Fabrication of Hyperabrupt GaAs Varactor Diode for W-band Waveguide VCO

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Abstract **— In this work, we fabricated a hyperabrupt varactor diode and W-band waveguide VCO using fabricated varactor diode. With the anode diameter of 90 µm, a maximum reverse breakdown voltage of 40 V at a leakage current of 30 µA, a maximum capacitance of 5.82 pF, and a minimum capacitance of 0.7 pF were obtained, resulting in a C_{max}/C_{min} ratio of 8.31.**

Fabricated VCO showed an excellent linearity of 1.6 % within 800 MHz. The bandwidth of the VCO was 1.165 GHz from 93.305 GHz to 94.47 GHz, and the output power was from 14.6 dBm to 15.42 dBm.

Index Terms **— Voltage controlled oscillators (VCOs), Varactors, Millimeter wave devices.**

I. Introduction

For the development of the vehicle collision avoidance system and military application including the smart bombs, Frequency Modulated Continuous Wave (FMCW) radar technology operating at W-band is excellent solution [1. 2].

For the improved performance of the FMCW radar system, development of a waveguide VCO with high linearity, wide bandwidth is very important. A high performance varactor diode is very important device to realize such a high performance VCO [3].

Hyperabrupt doping profile in the design of the Schottky contact layer is a promising solution to realize a high performance varactor diode with high breakdown voltage and large capacitance ratio [4].

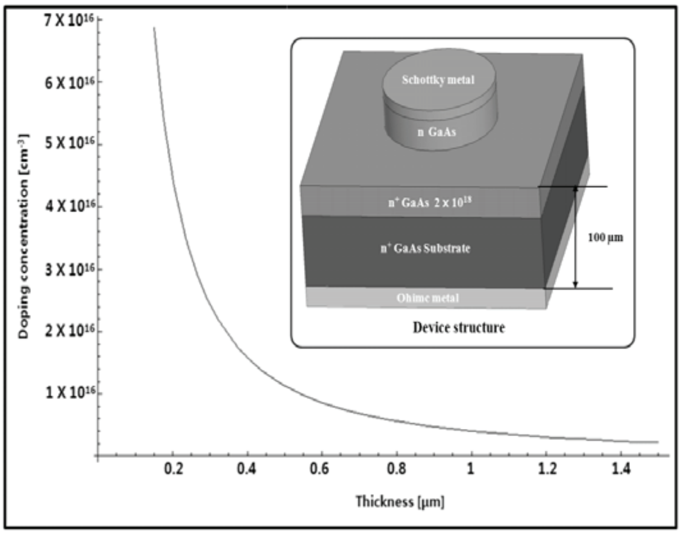
In this work, we fabricated the Schottky contact varactor diode with a hyperabrupt doping profile, packaged the diode, and fabricated a W-band waveguide VCO using the packaged varactor diode. To optimize the hyperabrupt varactor diode, we performed computer simulation and obtained hyperabrupt doping profile for high breakdown voltage and large capacitance ratio. Also, we considered various cases of anode size and device thickness for large reactance ratio and suitable series resistance of the varactor diode.

II. Design of the Hyperabrupt Varactor Diode

The hyperabrupt varactor diode epitaxial structures were grown by molecular beam epitaxy (MBE). The epitaxial structure of the hyperabrupt varactor diode consist of 1 µm n^+- GaAs ohmic contact layer (2×10^{18} cm^{-3}), and 1.5 µm n-type hyperabrupt GaAs Schottky contact layer on a n^+-GaAs substrate (1×10^{18} cm^{-3}). Doping concentration of hyperabrupt n-GaAs Schottky layer changes from 1×10^{17} to 4×10^{15} cm^{-3} [5]. Fig. 1 shows the epitaxial structure and doping profile of n-GaAs Schottky contact layer of the hyperabrupt varactor diode.

Doping condition	Doping concentration	Thickness [µm]
n GaAs (hyperabrupt)	$1 \times 10^{17} \sim 4 \times 10^{15}$	1.5
n+ GaAs	2×10^{18}	1
n^+ GaAs Substrate		

(a)



(b)

Fig. 1. Doping profile and device structure of hyperabrupt doped varactor diode. (a) Epitaxial structure of varactor diode. (b) Doping profile of n-GaAs hyperabrupt layer.

III. Fabrication and Characterization of the Hyperabrupt Varactor Diode

The epi-wafer was first thinned down to 100 µm. Ohmic (cathode contact) metallization was performed on the bottom of the wafer, and a low specific contact resistance was obtained with the rapid thermal annealing. 1.5 µm deep mesa etching was performed to provide isolated active-areas using phosphoric acid/H_2O_2/H_2O. Finally, Ti/Au Schottky contact (anode contact) process was performed [6-8]. The anode diameter is 90 μm. Fig. 2 shows a fabricated varactor, with an inset of a packaged varactor diode.

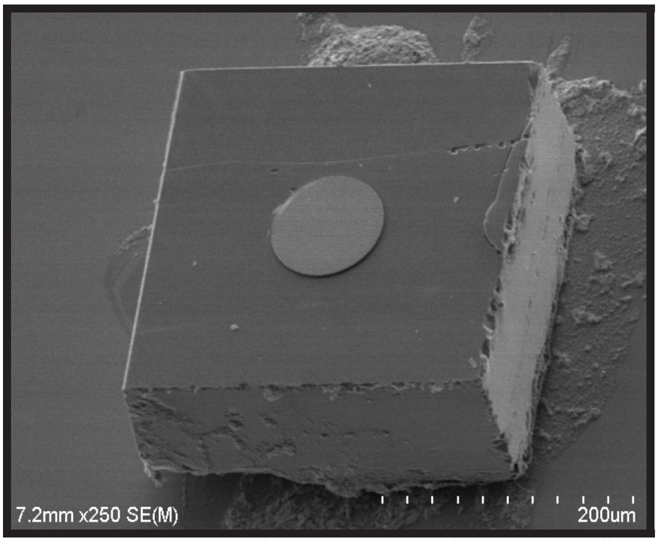


Fig. 2. SEM view of fabricated GaAs hyperabrupt varactor diode.

As shown in Fig. 3, packaging for the varactor diode consists of a stud, a lid, a base plate and a ceramic ring. Wedge bonding and silver epoxy were used for the anode and the cathode contact, respectively. I-V and C-V characteristics were measured using Keithley 4200 DC parameter analyzer and a Keithley 590 CV parameter analyzer. Fig. 4 shows the measured I-V characteristics under reverse bias condition. the reverse breakdown voltage of 40 V at a reverse leakage current of 30 μA were obtained. As shown in Fig 5, with a 100 kHz signal, measured capacitances varied from 5.82 to 0.7 pF, the giving C_{max}/C_{min} ratio of 8.31. These results compare favorably with published data [9-11] showing high potential of our diode for the W-band VCO application.

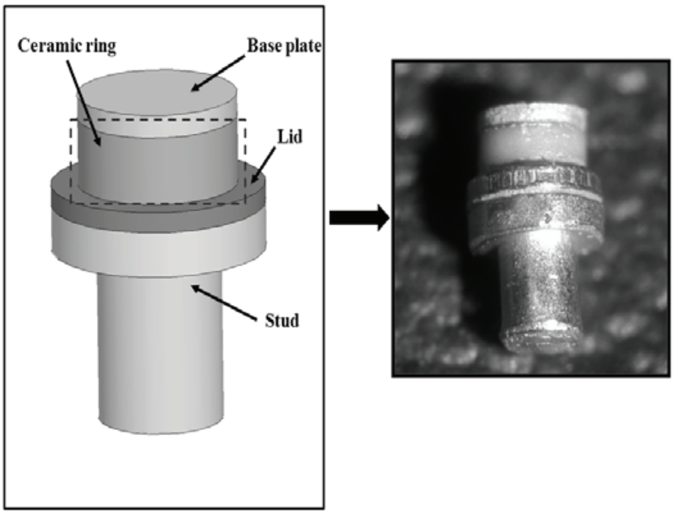


Fig. 3. Packaged GaAs hyperabrupt varactor diode.

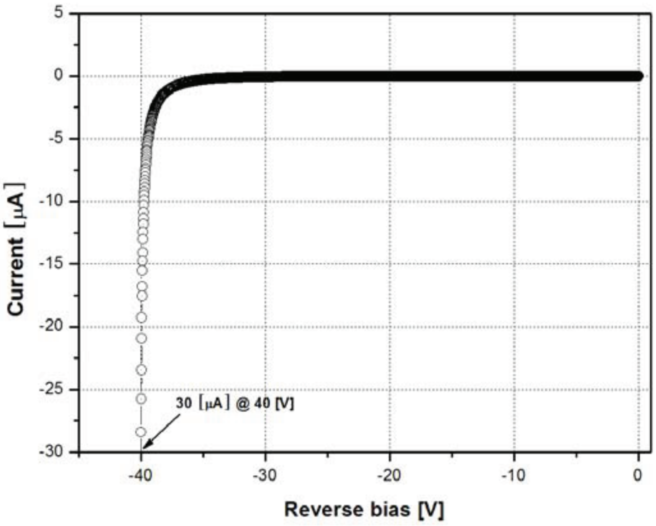


Fig. 4. I-V characteristics of fabricated varactor diode.

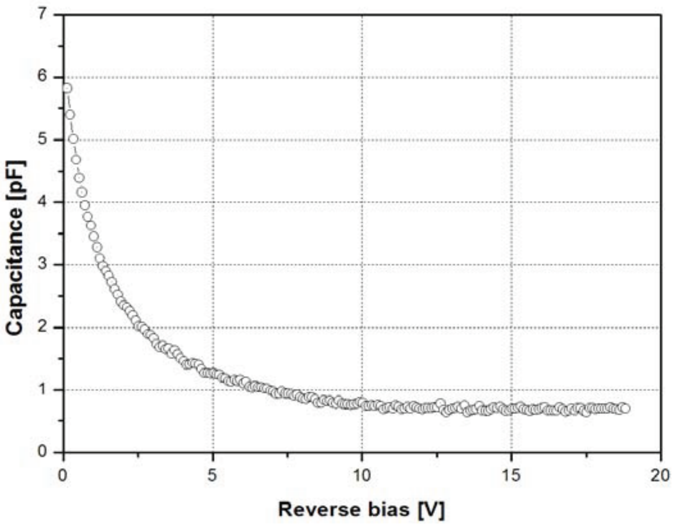


Fig. 5. C-V characteristics of fabricated varactor diode.

IV. VCO APPLICATION

As shown in Fig. 6, a packaged varactor diodes and a commercial Gunn diode were mounted at the lower cavity with a regulating distance, and the bias posts are located at the upper cavity. DC bias is supplied through low pass filters to the Gunn and varactor diodes, and the output power is tuned by a moving back short position [12]. Fig. 7 shows the fabricated waveguide VCO. Bandwidth and output power of the fabricated VCO were measured using an Agilent E4407B spectrum analyzer with a extended harmonic mixer and an Agilent E4419B EPM series power meter.

As shown in Fig. 8, a bandwidth of 1.165 GHz from 93. 305 GHz to 94.47 GHz and the output power from 14.58 dBm to 15.57 dBm were obtained. Also 1.6 % linearity of 800 MHz was observed with a bias of from 3 V to 10.5 V. Fig. 7 also shows the linear fit result of measured bandwidth of the waveguide VCO. The VCO operates at 94.395 GHz with a phase noise of -102.21 dBc/Hz at 1 MHz offset and output power of 15.68 dBm. This is an excellent result for the application of the FMCW radar system.

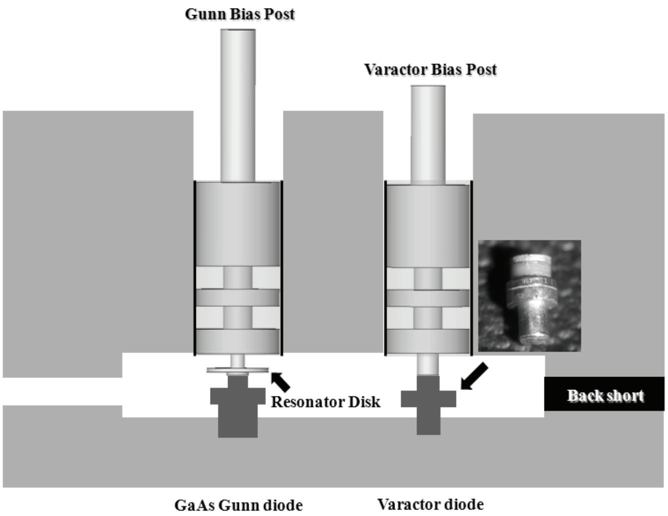


Fig. 6. Schematic diagram of waveguide VCO.

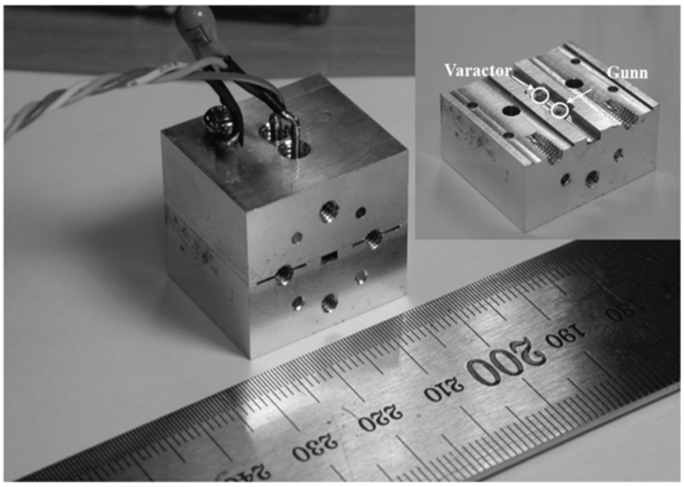


Fig. 7. Fabricated waveguide VCO.

IV. Conclusion

In this work, we designed and fabricated a hyperabrupt varactor diode to be used in a W-band waveguide VCO. With the anode diameter of 90 µm, a maximum reverse breakdown voltage of 40 V at a leakage current of 30 µA, a maximum capacitance of a 5.82 pF, and a minimum capacitance of 0.7 pF were obtained, resulting in a C_{max}/C_{min} ratio of 8.31.

Fabricated VCO showed an excellent linearity of 1.6 % within 800 MHz. The bandwidth of the VCO was 1.165 GHz from 93.305 GHz to 94.47 GHz, and the output power was from 14.6 dBm to 15.42 dBm.

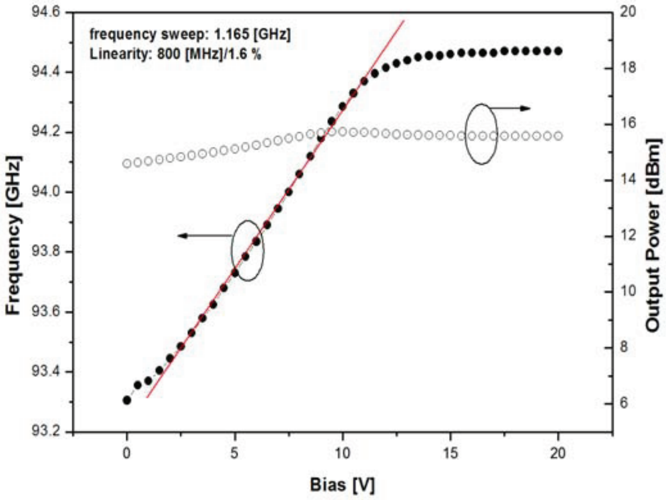


Fig. 8. Measurement results of bandwidth and output power of VCO.

Acknowledgement

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