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Ku-band Compact Multi-layer Monolithic Microwave Digital Attenuator using InP/InGaAs PIN Diodes

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1. Introduction

A monolithic microwave attenuator is one of the key components in high-frequency communication systems such as automotive collision-avoidance and RF front-end radars [1]. Especially, a digital attenuator offers better linearity, high power handling with easy and accurate control and good thermal stability over a large temperature range [2]. In digital attenuators, PIN diodes and FET devices mainly have shown good switching performances in high frequency applications. In achieving a switching function between through-path and attenuation-path in a digital attenuator, PIN diodes have shown higher performances than FET devices in terms of high switching rate, low-insertion loss, high isolation and high power handling capabilities. Among various kinds of PIN diodes for high frequency applications, InGaAs PIN diode based on InP-based material systems has material-related excellent properties, such as high electron mobility, low turn-on voltage, high cutoff frequency and compatibility with InP-based HBTs for high frequency applications [3].

In this work, a 3-bit digital attenuator using InP/InGaAs PIN diodes is proposed and demonstrated. The proposed attenuator is fabricated by using a benzocyclobutene (BCB)-based multi-layer MMIC technology. The multi-layer fabrication technology reduces the intrinsic area of the 3-bit digital attenuator.

2. Circuit configuration

Fig.1 shows a 3-bit digital attenuator design, which consists of three attenuation sections of 1dB, 2dB and 4dB, respectively. Pi-networks were chosen due to their good impedance matching characteristics and the simple configuration [2]. In order to perform dc blocking and RF bypassing, dc blocking capacitors at the input/output ports and at the resistive Pi-networks were used. The thin-film resistors in the bias networks were used to provide the low-loss RF isolation and control the bias current. A thin-film resistance value of 1 kΩ was selected to draw the current flow of 8 mA, fully turning on the PIN diodes. The shunt capacitors in each arm of bias networks were used for noise immunity and stability.

The attenuation is controlled by the control voltages of V1, V2 and V3. At each attenuation stage, a positive control voltage forward-biases the through-path PIN diodes while reverse-biasing the attenuation-path PIN diodes. On the contrary, a negative voltage on V1, V2 and V3 turns on the attenuation-path PIN diodes while turning off the through-path PIN diodes.

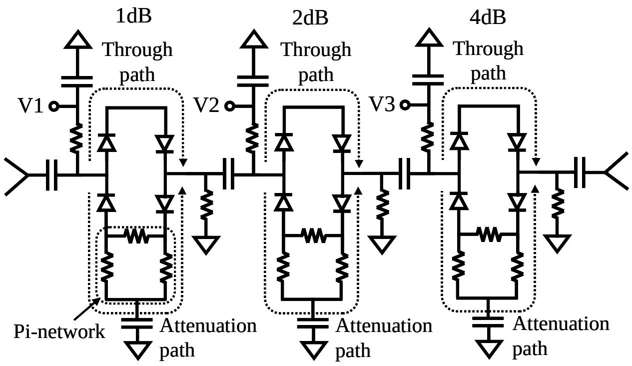

Fig. 1. Circuit configuration of a 3-bit Attenuator.

3. Device structure and fabrication

Fig. 2 shows a schematic cross-sectional view of the monolithically integrated InP/InGaAs PIN attenuator. In this work, InGaAs PIN diodes, thin film resistors and MIM capacitors were integrated on an InP substrate and fabricated by using the benzocyclobutene(BCB)-based multi-layer MMIC technology. The epitaxial layers were grown by MBE, and the devices were fabricated by using the optical lithography and wet etching technique. The details on the epitaxial layers and process are described elsewhere [4]. The area and intrinsic layer thickness of the InGaAs PIN diode were chosen to be 14 x 14 μm^2 and 1.3 μm, respectively. A 600 Å NiCr layer was evaporated to form thin-film resistors with a sheet resistance of 25 Ω/□

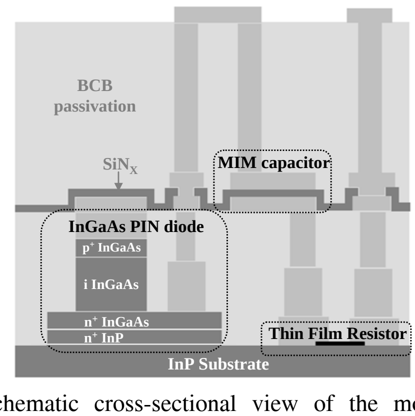

Fig. 2. Schematic cross-sectional view of the monolithically integrated InP/InGaAs PIN attenuator.

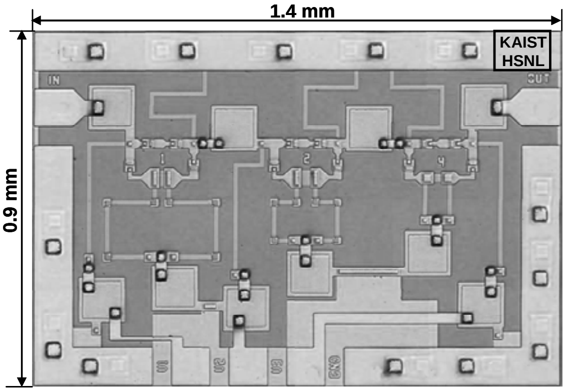

Fig. 3. Microphotograph of the fabricated 3-bit digital MMIC attenuator using InP/InGaAs PIN diodes.

and a 2000 Å SiN_X dielectric layer was deposited to make MIM capacitors with a capacitance value of 300 pF/mm^2. A microphotograph of the fabricated 3-bit digital attenuator is shown in Fig. 3. The chip size was reduced to 1.4 x 0.9 mm^2 by using the multi-layer process compared to that of GaAs MESFET, pHEMT and SiGe PIN attenuators [2],[5],[6].

4. Measurement results

The microwave performance of the fabricated 3-bit digital attenuator was measured using a network analyzer (Anritsu 37397D). The control voltages of the attenuator were −15 V (attenuation state) and +15 V (through state). The DC current of InGaAs PIN diodes was 8 mA for on-state. On-wafer S-parameter measurements of the 3-bit MMIC attenuator were conducted for 8 attenuation states.

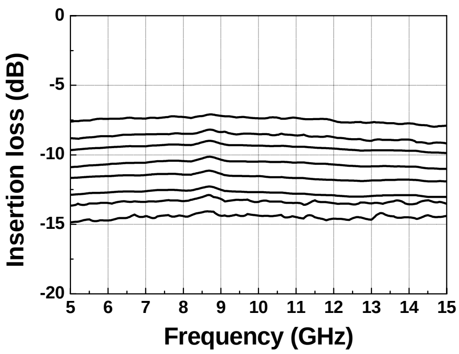

Fig. 4. Measured insertion losses of the 3-bit digital MMIC attenuator.

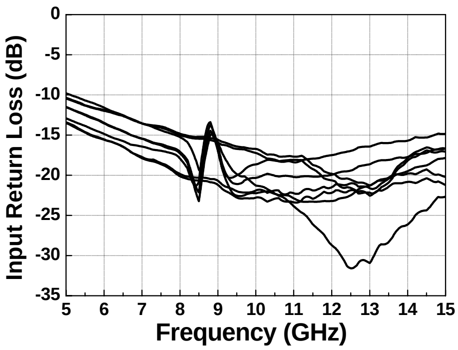

Fig. 5. Measured input return losses of the 3-bit digital MMIC attenuator.

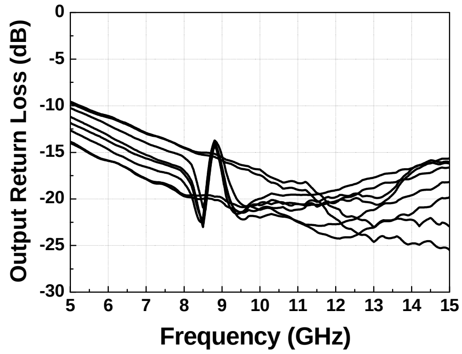

Fig. 6. Measured output return losses of the 3-bit digital MMIC attenuator.

Attenuation increments are 1.0 dB within the 7 dB attenuation range from 5 to 15 GHz.

The measured insertion loss of the 3-bit digital attenuator is shown in Fig. 4. The minimal insertion loss is 7-8 dB in the entire 5-15 GHz band. Rather high insertion loss is believed to be due to the losses at dc blocking capacitors and biasing thin film resistors. An optimized biasing circuit design can improve the insertion loss characteristic. Figs. 5 and 6 show the measured input and output return losses for all 8 attenuation states. The input/output return loss was less than -10 dB at any attenuation setting from 5 to 15 GHz, which demonstrates good input/output matching characteristics.

5. Conclusion

In summary, a digital attenuator using InP/InGaAs PIN diodes was proposed for the first time and its attenuation performance has been successfully demonstrated. The fabricated attenuator showed a 7 dB insertion loss with input and output return losses less than -10 dB over all attenuation states, demonstrating good impedance matching characteristics. The intrinsic circuit size of the fabricated 3-bit digital attenuator was significantly reduced by the BCB-based multi-layer MMIC technology.

Acknowledgements

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