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# 1957
# Invention of the Esaki diode

**~ Discrete Semiconductor/Others ~**

In July 1957, Esaki of Sony observed a tunnel current component expected in quantum theory during his experiment to measure current-voltage characteristics of an alloy junction (abrupt junction) of p-type and n-type Ge doped with high concentration (degenerated) at low temperature (200K). It was the first discovery of quantum tunneling current in semiconductor crystals. In response to this achievement, the Nobel Prize in Physics was awarded in 1973.

The tunneling current appears in the forward direction of the current-voltage characteristic of a p-n junction and appears in a lower voltage region than the region of normal junction current flow. Thus, the current-voltage characteristic has a negative resistance, which is particularly valuable for high-frequency oscillation, amplification, and high-speed switching. For this reason, diodes with negative resistance at room temperatures using Ge, Si, and compound semiconductors such as InSb were commercialized, and they were called Esaki diodes or Tunnel diodes.

In the 1960s and 1970s, the development of amplifiers in the X band and the Ku band were actively carried out, and a 14-14.5GHz amplifier using tunnel diodes was mounted on the INTELSAT-V communication satellite. However, since they were two-terminal elements, there was a disadvantage that it required a large and heavy isolator for isolation between the input and output, and when a three terminal device such as GaAs FETs with good isolation characteristics between input and output were developed, it was replaced by a transistor amplifier.

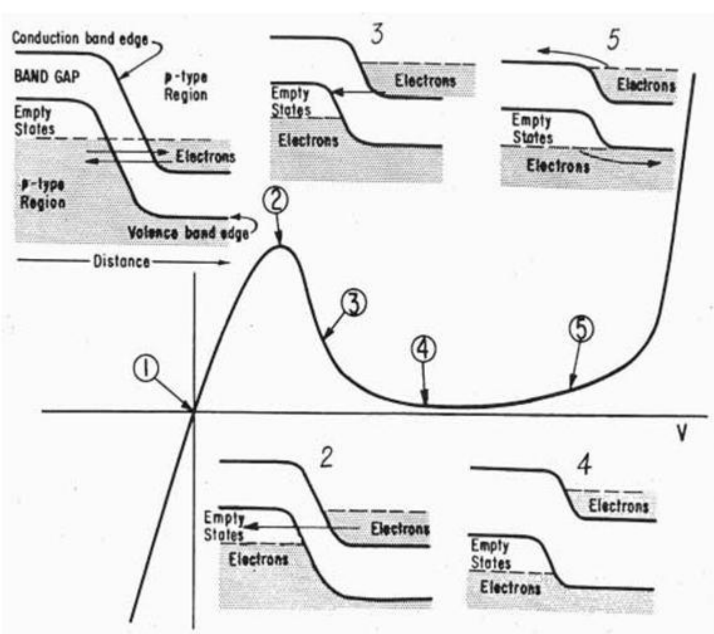


Fig.1 Explanation of tunnel diode operation

When a voltage is gradually applied from the zero bias in the forward direction of the p-n junction, the current starts to flow due to the tunnel effect, then it gets into the negative resistance region, to no current flow, and the current starts to flow again by the further voltage application.

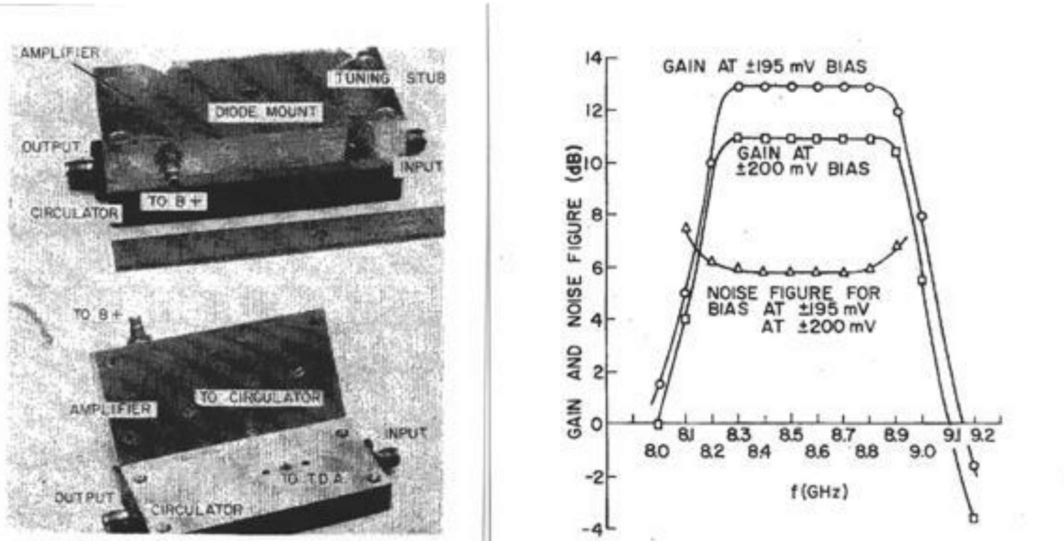


*FIGURE 4*—**Amplifier and circulator.** *FIGURE 5*—**Gain and noise figure versus frequency.**

Fig. 2: Photograph and gain-frequency characteristics of X-band push-pull tunnel diode amplifier [3]

References:

[1] The Nobel Prize in Physics 1973 Leo Esaki, Ivar Giaever, Brian D. Josephson http://nobelprize.org/nobel_prizes/physics/laureates/1973/

[2] L. Esaki, “Discovery of the tunnel diode”, IEEE Trans. Electron Devices, vol. ED-23, No. 7, PP. 644-647, (July 1976) http://www.shmj.or.jp/innovation50/article/ENCORE61_esaki_1.pdf

[3] C.W. Lee, “Push-pull tunnel-diode amplifier”, IEEE ISSCC Digest of Tech. Papers, pp. 102-103, (Feb. 1967)

[4] P.T. Ho, “Ku-band tunnel diode amplifier for the INTELSAT-V communication satellites”, European Microwave Conference, pp. 601-608, (Sept. 1981)

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Version 2019/2/20