

Tunnel diode

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A **tunnel diode** or **Esaki diode** is a type of semiconductor that is capable of very fast operation, well into the microwave frequency region, made possible by the use of the quantum mechanical effect called tunneling.

It was invented in August 1957 by Leo Esaki when he was with Tokyo Tsushin Kogyo, now known as Sony. In 1973 he received the Nobel Prize in Physics, jointly with Brian Josephson, for discovering the electron tunneling effect used in these diodes. Robert Noyce independently came up with the idea of a tunnel diode while working for William Shockley, but was discouraged from pursuing it.^[1]

These diodes have a heavily doped p–n junction only some 10 nm (100 Å) wide. The heavy doping results in a broken bandgap, where conduction band electron states on the n-side are more or less aligned with valence band hole states on the p-side

Tunnel diodes were first manufactured by Sony in 1957^[2] followed by General Electric and other companies from about 1960, and are still made in low volume today.^[3] Tunnel diodes are usually made from germanium, but can also be made from gallium arsenide and silicon materials. They are used in frequency converters and detectors.^[4] They have negative differential resistance in part of their operating range, and therefore are also used as oscillators, amplifiers, and in switching circuits using hysteresis.

In 1977, the Intelsat V satellite receiver used a microstrip tunnel diode amplifier (TDA) front-end in the 14 to 15.5 GHz band. Such amplifiers were considered state-of-the-art, with better performance at high frequencies than any transistor-based front end.^[5]

The highest frequency room-temperature solid-state oscillators are based on the resonant-tunneling diode (RTD).^[6]

There is another type of tunnel diode called a metal–insulator–metal (MIM) diode, but present application appears restricted to research environments due to inherent sensitivities.^[7] There is also a metal–insulator–insulator–metal MIIM diode which has an additional insulator layer. The additional insulator layer allows "*step tunneling*" for precise diode control.^[8]

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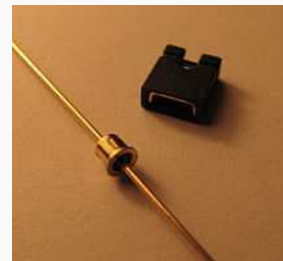
Forward bias operation

Under normal forward bias operation, as voltage begins to increase, electrons at first tunnel through the very narrow p–n junction barrier, filled electron states in the conduction band on the n-side become aligned with empty valence band hole states on the p-side of the p–n junction. As voltage increases further these states become more misaligned and the current drops. This is called *negative resistance* because current decreases with increasing voltage. As voltage increases yet further, the diode begins to operate as a normal diode, where electrons travel by conduction across the p–n junction, and no longer by tunneling through the p–n junction barrier. The most important operating region for a tunnel diode is the negative resistance region. Its graph is different from normal p–n junction diode.

Reverse bias operation

Main article: Backward diode

Tunnel diode



1N3716 tunnel diode (with 0.1" jumper for scale)

Type	Passive
Working principle	Quantum mechanical effect called tunneling
Invented	Leo Esaki
First production	Sony
Pin configuration	anode and cathode

Electronic symbol



10mA germanium tunnel diode mounted in test fixture of Tektronix 571 curve tracer



Figure 6: 8–12 GHz tunnel diode amplifier, circa 1970

When used in the reverse direction, tunnel diodes are called **back diodes** (or **backward diodes**) and can act as fast rectifiers with zero offset voltage and extreme linearity for power signals (they have an accurate square law characteristic in the reverse direction). Under reverse bias, filled states on the p-side become increasingly aligned with empty states on the n-side and electrons now tunnel through the pn junction barrier in reverse direction.

Technical comparisons

In a conventional semiconductor diode, conduction takes place while the p–n junction is forward biased and blocks current flow when the junction is reverse biased. This occurs up to a point known as the “reverse breakdown voltage” when conduction begins (often accompanied by destruction of the device). In the tunnel diode, the dopant concentrations in the p and n layers are increased to the point where the **reverse breakdown voltage** becomes **zero** and the diode conducts in the reverse direction. However, when forward-biased, an odd effect occurs called quantum mechanical tunnelling which gives rise to a region where an *increase* in forward voltage is accompanied by a *decrease* in forward current. This negative resistance region can be exploited in a solid state version of the dynatron oscillator which normally uses a tetrode thermionic valve (or tube).

The tunnel diode showed great promise as an oscillator and high-frequency threshold (trigger) device since it operated at frequencies far greater than the tetrode could, well into the microwave bands. Applications for tunnel diodes included local oscillators for UHF television tuners, trigger circuits in oscilloscopes, high-speed counter circuits, and very fast-rise time pulse generator circuits. The tunnel diode can also be used as low-noise microwave amplifier.^[9] However, since its discovery, more conventional semiconductor devices have surpassed its performance using conventional oscillator techniques. For many purposes, a three-terminal device, such as a field-effect transistor, is more flexible than a device with only two terminals. Practical tunnel diodes operate at a few milliamperes and a few tenths of a volt, making them low-power devices.^[10] The Gunn diode has similar high frequency capability and can handle more power.

Tunnel diodes are also more resistant to nuclear radiation than other diodes. This makes them well suited to higher radiation environments such as those found in space.

Longevity

Tunnel diodes are notable for their longevity, with devices made in the 1960s still functioning. Writing in *Nature*, Esaki and coauthors state that semiconductor devices in general are extremely stable, and suggest that their shelf life should be "infinite" if kept at room temperature. They go on to report that a small-scale test of 50-year-old devices revealed a "gratifying confirmation of the diode's longevity". As noticed on some samples of Esaki diodes, the gold plated iron pins can in fact corrode and short out to the case. This can usually be diagnosed, and the diode inside normally still works.^[11]

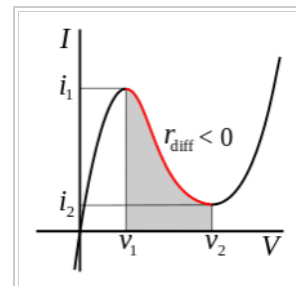
However, these components are susceptible to damage by overheating, and thus special care is needed when soldering them.

See also

- Avalanche diode
- Gunn diode
- IMPATT diode
- Lambda diode
- Resonant tunnelling diode
- Tunnel junction
- Zener diode

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IV curve similar to a tunnel diode characteristic curve. It has negative resistance in the shaded voltage region, between v_1 and v_2 .



I-V curve of 10mA germanium tunnel diode, taken on a Tektronix model 571 curve tracer.

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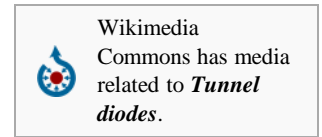
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External links

- Tunnel Diode tutorial (<http://www.radio-electronics.com/info/data/semicond/tunneldiode/tunneldiode.php>)

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Categories: Diodes



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