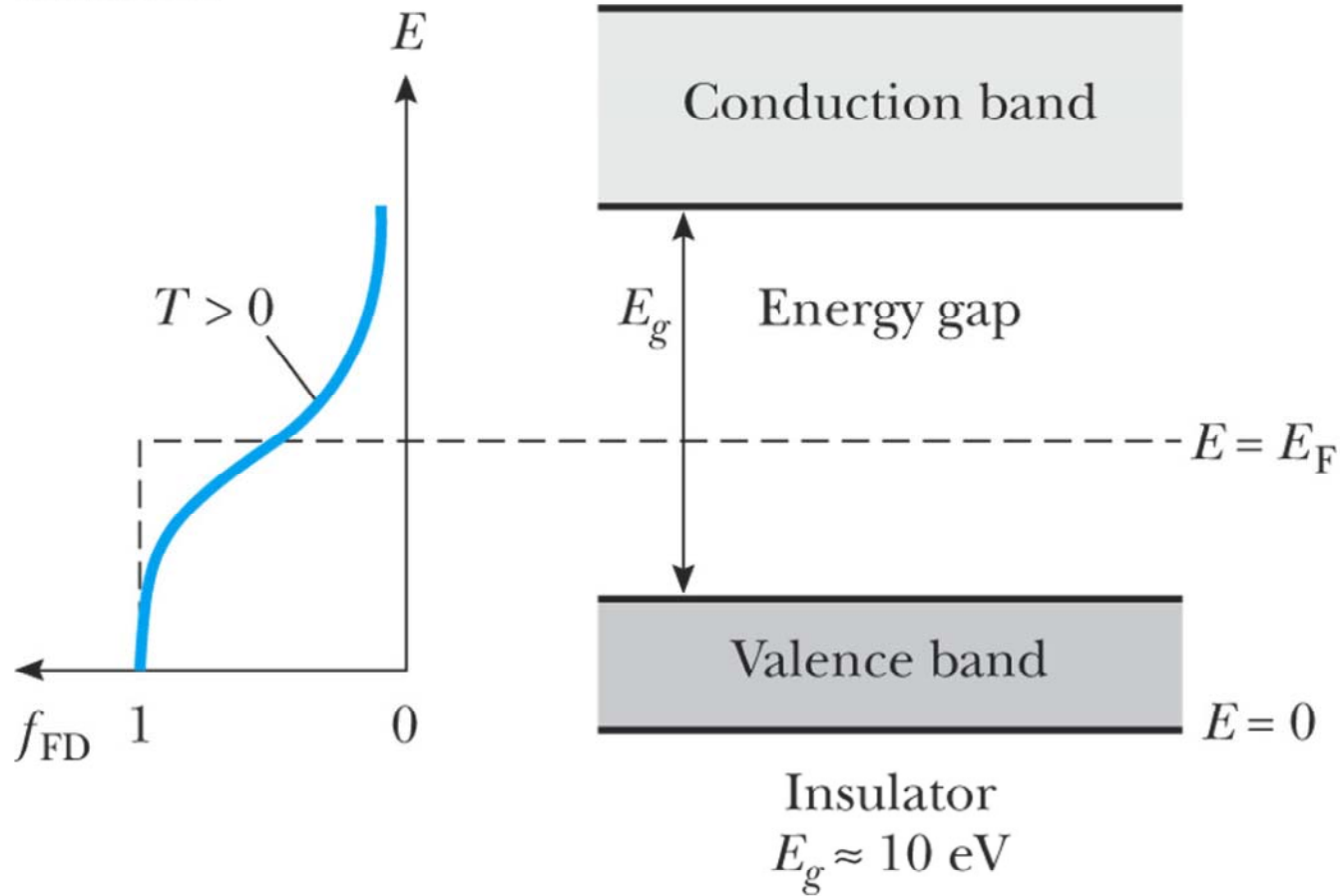


그림 10.24 다이아몬드의 에너지 띠. 페르미(Fermi)에너지는 차 있는 아래 에너지 띠의 맨 꼭대기에 위치한다. 원자가 띠에 있는 전자가 전도 띠로 올라가기 위해서 최소한 6eV가 필요하므로, 다이아몬드는 부도체이다.





Insulators



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Semiconductors

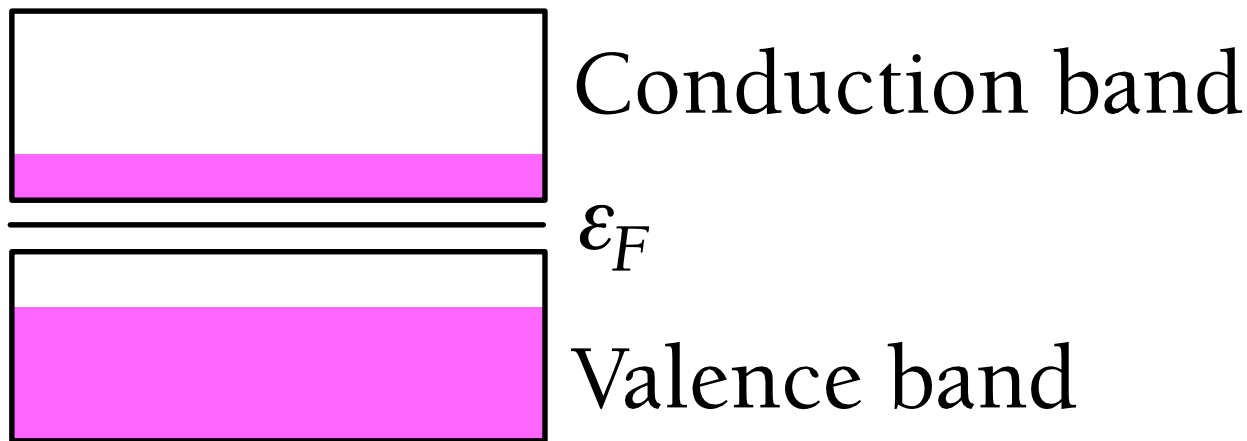
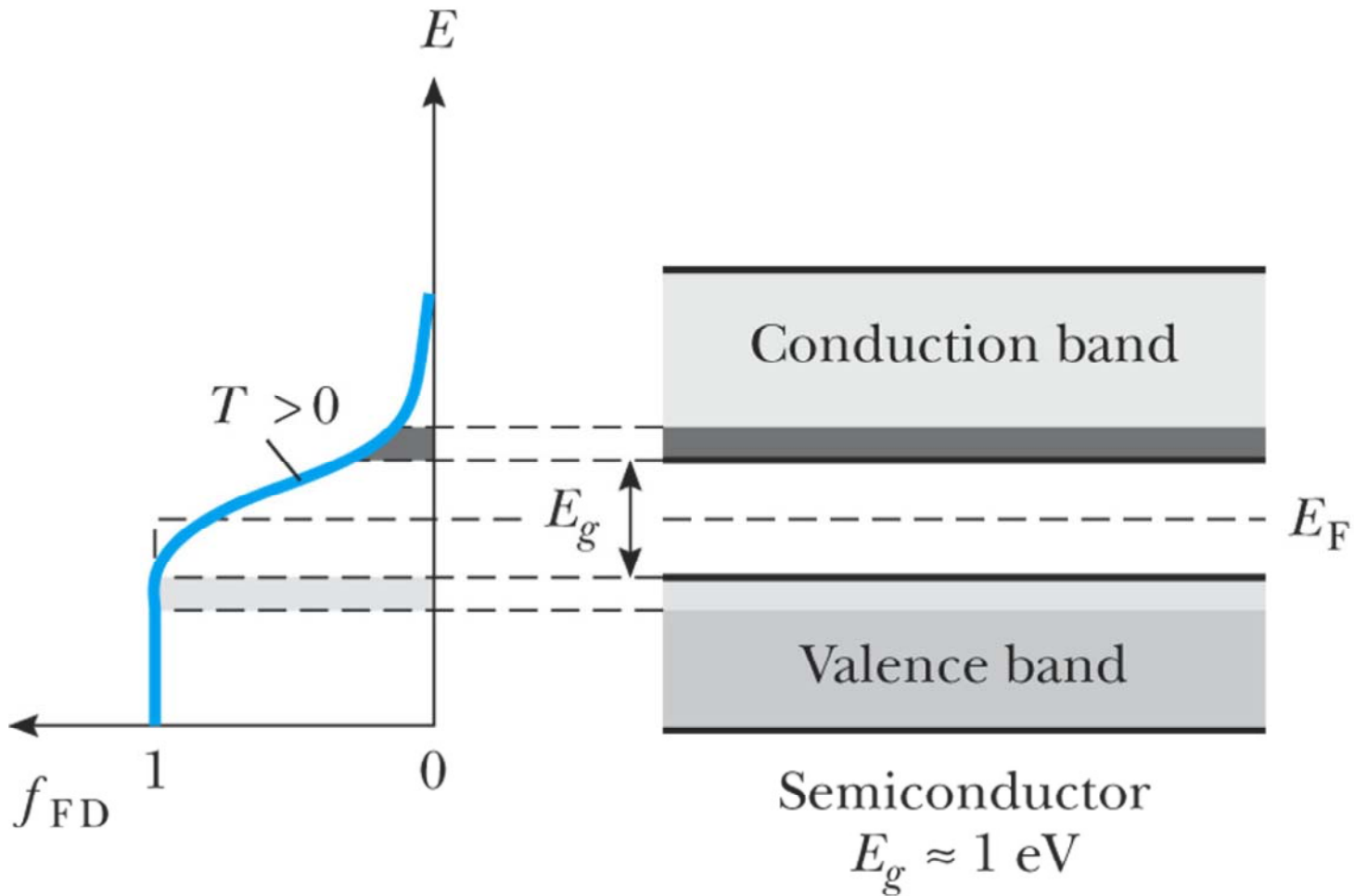


그림 10.25 반도체에서는 원자가 띠와 전도 띠가 부도체에서보다 작은 간격에 의해 분리되어 있다. 여기에서는 원자가 띠 꼭대기에 있는 적은 수의 전자들이 간격을 뛰어넘어 전도 띠로 옮겨갈 수 있을 만큼의 충분한 열 에너지를 받을 수 있다. 그러므로 Fermi 에너지는 띠 간격의 중간에 위치한다.



Semiconductors



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n-Type Semiconductor

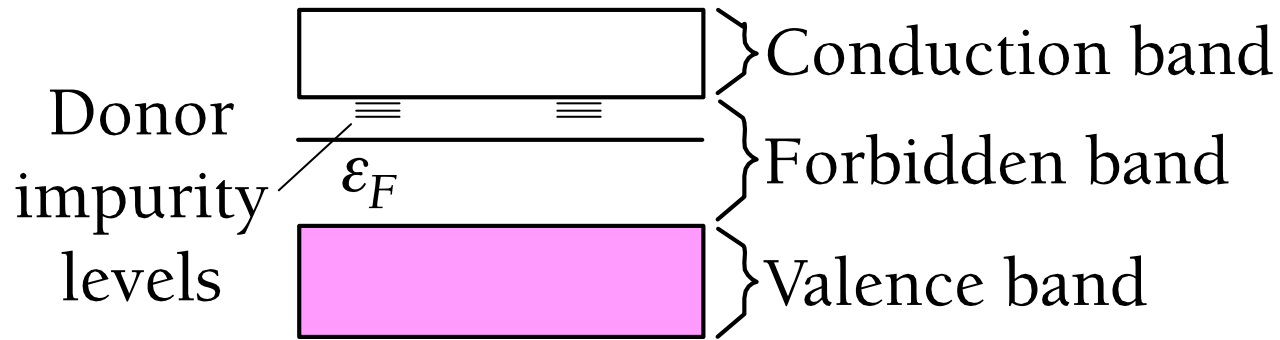
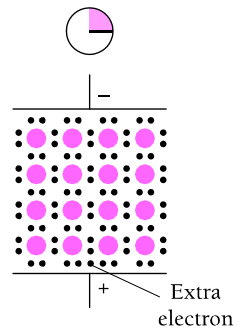
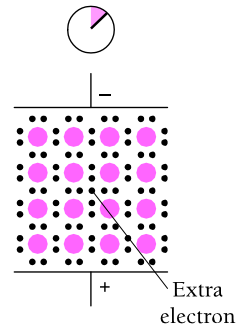
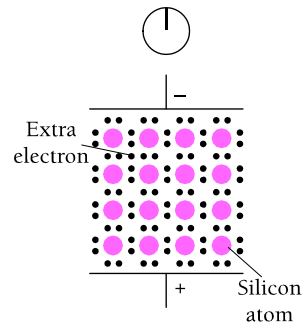


그림 10.26 실리콘 결정에 비소의 첨가는 정상적으로는 금지된 띠 안에 주개(donor) 준위를 만들고, n-반도체를 형성한다.



n-Type Semiconductor





p-Type Semiconductor

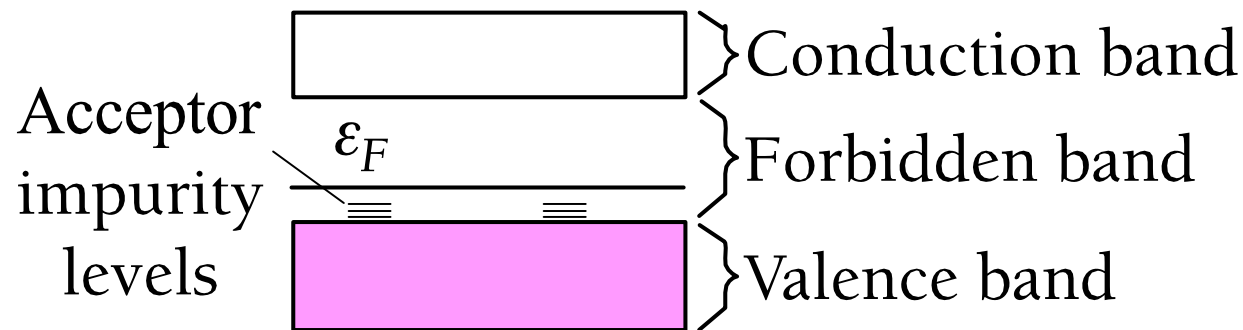
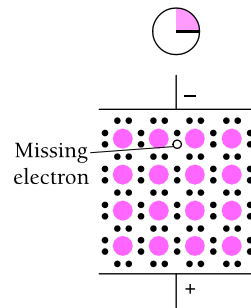
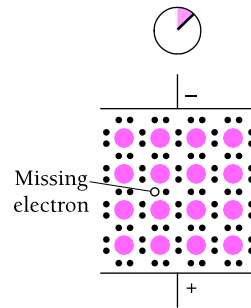
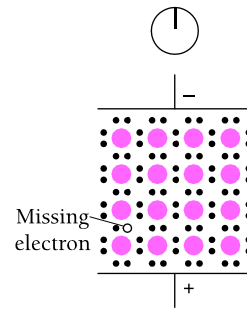
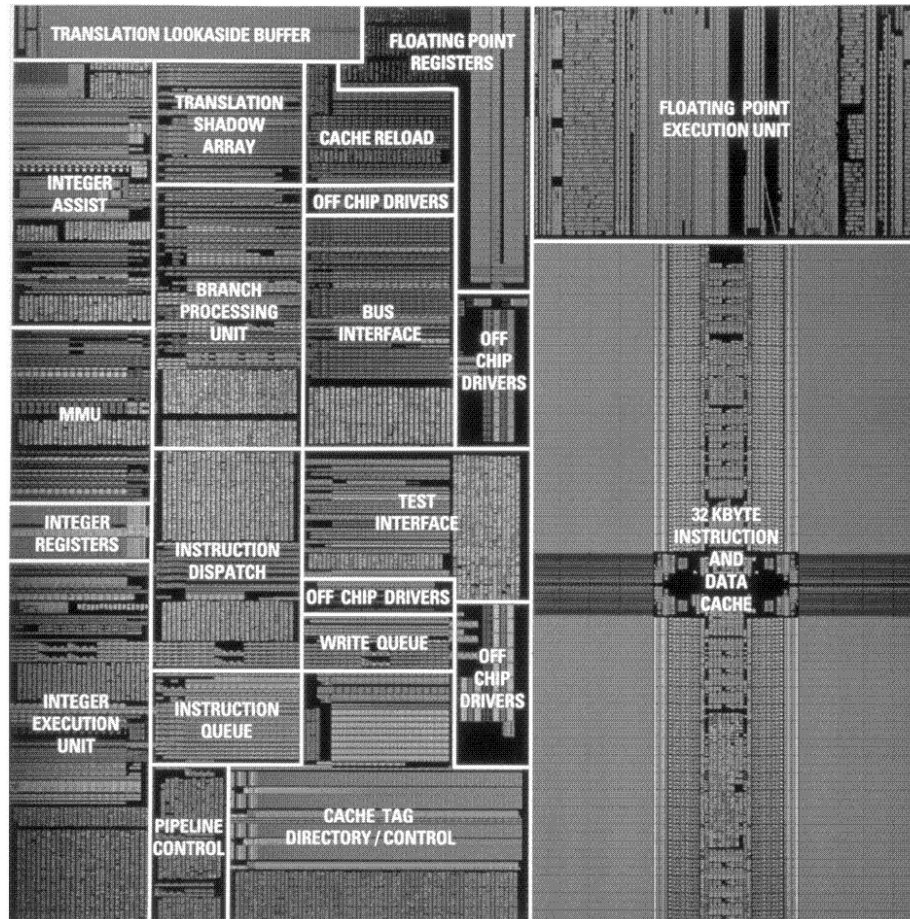


그림 10.29 실리콘 결정에서의 비소(As) 흔적은 금지된 띠에 주개 준위를 만들고 p-형 반도체가 되게 한다.

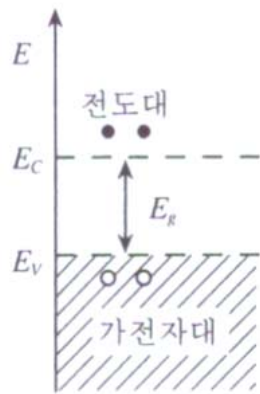


p-Type Semiconductor

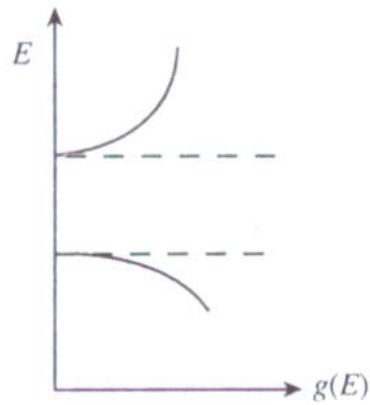




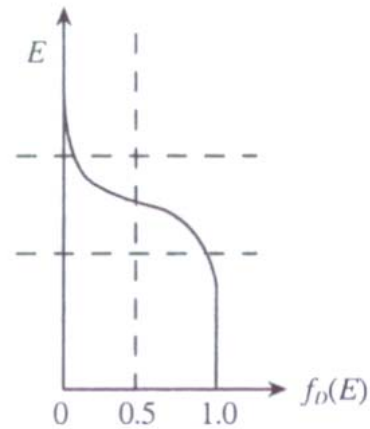
IBM PowerPC 601의 마이크로프로세서는 사방 10.95mm인 사각형 안에 280만개의 트랜지스터가 포함되어 있다. 칩 각 부분의 역할이 표시되어 있다.



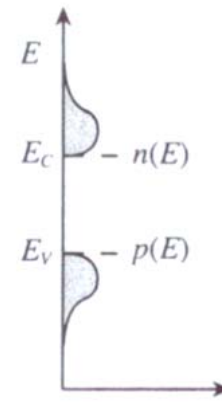
(a)



(b)

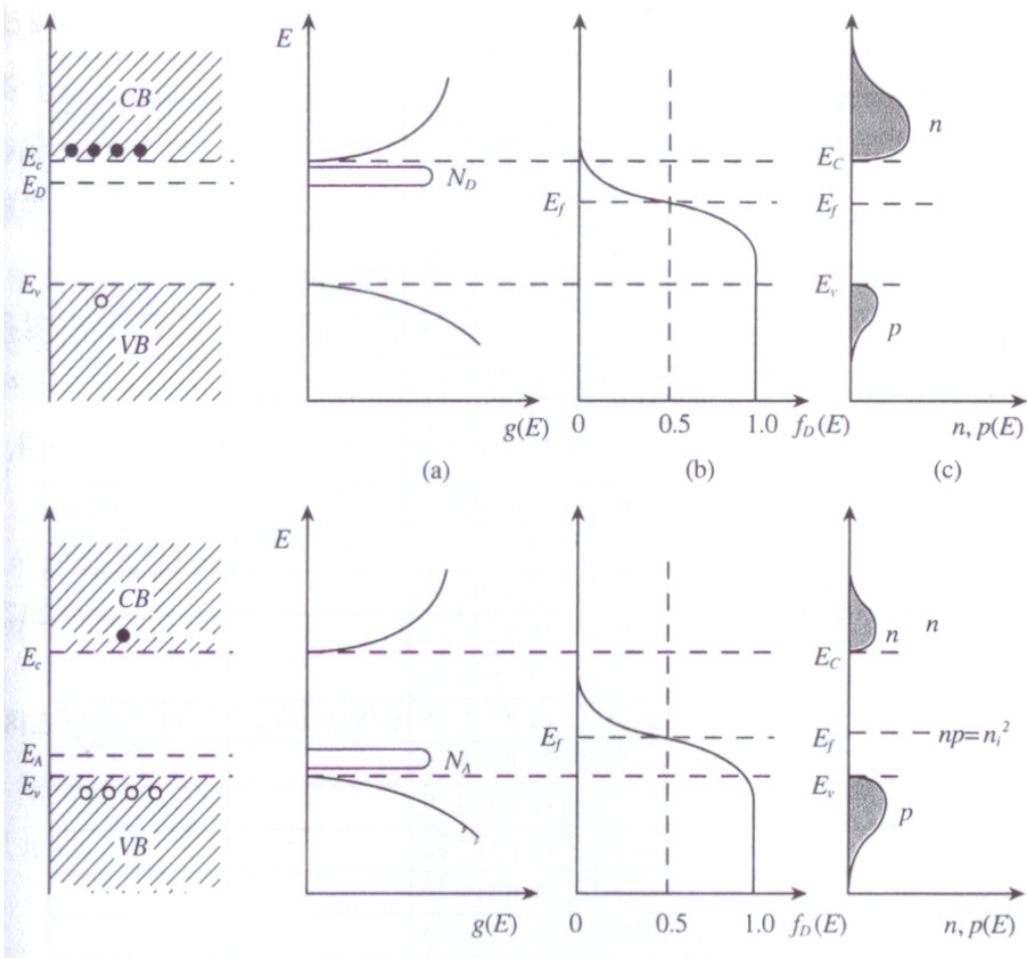


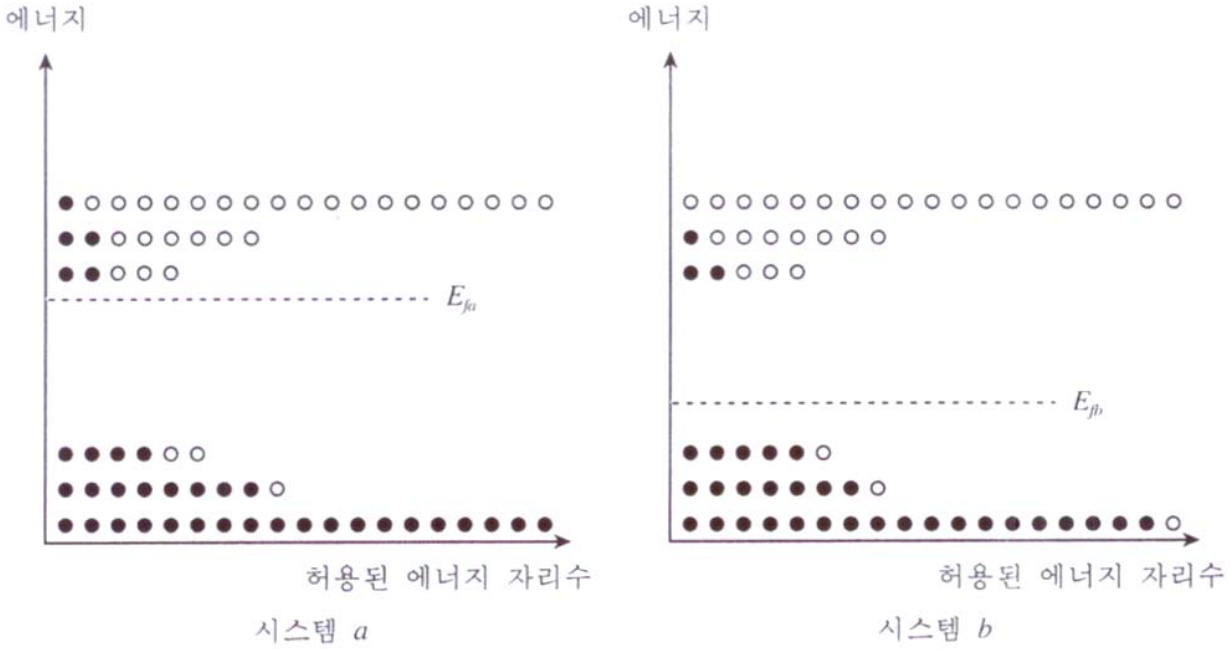
(c)



(d)

김원찬, 반도체 소자의 이해, 대영사, 1999.



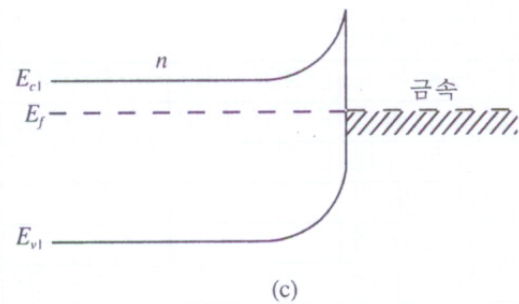
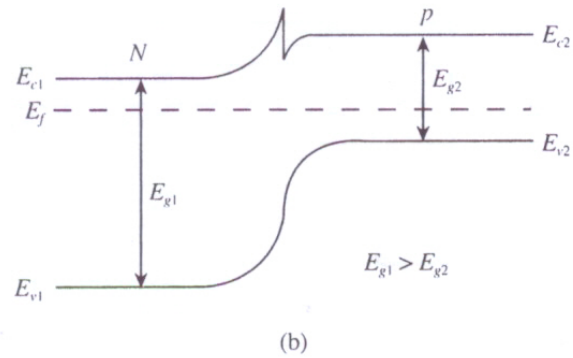
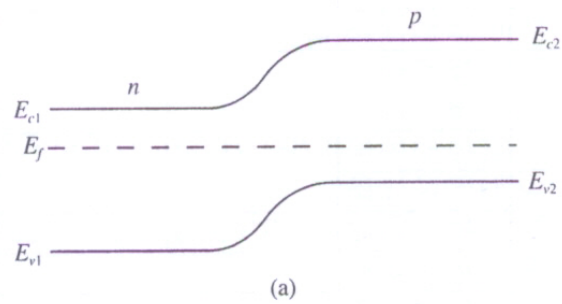


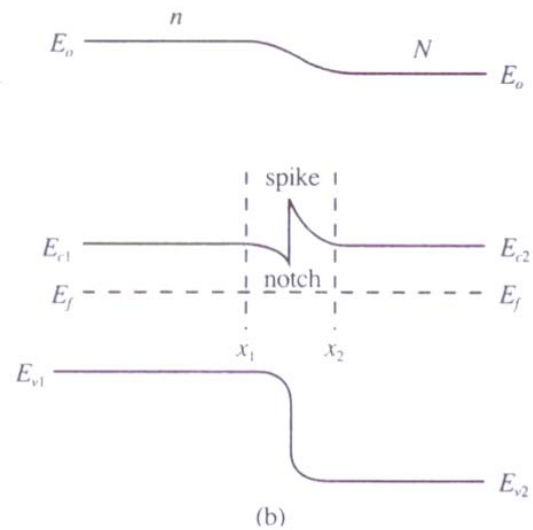
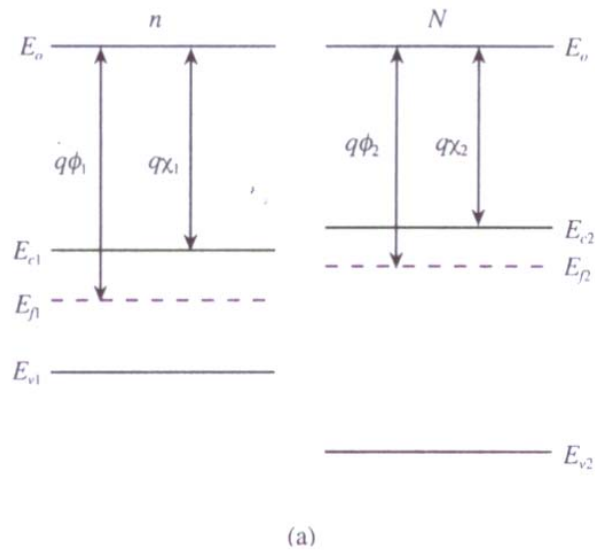
$$n_a(E)v_b(E) = n_b(E)v_a(E)$$

$$n(E) = g(E)f_{FD}(E) \quad v(E) = g(E)(1 - f_{FD}(E))$$

$$g_a f_{FDa} g_b (1 - f_{FDb}) = g_b f_{FDb} g_a (1 - f_{FDa})$$

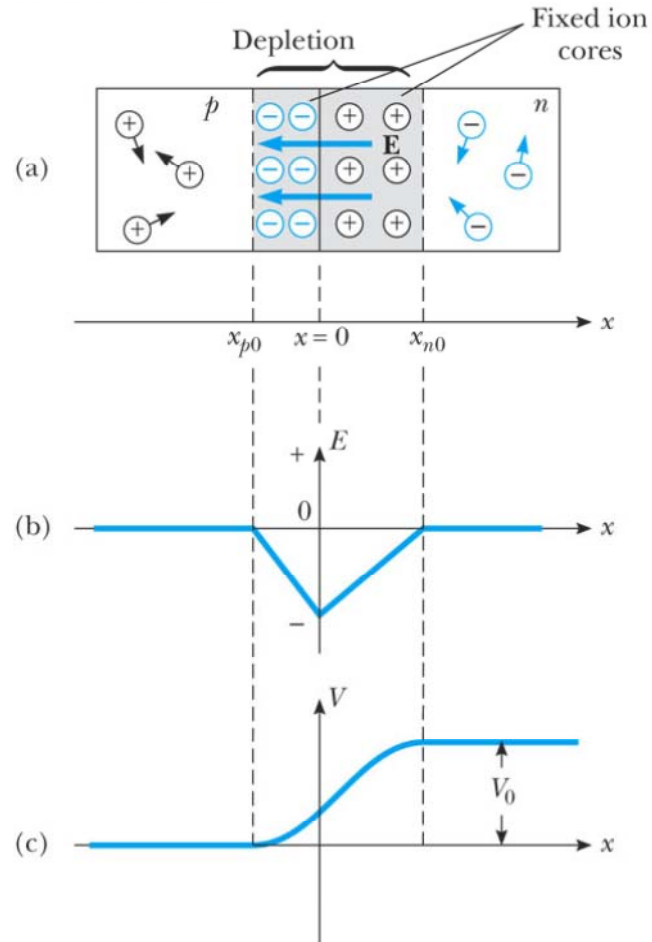
$$f_{FDa} = f_{FDb} \quad E_{fa} = E_{fb}$$





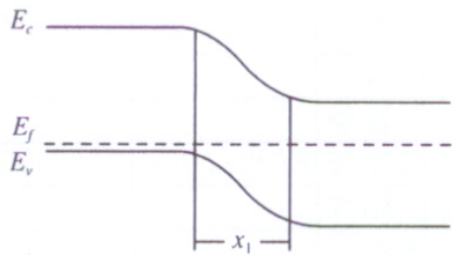


Diode (pn Junction)

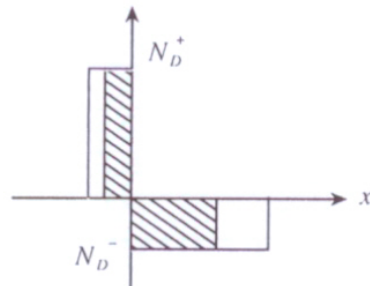


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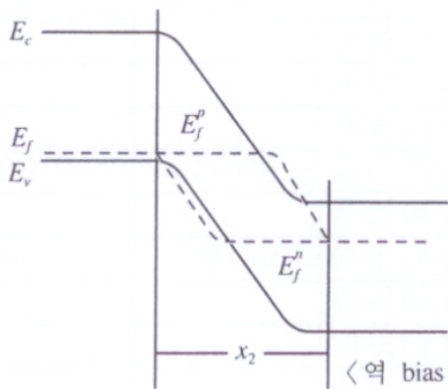




< bias 없을 때 >

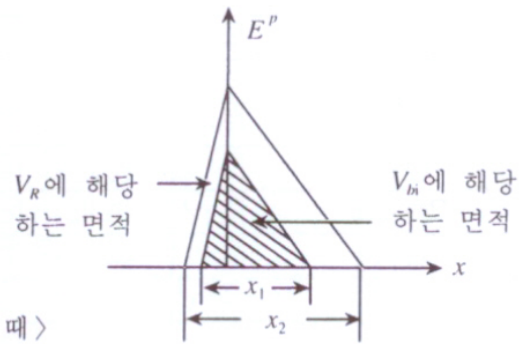


(b)



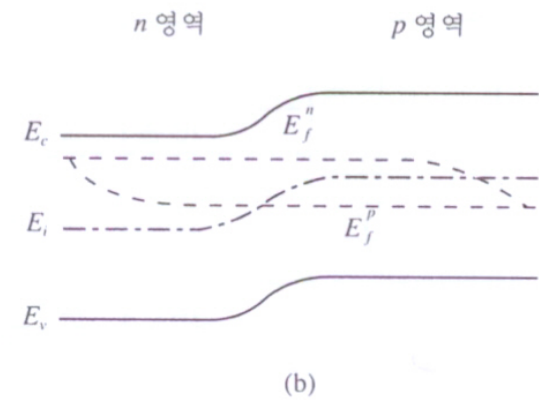
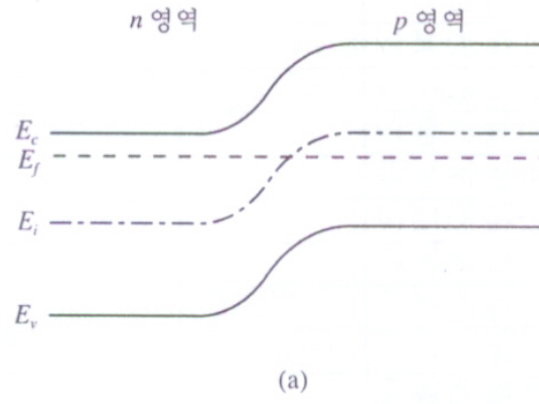
< 역 bias 있을 때 >

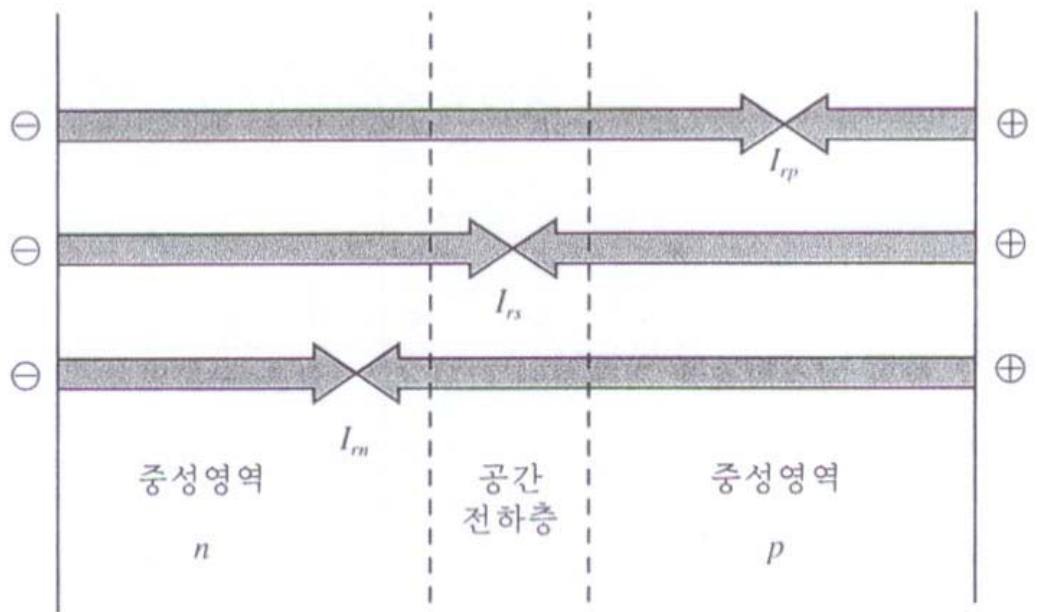
(a)



(c)

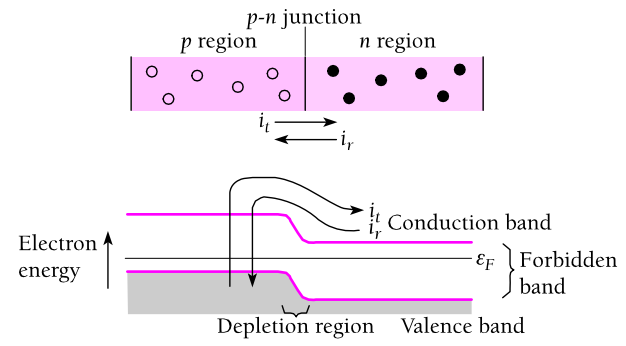




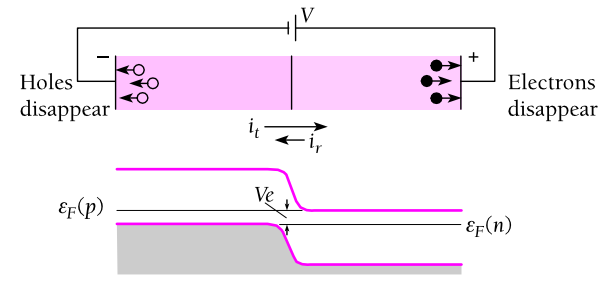




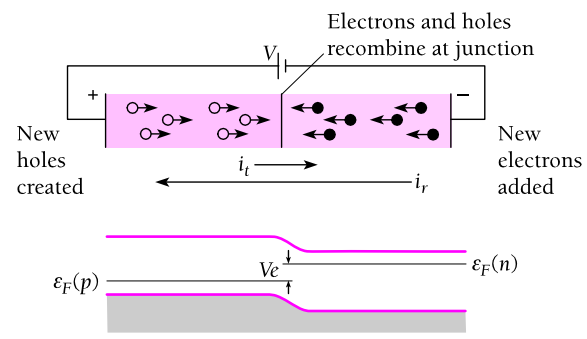
- free electron
- hole
- i_t = thermal electron current
- i_r = recombination electron current



(a) No bias

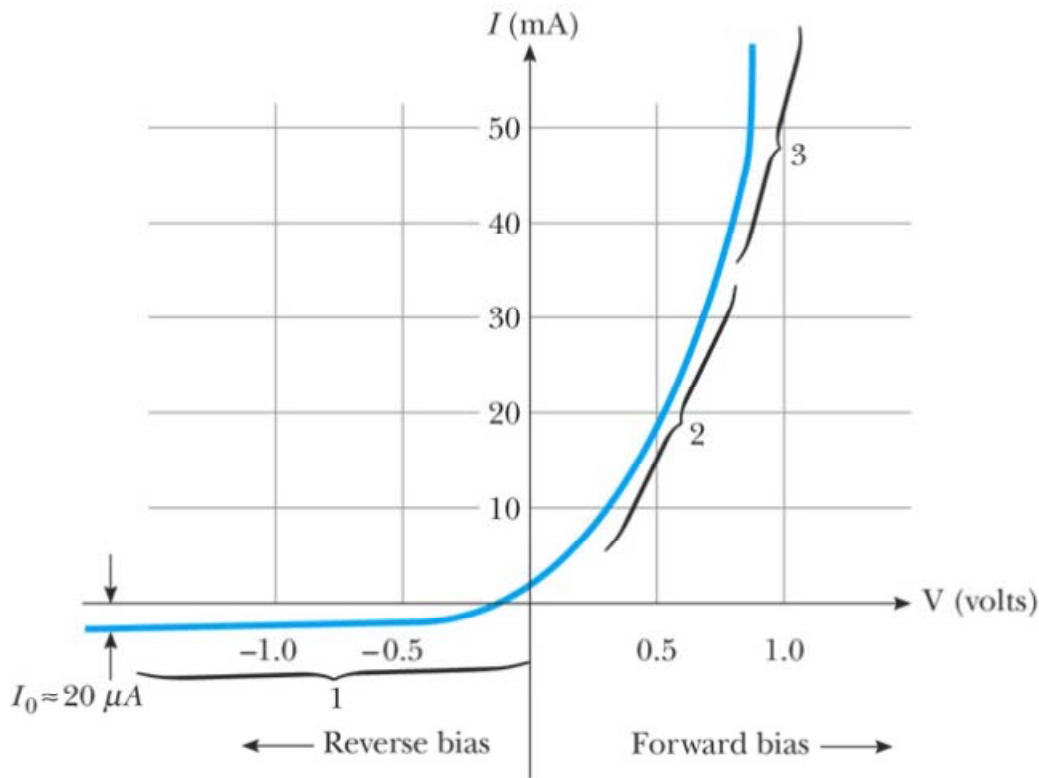
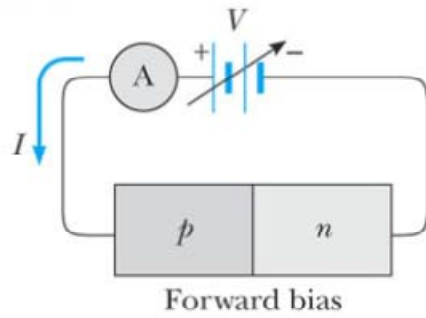


(b) Reverse bias



(c) Forward bias

그림 10.30 반도체 다이오드의 작동



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$$I = I_0 \left(e^{qV/k_B T} - 1 \right)$$



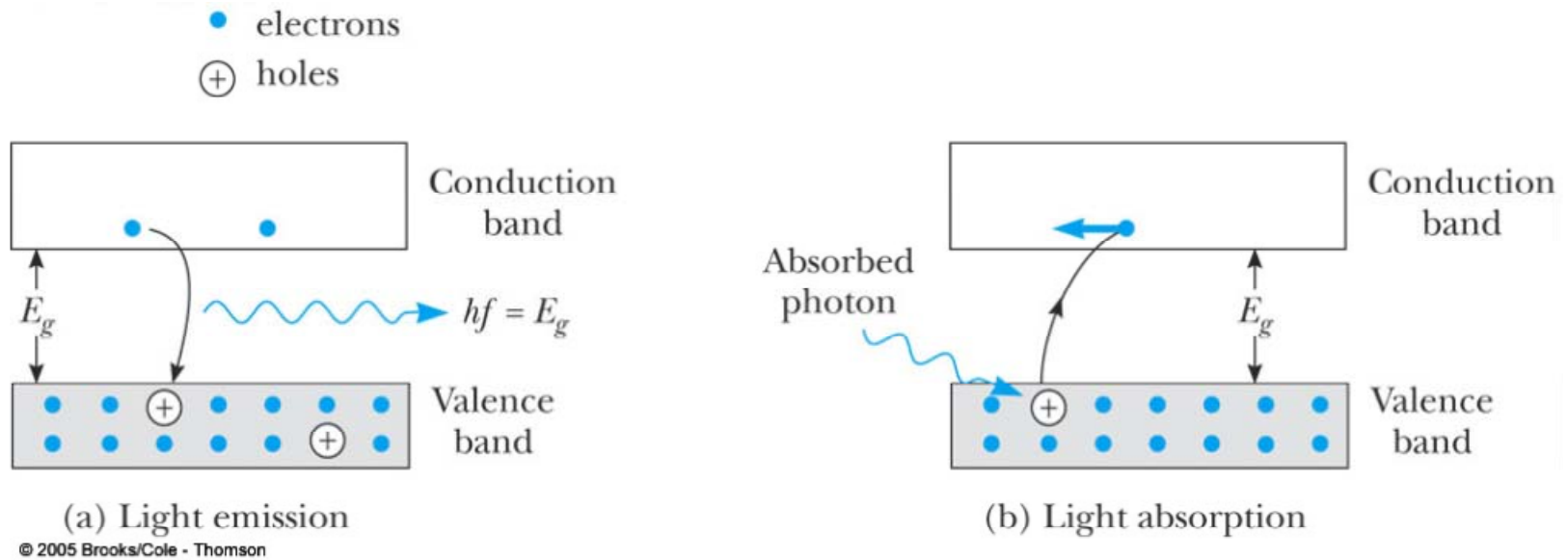
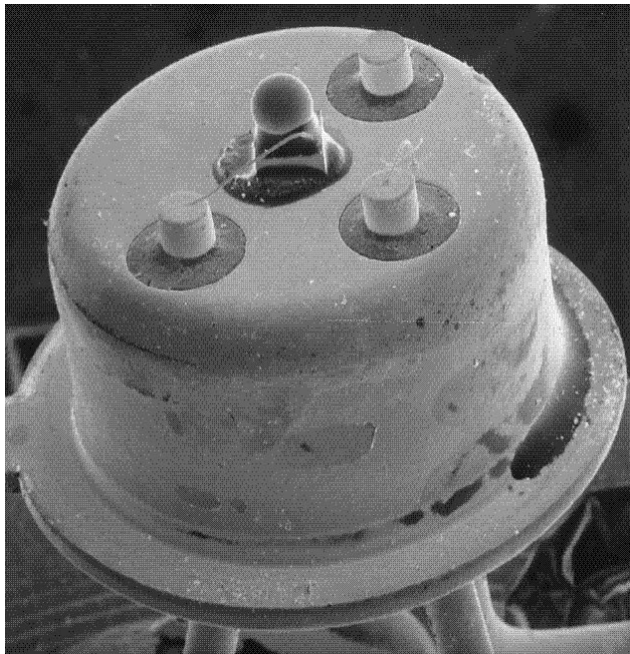


Fig. 12-31, p.437





광 다이오드는 구면의 유리 렌즈를 그 위에 가지고 있다. 이 다이오드는 인(phosphorus)으로 도핑된 갈륨-비소(gallium arsenide)로 만들어졌으며, 광섬유 전화 전송선에 사용되는 파장 620nm의 단색광의 빛을 낸다.



우주 왕복선 Discovery호로 쏘아 올려진 Hubble 우주 망원경. 망원경에 전력을 공급하는 두 장의 태양전지판이 배치되어 있다.



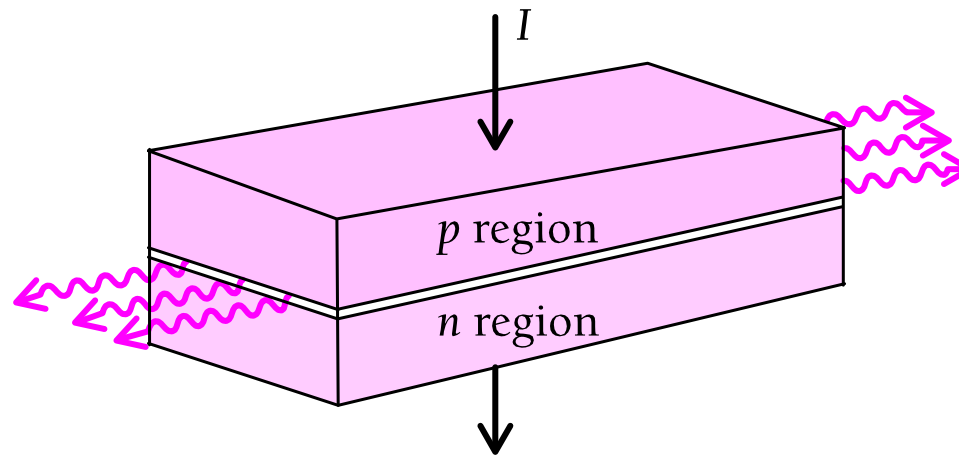


그림 10.32 반도체 레이저. 각 방향의 크기는 mm(micrometer)보다 작으며, 나오는 빛은 모든 다른 레이저에서와 마찬가지로 결맞은 빛이다. 빛이 나오는 p와 n접합영역은 단지 수 마이크로미터 두께 밖에 가지지 않는다.



Blue LED - Nakamura



Shuji Nakamura

(From Wikipedia, the free encyclopedia)

Shuji Nakamura (born in May 22, 1954, Seto, Ehime, Japan) is a professor at the University of California, Santa Barbara (UCSB). Nakamura graduated from the University of Tokushima in 1977 with a degree in electronic engineering, and obtained a master's degree in the same subject two years later, after which he joined the Nichia Corporation, also based in Tokushima. It was while working for Nichia that Nakamura invented the first high brightness GaN LED which has the distinctive advantage of producing blue light, and which went into production in 1993. He was awarded a Doctor of Engineering degree from the University of Tokushima in 1994. In 2001, Nakamura sued his former employer, Nichia Corporation of Japan, over his bonus for the discovery, which was originally 20,000 Yen. Although Nakamura originally won an appeal for 20 billion Yen, Nichia appealed the award and the parties settled in 2005 for 840 million Yen, at the time the largest bonus ever paid by a Japanese company.





Tunnel Diode

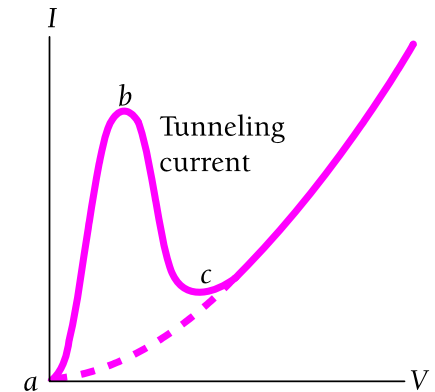
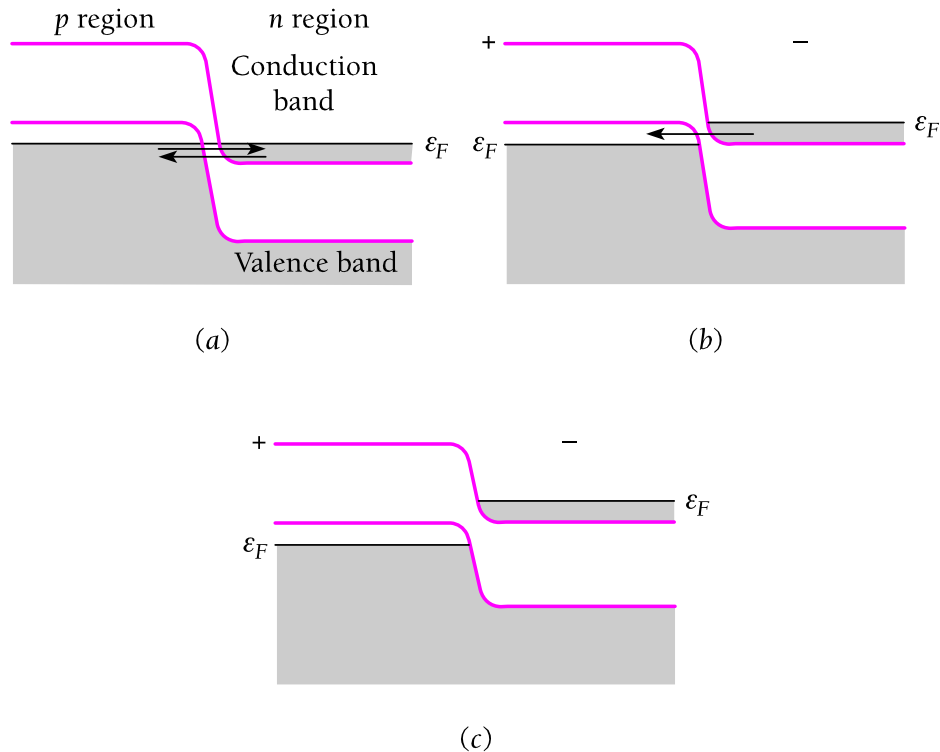


그림 10.33 터널 다이오드의 작동. (a) 바이어스가 없을 때, 전자는 p와 n영역으로 양쪽에서 모두 터널한다. (b) 작은 순방향 바이어스, 전자는 단지 n에서 p영역으로만 터널한다. (c) 좀더 큰 순방향 바이어스, 이제는 p영역의 원자가 띠와 n영역의 전도 띠가 겹치지 않게 되므로 터널링이 일어날 수 없게 된다. 좀더 높은 전압에서는 그림 10.30과 같은 보통의 다이오드처럼 행동한다.



Zenor Diode

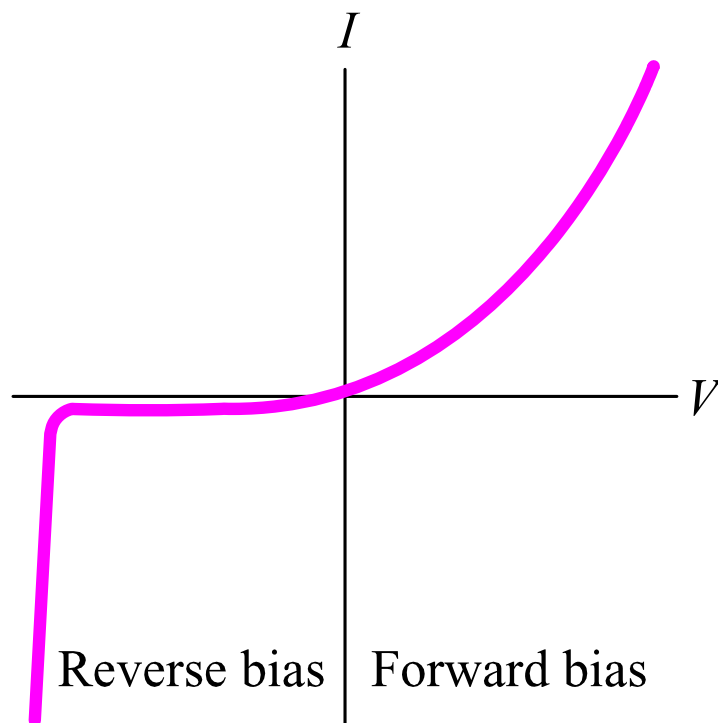
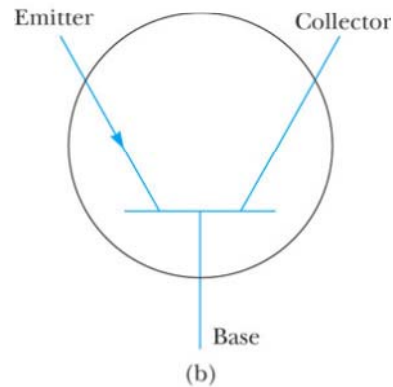
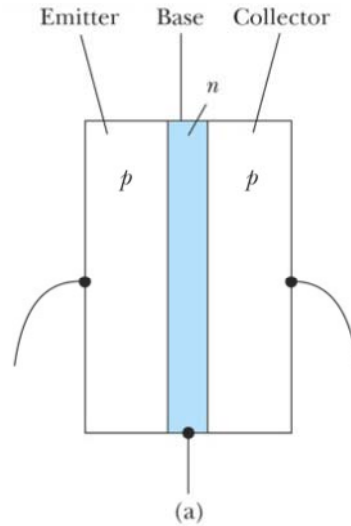


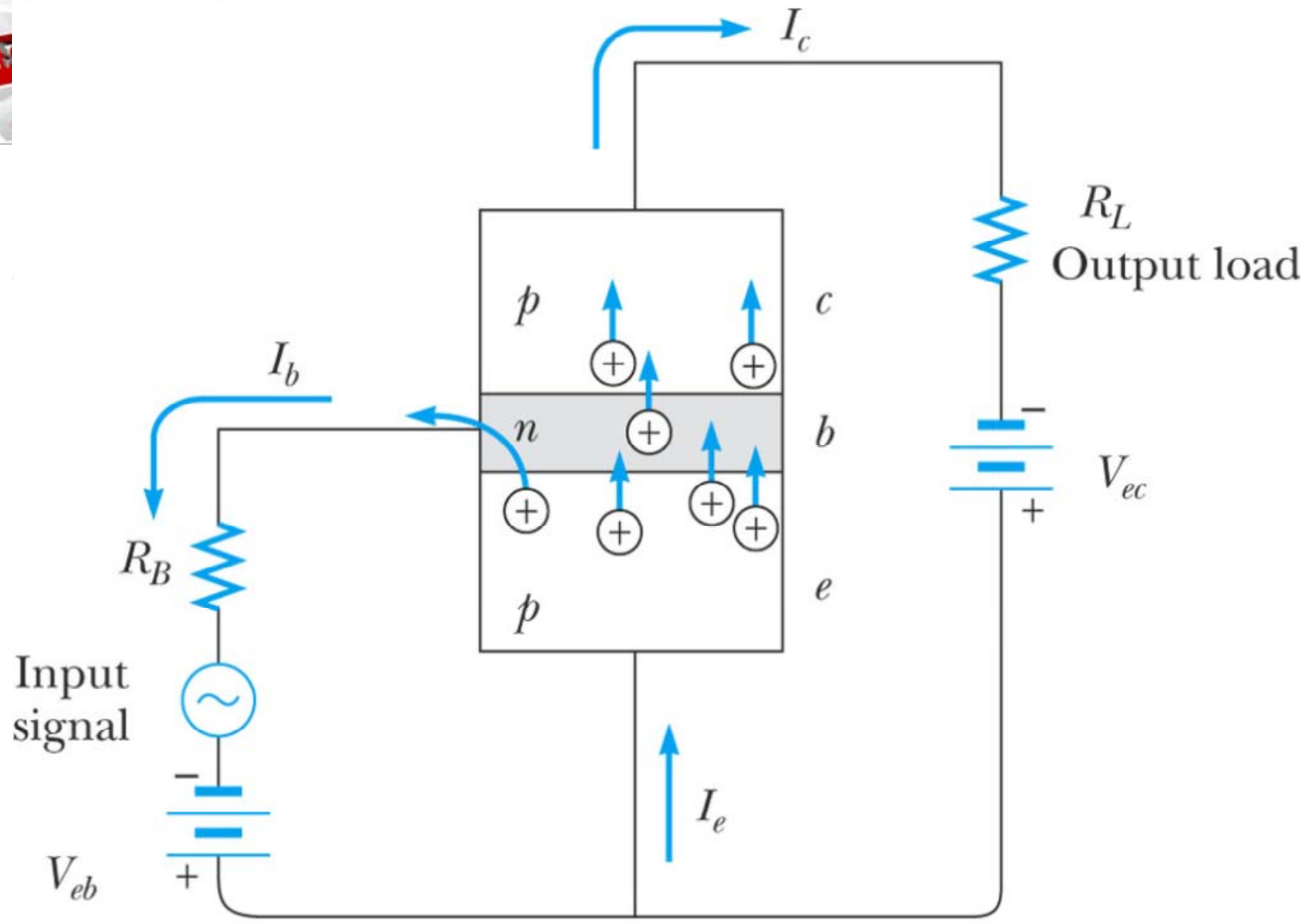
그림 10.35 제너 다이오드(Zenor diode)의 전압-전류 특성.



Bipolar Junction Transistor



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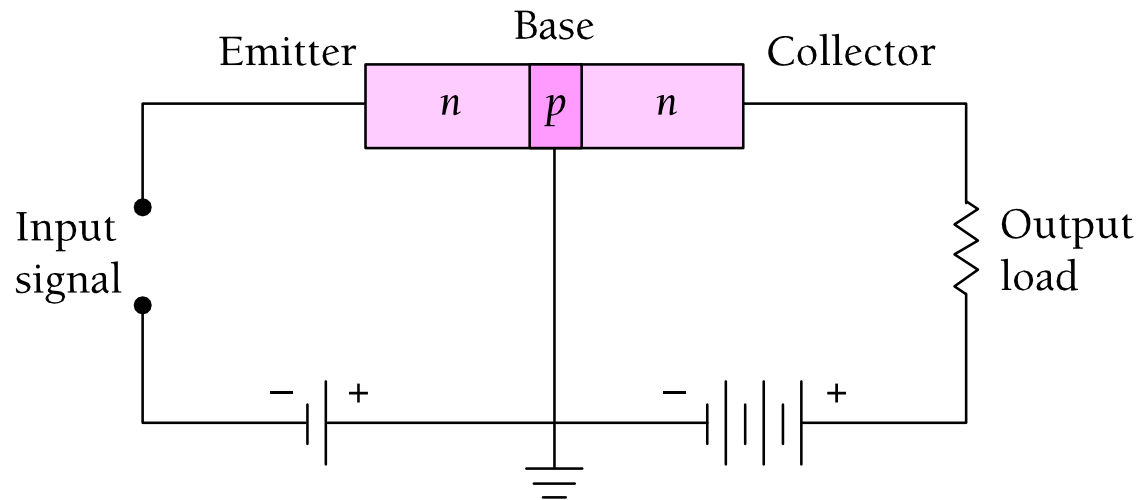
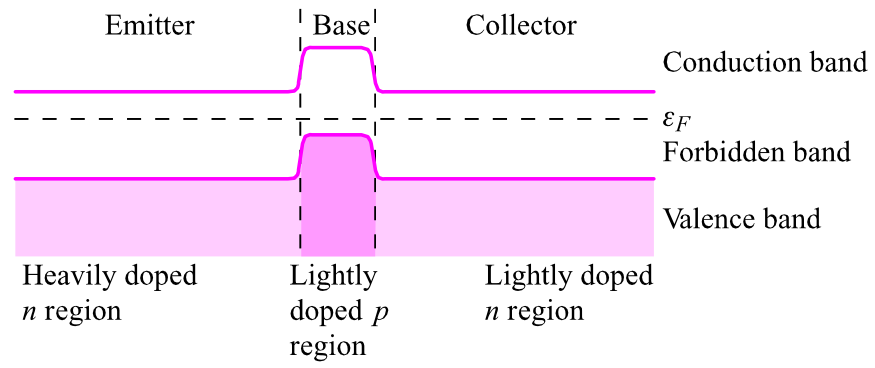
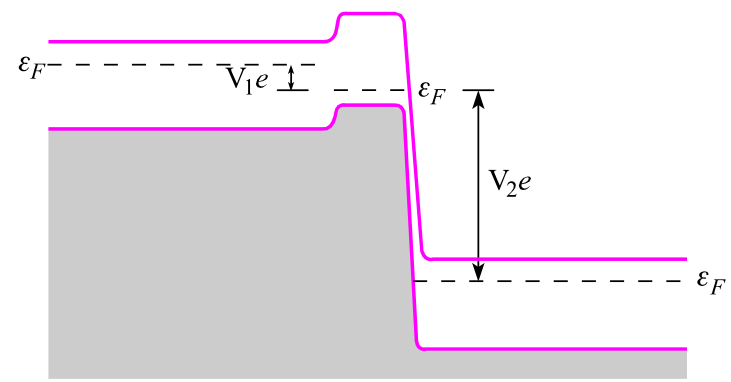


그림 10.36 간단한 접합 트랜지스터 증폭기.

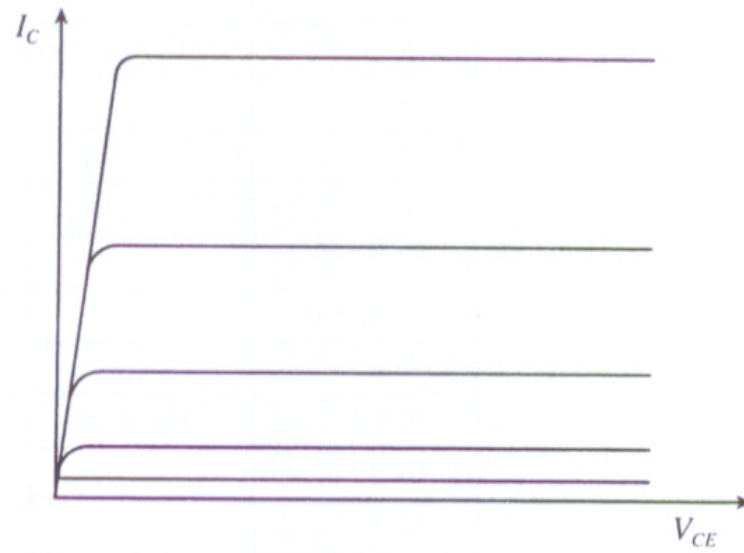


(a)



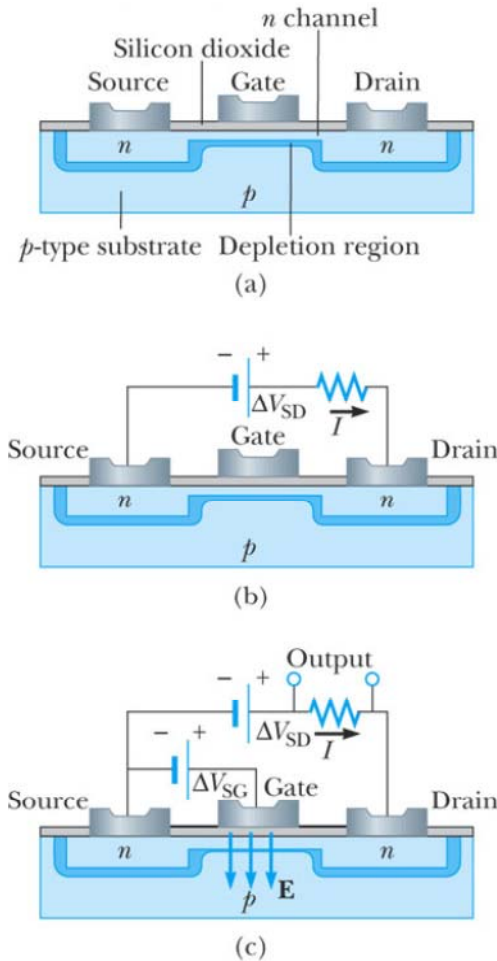
(b)

그림 10.37 (a) 배선되지 않은 npn 트랜지스터. (b) 그림 10.36과 같은 배선으로 된 트랜지스터. 이미터(emitter)와 베이스(base) 사이의 순방향 바이어스 V_1 은 작고, 베이스와 컬렉터(collector) 사이의 역방향 바이어스 V_2 는 크다. 베이스가 매우 얇기 때문에, 전자들은 베이스에 있는 구멍과 재결합 없이 이미터에서 컬렉터로 옮겨갈 수 있다. 전자가 컬렉터에 도달하면 충돌에 의해 에너지를 잃고, 그런 후에는 $V_2 e$ 가 너무 높아서 베이스로 되돌아갈 수 없다.



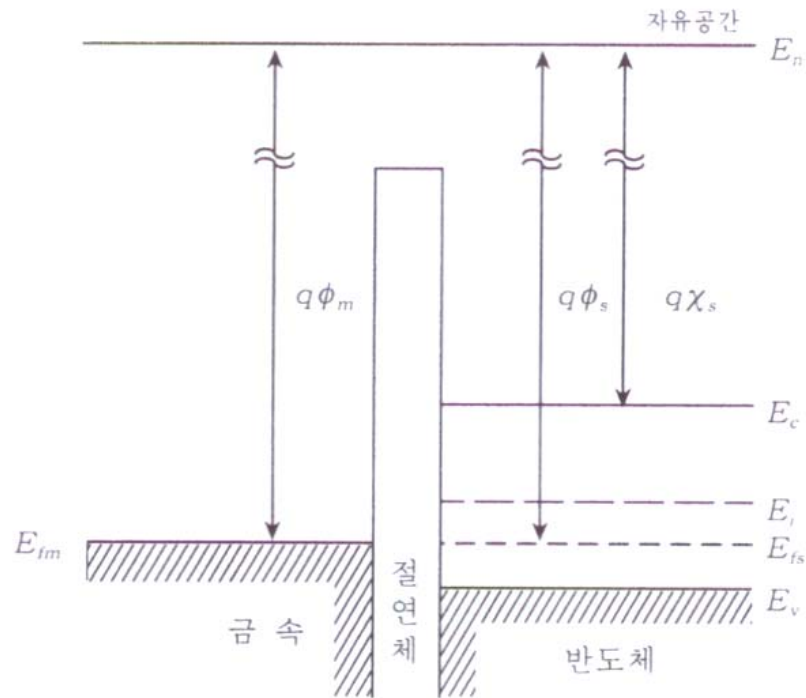
MOSFET

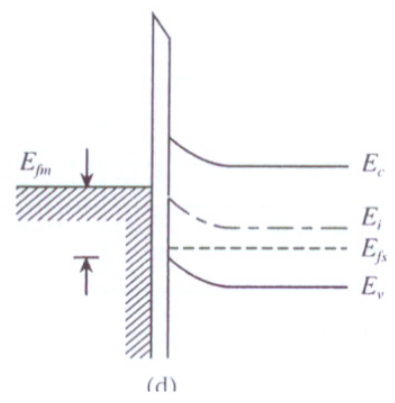
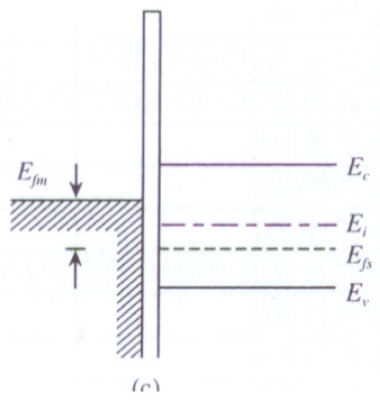
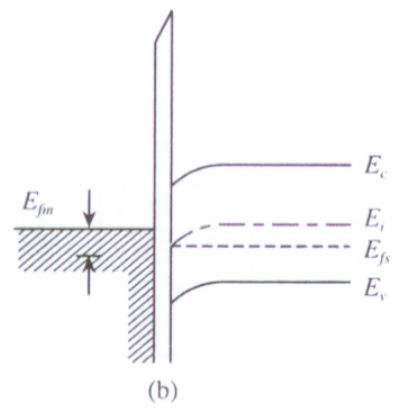
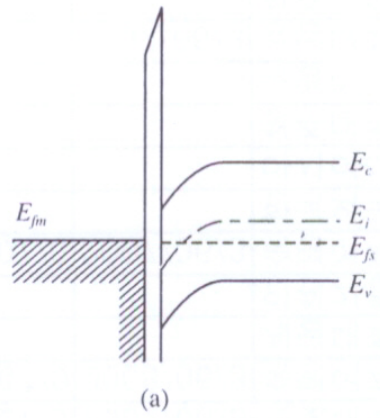
(Metal-Oxide-Semiconductor Field-Effect Transistor)

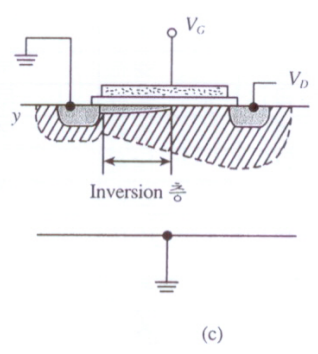
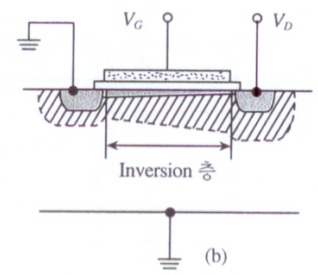
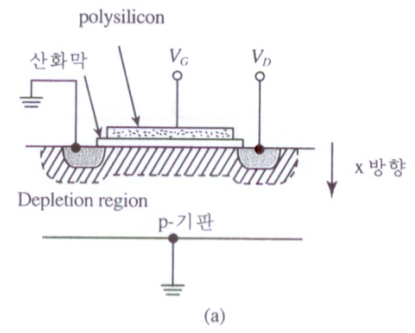
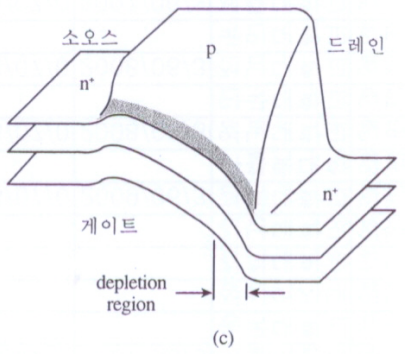
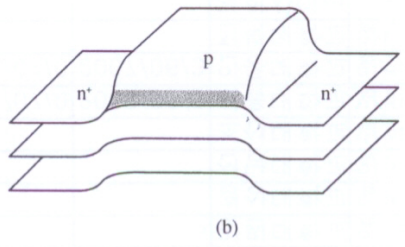
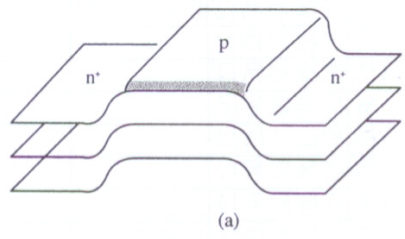
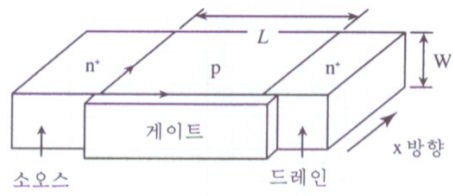


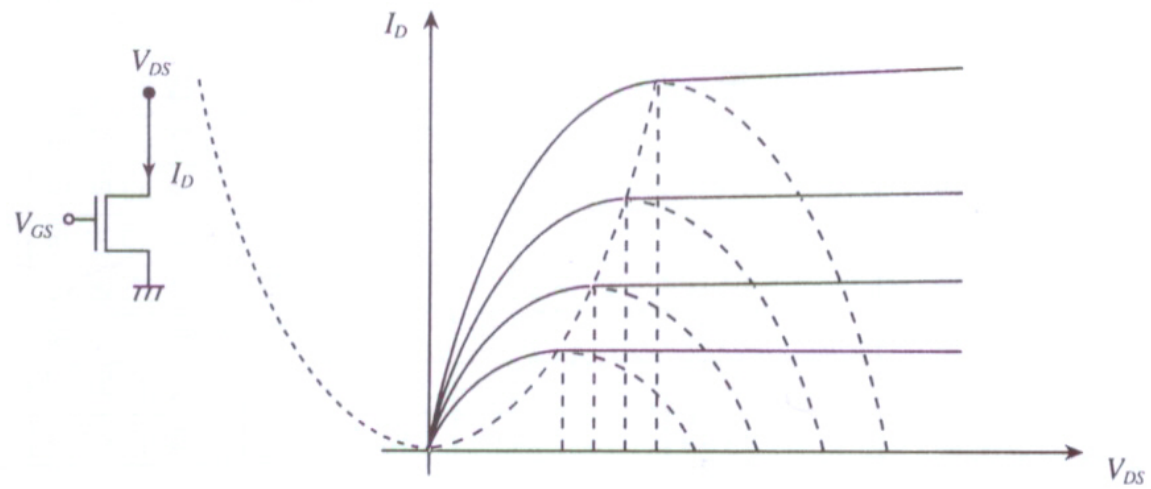
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Nobel Prize in Physics 2000

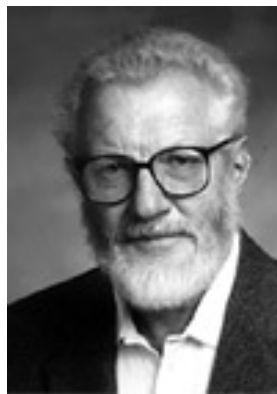
"for basic work on information and communication technology"

"for developing semiconductor heterostructures used in high-speed- and optoelectronics"

"for his part in the invention of the integrated circuit"



Zhores I. Alferov
(1930–)



Herbert Kroemer
(1928–)

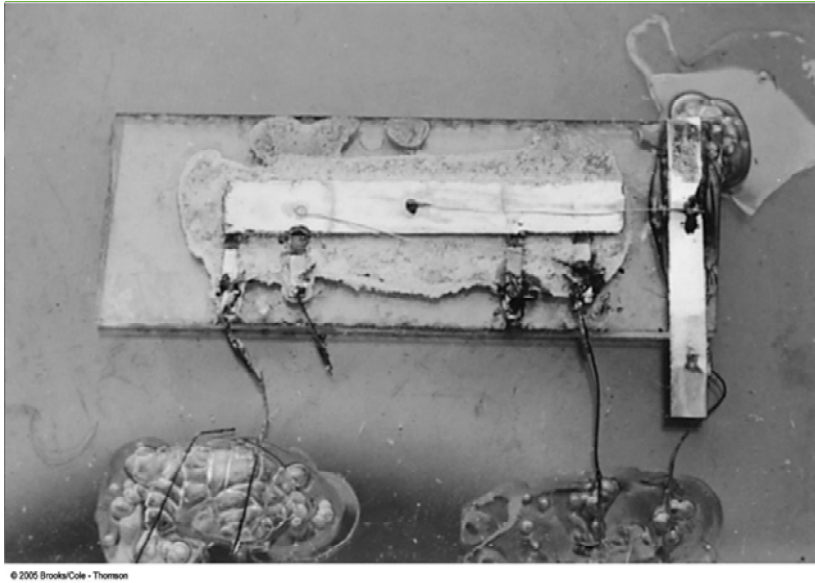


Jack S. Kilby
(1923–2005)

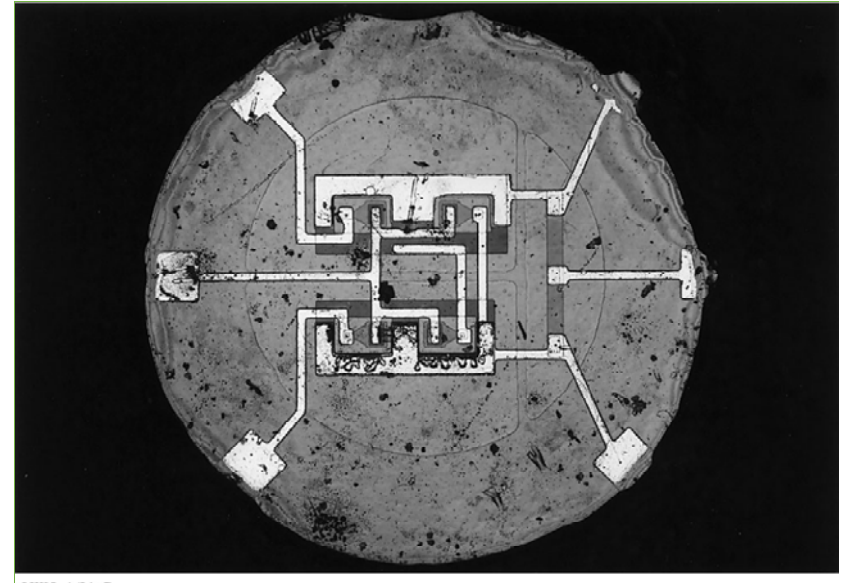




The First Integrated Circuits

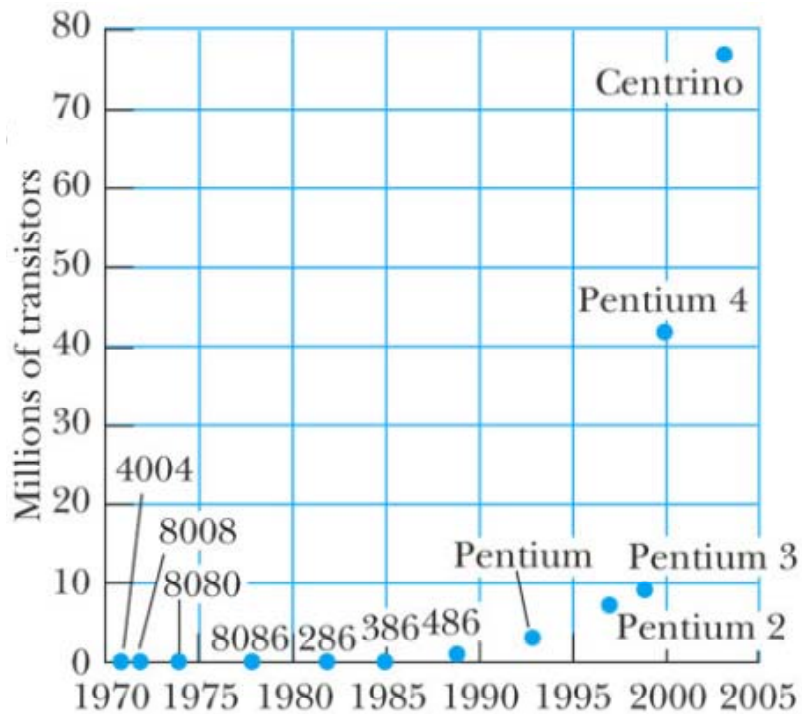


Jack S. Kilby: Sep. 12, 1958



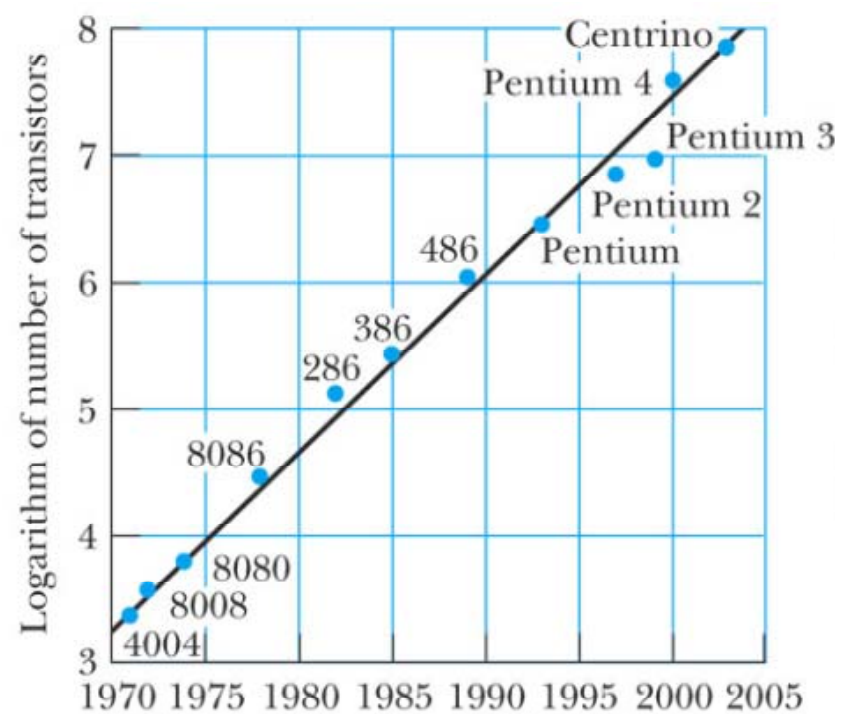
Robert Noyce (1927–1990)
nicknamed "the Mayor of Silicon Valley", co-founded
Fairchild Semiconductor in 1957 and Intel in 1968.

He is also credited (along with Jack Kilby) with the invention of the integrated circuit or microchip although Kilby's invention was 6 months earlier.



(a)

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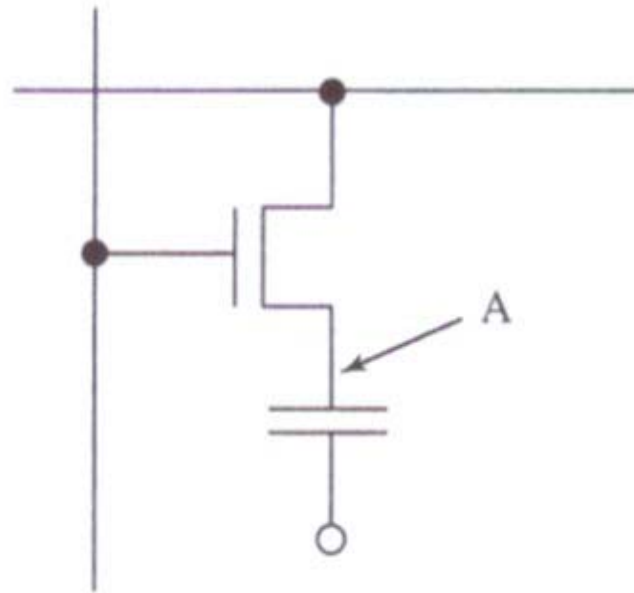


(b)





DRAM Cell





한국의 반도체



윤종용
(1944-)



진대제
(1952-)



황창규
(1953-)