RESEARCH NEWS

World's first single carbon nanotube radio

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The radio is a device based on wireless transmission of signals by modulating the frequencies of radio waves. Since its invention, the radio has been playing an important role in modern civilization due to its use in the mass media (audio/video), radar, cellular phones and wireless computer network. Historically, the Indian physicist Jagadish Chandra Bose started his pioneering research work on the generation/detection of millimetre wave radiation more than 100 years ago. In 1897, he demonstrated his apparatus to detect radio frequency (RF) in the Royal Institution, London[1]. Some concepts from his original 1897 paper[2] have been incorporated into the 1.3 mm receiver of the NRAO 12 m radio telescope at Tuscon, Arizona, USA. There was a gradual transformation in the dimension of radio from a bulky device with vacuum tube technology to a much smaller and sophisticated device based on solid state transistor technology. However, the transistor using silicon-based technology is reaching its physical limits. Recently, the progress in nanotechnology has given a thrust in the research of new nanoscale materials. Carbon nanotube is an interesting nanomaterial with unique electrical and mechanical properties[3–5]. Carbon nanotubes have been used as components in high-frequency electronics like high-frequency field-effect transistors and RF detectors/mixers[6,7].

Researchers in California have reported the development of the world's first working radio device based on nano-sized radio-wave receivers and detectors fabricated from a single carbon nanotube[8,9]. Although, other researchers have fabricated nano-sized radio detectors in the past, the above-mentioned study illustrates the demonstration of the RF components in an actual working radio system for the first time. Zettl and co-workers from Lawrence Berkeley National Laboratory, University of California, Berkeley, USA, have fabricated a fully integrated radio receiver from a single carbon nanotube[8]. This radio receiver has dimension orders of magnitude lower than any previous radio. A single carbon nanotube served as all the four essential components (antenna, tuner, amplifier and demodulator) of a radio at the same time. In the nanotube radio, antenna and tuner can operate in a completely different way compared to the traditional radio. The antenna receives signals via high-frequency mechanical vibrations of the nanotube rather than electrically. These vibrations become significant only when the frequency of the incoming wave matches the resonance frequency of the nanotube. The resonance frequency of the nanotube can be tuned to receive only a preselected band of the electromagnetic spectrum. Field emission of electrons from the tip of the charged nanotube has been utilized to detect vibrations and to amplify/demodulate the signal. Simulation studies have shown the distribution of electric field surrounding the nanotube radio during the operation of the radio. The field is strongest at the tip of the nanotube and varies as the nanotube vibrates. This effect allows the nanotube to demodulate the radio signal.

Zettl and co-workers have demonstrated the coarse tuning of the nanotube radio from a low-frequency, frequency-modulated (FM) radio band (~100 MHz), to much higher frequency bands (~350 MHz) along with the fully reversible fine tuning of resonance frequency of the nanotube. Carbon nanotubes with resonance frequencies from 10 to 400 MHz and quality factor (Q) ~500 were used in their experiments.

A high-resolution transmission electron microscope (TEM) allows them to observe the nanotube radio in action. The TEM image (Figure 1) shows a single carbon nanotube of 1 μm length and 10 nm width protruding from an electrode. A direct current voltage source (battery) has been connected to the electrodes as a power source for the operation of the radio in vacuum of the order of 10^{-7} Torr. The nanotube starts to vibrate vigorously when a radio wave of specific frequency impinges on it. The nanotube radio has been used to receive and play music from FM radio transmissions such as 'Layla' by Eric Clapton and 'Good vibrations' by the Beach boys. The nanotube radio faithfully reproduced the audio signal and the music was clearly audible to the human ear. Figure 2 illustrates the gradual transformation in size of the radio with time. It started with the Philco vacuum tube radio of the 1930s to the

Figure 1. TEM image of a single carbon nanotube protruding from an electrode. (Courtesy: Zettl and co-workers, Lawrence Berkeley National Laboratory and UC Berkeley, USA.)

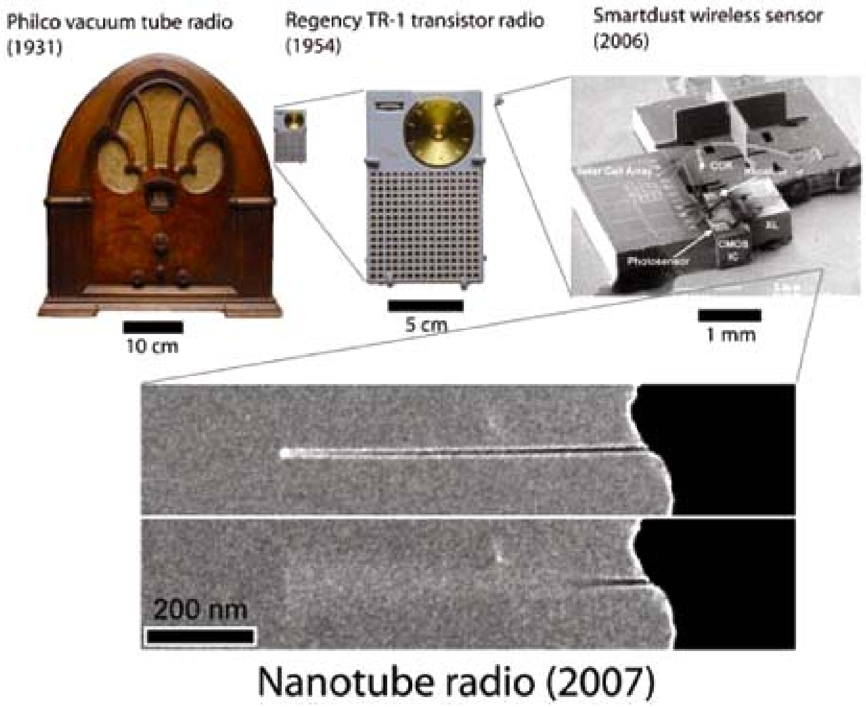

Figure 2. Gradual miniaturization of radio with time. (Courtesy: Zettl and co-workers, Lawrence Berkeley National Laboratory and UC Berkeley, USA.)

pocket-sized transistor radio of the 1950s and the recent single-chip radio found in cellphones and wireless sensors. This single nanotube radio is over 19 orders of magnitude smaller than the Philco vacuum tube radio of the 1930s.

Rutherglen and Burke[9] from the University of California, Irvine, USA, have demonstrated a carbon nanotube to demodulate amplitude modulated signal with frequencies up to 100 kHz. Their device represents a room-temperature, two-terminal nonlinear device, simpler than the previous three-terminal mixers/detectors. They incorporated the detector into a complete radio system for successful wireless transmission of music from an iPod to a speaker several feet away from the music player. The audio quality of the signal demodulated by the carbon nanotube was clear to the human ear. Their study demonstrates the possibility of fabricating other components of the radio at nanometre scale in the near future. This may finally lead to a fully integrated nanoscale wireless communication system.

Due to the small size, such a nanoscale device has potential medical applications. The nanotube radio can be inserted inside the living human cell to give a subcellular remote controlled interface. This special kind of nanoradio can be used to see inside the cells in real time and under normal conditions. Zettl's team is currently working on the method to integrate this nanotube radio with biological systems, and this will help in understanding cell biology at the molecular level.

For further reading, see http://www.physics.berkeley.edu/research/zettl/projects/nanoradio/radio.html. The audio file playing the song 'Layla' can be heard through the above website. (Courtesy: Zettl and co-workers, Lawrence Berkeley National Laboratory and UC Berkeley, USA.)

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