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2004

Development of InGaP/InGaAs HEMT MMIC for 76GHz automotive radar

(Fujitsu)

~ Discrete Semiconductor/Others ~

In recent years, various peripheral monitoring sensors, such as image sensors, millimeter- wave radars, laser radars, and sonars, have been used to monitor the peripheral hazards of vehicles. The millimeter-wave radar can provide a detection distance of 150 m or more and can measure the relative speed to the observed object simultaneously. It is not affected by sunlight (backlighting) and has high transparency against rain, fog, etc. The millimeter-wave radar is now installed in vehicles of many manufacturers.

In Japan, the use of the 60 GHz frequency was approved for automotive radars in 1995. The world's first 60 GHz automotive radar developed by Fujitsu TEN was installed in the Komatsu dump trucks in March 1997 (1). The millimeter-wave transmitter/receiver as the heart of the radar consisted of four chips of AlGaAs/GaAs HEMT MMICs (Microwave Monolithic Integrated Circuits) with a gate length of 0.25μm. The 60GHz radio wave was highly attenuated in the air (by oxygen molecules), which was a problem for the radar. In 1999, the use of 76 GHz, a frequency common to Japan, Europe, and the U.S., was assigned.

Fujitsu developed six MMIC chip sets, including a 76-GHz amplifier and a 76-GHz mixer, using InGaP/InGaAs HEMT technology with a gate length of 0.15 μm for the millimeter-wave transmitter/receiver part of the 76-GHz radar in 1998 (2). They succeeded in combining them into three chips in 2003. Fujitsu TEN's 76-GHz millimeter-wave radar using these chips was installed in the Honda INSPIER (4). The company succeeded in combining them into a single chip in 2004 (5, 6). Fujitsu TEN's 76GHz millimeter-wave radar using this chip was installed in the Toyota Lexus LS460 in 2005, in the Toyota Crown in 2008 as the rear looking radar, and in the Toyota Crown MAJESTA in 2009 as the world's first forward looking radar (7).

The automobile radar used the FM-CW (Frequency Modulated Continuous Wave) system, which was able to measure distance to a target and relative velocity. Its system configuration is shown in Figure 1. The emitted radio wave whose frequency changed with time interfered with the reflected radio wave from an object and a beat signal was generated. The signal was detected and analyzed to determine both distance and relative speed simultaneously. The millimeter-wave transmitter/receiver (millimeter-wave unit) and the planar antenna connected to it were vibrated left and right by an actuator in order to scan the millimeter-wave beam (5).

A block diagram of the millimeter-wave unit on a single chip is shown in Figure 2 (5). The 38 GHz signal, which frequency was modulated by a voltage-controlled oscillator (VCO), was divided into two by a branch-line hybrid circuit. One of the divided signals was amplified by the 38 GHz amplifier, entered the multiplier, was amplified again by the 76 GHz amplifier, and was supplied to the local port of the mixer. Another separated signal was amplified by the 38 GHz amplifier, entered the multiplier, was further amplified by the 76 GHz amplifier, passed through the branch line hybrid, and was radiated from the antenna. The received signal which was separated through the 76 GHz branch hybrid, was amplified by the amplifier, entered a 180 degree hybrid coupler. The signal was then down-converted by a pair of single-ended mixers and output as IF signal.

The MMIC was fabricated with InGaP/InGaAs HEMT process technologies. The cross-sectional structure of the HEMT was shown in Figure 3 (2). An n-InGaP layer and an i-InGaAs layer were grown on a semi-insulating GaAs substrate using the MOCVD. The gate electrode was a T-shape (recess) structure with a gate length of 0.15 μm. The HEMT had the characteristics of f_T (cutoff frequency) of 90 GHz, f_{max} (maximum oscillation frequency) of 170 GHz, and a maximum stable gain (MSG) of 9 dB at 76 GHz. The millimeter-wave radio wave with power of approximately 10 mW enabled to output from the MMIC. The Co-Planer Waveguide (CPW) was used as the millimeter-wave transmission line in the chip, and the input-output and inter-stage matching circuits were formed with the distributed-element circuits of the CPW. Photographs of a portion of the circuit and the entire integrated MMIC chip are shown in Figures 4 and 5, respectively. To avoid unwanted mode generation, more than 250 cylindrical gold pillars (diameter: 40μm, height: 20μm) were formed on the surface of the chip everywhere as shown in Figure 6.

In the 2010s, advances in microfabrication technology led to the development of 76 GHz millimeter-wave radar transmitter/receiver ICs by using SiGe BiCMOS processes. The replace of compound semiconductor MMICs to SiGe BiCMOS MMICs started. In 2012, Fujitsu TEN commercialized a 76-GHz three-dimensional scanning radar with a multi-channel transmitter/receiver which consisted of SiGe BiCMOS MMICs and electronic scanning utilizing phased array antennas instead of conventional mechanical scanning, and achieved accumulative production of 1 million units by October 2016 (8, 9).

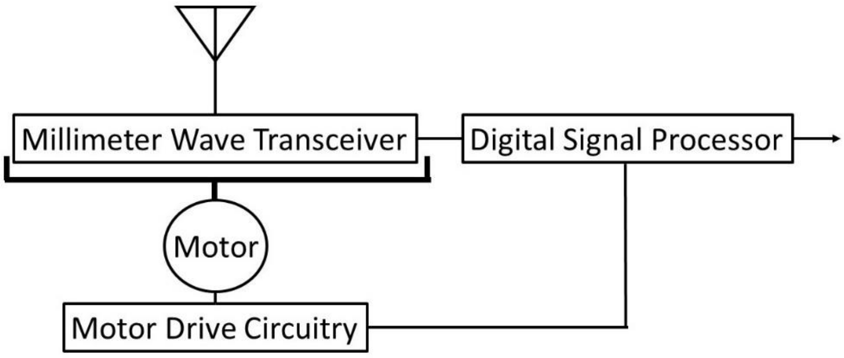

Figure 1 Block diagram of radar system

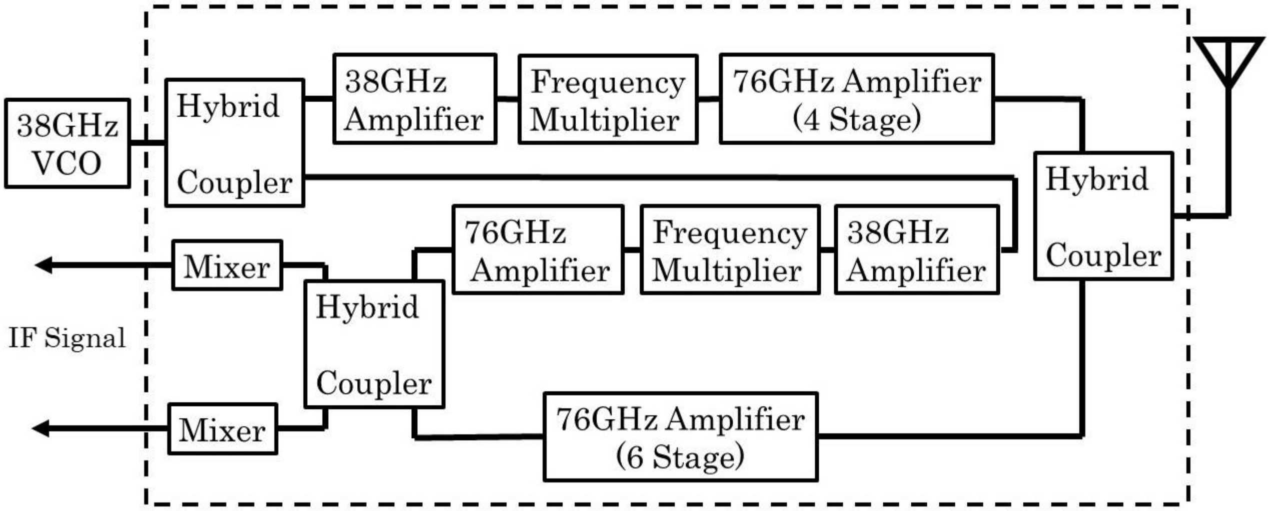

Figure 2 Block diagram of millimeter wave radar

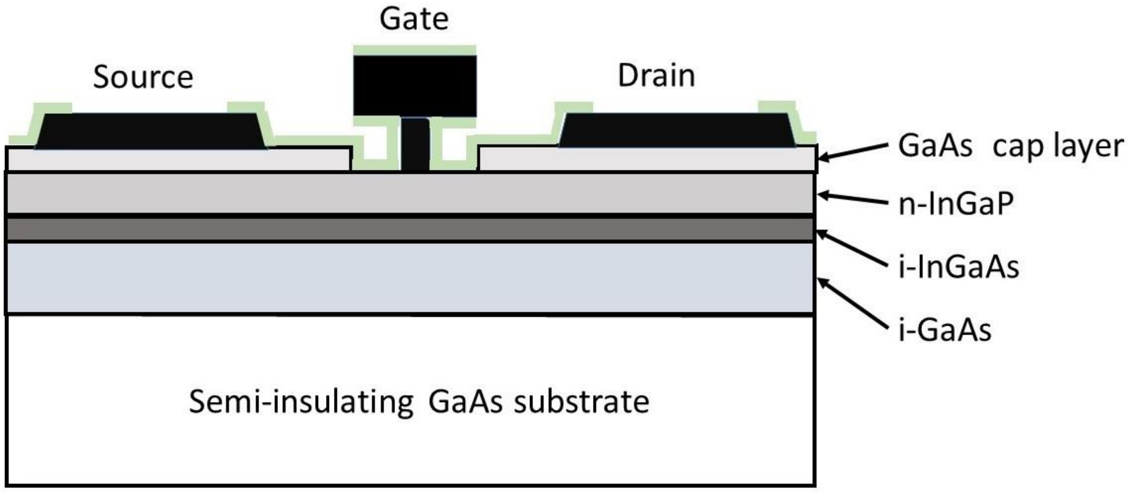

Figure 3 InGaP/InGaAs HEMT cross sectional structure

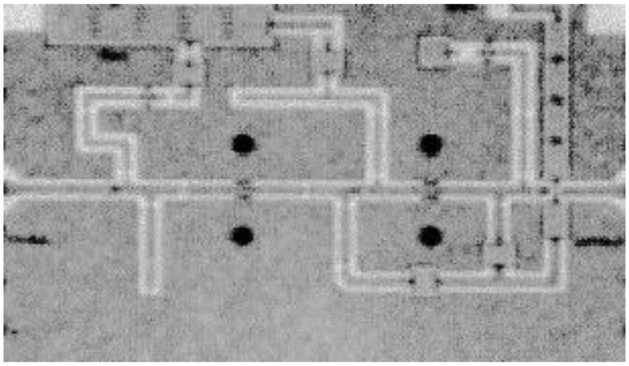

Figure 4 Photographs of a part of 76 GHz amplifier chip (2)
(Courtesy of Fujitsu Limited)

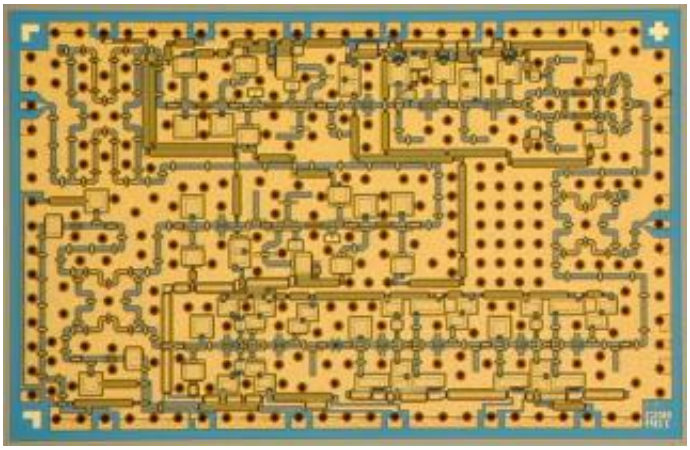

Figure 5　Photograph of single chip integrated MMIC (4)　(size:2.3mm x 3.7mm)
(Courtesy of DENSO TEN Limited)

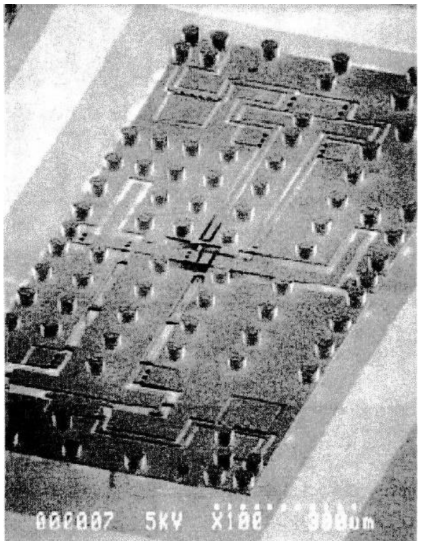

Figure 6　Bird-eye overview of MMIC by scanning electron microscopy (SEM) (3)
（Courtesy of Fujitsu Limited）

Figure 7　3D-scan 76GHz automotive radar (8)
（Courtesy of DENSO TEN Limited）

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