

Lecture at National Tsing Hua University (Jan. 25, 2010, Hsin-Chu)  
Lecture at Academia Sinica (Jan. 26, 2010, Taipei)

### In Half a Century of Research What did I learn?

Leo Esaki

I was just twenty years old when the Second World War ended. In 1945-46, we physics students were really fascinated by the introduction of the revolutionary knowledge of “Quantum Mechanics” which had not yet been widely disseminated. I was interested in putting the new knowledge of quantum mechanics to practical use. In 1947, I moved on to life as a researcher in the electronics industry, where I explored the possibility of creating quantum electron devices. Coincidentally, 1947 was the year in which the epoch-making transistor was invented.

There is a tendency to assume that the future is simply a natural extension of the past and the present. However, the transistor is substantially different from the vacuum tube and no amount of research and improvement of the vacuum tube could have led to the birth of the transistor. That taught us an important lesson: in periods of great change, innovations and breakthroughs shape and form the future. Needless to say, it is the power of individual creativity which plays the decisive role in this process.

In 1956, I initiated the investigation of the quantum mechanical tunneling in narrow Ge p-n junctions. We first obtained a backward diode which was more conductive in the reverse direction than in the forward direction. The junction width of that diode was approximately 20 nanometers. When the junction width narrowed down to about 10 nanometers, the current-flow mechanism was convincingly tunneling not only in the reverse direction but also in the low-voltage range of the forward direction, giving rise to a prominent current-peak. Since the current-peak associated with a negative resistance had never been predicted, the Esaki Tunnel diode - the very first quantum electron device - came as a total surprise in 1957.

The Esaki tunnel diode then leaped suddenly into fame, because of Shockley’s glowing comments at the International Conference held in conjunction with Brussels Expo 1958.

In 1960, I moved to IBM T.J. Watson Research Center, New York, which provided a desirable research environment in which to perform the scenario of putting quantum principles into practice to which I was committed. In 1969, Esaki and Tsu proposed a semiconductor superlattice, a “man-made periodic quantum structure” which is engineered by applying the advanced growth technique of MBE, after designing the periodic structure in accordance with the principles of quantum theory in such a way as to exhibit desirable electronic properties. The proposal is based on Bloch’s golden rule that “the periodic potential in the crystal lattice determines its electronic properties”. The lattice constant of this proposed superlattice is in the range of 1-10 nanometers, substantially longer than that of the host crystal, but shorter than the electron phase-coherent length.

Esaki and his coworkers’ pioneering research on superlattices and quantum wells in the 1970s and 1980s triggered a wide spectrum of experimental and theoretical investigations resulting in not only the observation of a number of intriguing phenomena, but also the emergence of a new class of transport and optoelectronic devices.

According to the Superlattice Story prepared by US Army Research Office in 1997,

*“The superlattice concept proposed under Army sponsored research triggered a revolution in solid state physics ……*

*The impact of Esaki’s research has been profound. The superlattice concept precipitated more than 10,000 publications and is directly involved in some 465 patents in the U.S. alone, by the end of 1996 …… The superlattice may be regarded as the trunk of a genealogical tree of quantum effect devices, …… The characteristic dimensions of superlattice devices certainly served as the precursor of today’s “smaller and smaller” nanotechnology emphasis.”*