QW-FET 구조를 가진 고성능 평판형 광검출기의 제작 및 특성평가

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Fabrication and Characterization of High Performance Planar Photodetectors on QW-FET Wafer

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Abstract - Metal-Semiconductor-Metal type photodetector was fabricated with AlGaAs/InGaAs Quantum Well FET structures using simplified processing steps. The DC and RF responses were measured by 850 nm wavelength injection laser. A DC responsivity in the quasisaturated regime was 0.45 A/W in CW measurements, and a bandwidth measured using a 850 nm 40 ps pulsed laser was 16 GHz. An electrical equivalent circuit model was extracted from measured S-parameter.

1. Introduction

The trend towards monolithic OEIC motivates appreciable research activity directed towards the employment of planar photodetectors which can be easily fabricated and are compatible with the FET process. The planar metal-semiconductor-metal (MSM) photodetectors are promising candidates for such OEIC applications owing to ease of fabrication, compatibility with field-effect transistor process technology[1,2]. To achieve high bandwidth (over 10GHz), sub-micron metal electrodes pattern which degraded the responsivity and process complexity is needed. To overcome the weakness of the sub-micron electrode detector and ensure the large bandwidth, we fabricated 2mm long electrode patterned MSM detector on the AlGaAs/InGaAs Quantum Well-FET structures using conventional lithography technique. The DC responsivity and bandwidth estimated using 40 ps-850 nm laser pulse. The equivalent circuit was obtained from the S-parameter measurements to confirm the RF characteristics.

2. Experiments

2.1 Device Structure

MSM detector was fabricated on AlGaAs/InGaAs Quantum Well-FET layer structure. The MBE grown layer structure consists of 30 nm-thick AlGaAs barrier enhancement layer, InGaAs channel layer, undoped GaAs and GaAs/AlGaAs superlattice buffer layer on the semi-insulating GaAs substrates.
After Ti/Au Schottky metal was deposited on the epilayers by e-beam evaporator, mesa was etched for device isolation. And then Si_3N_4 was deposited for device passivation and anti-reflection coating. The Schottky metal pattern was made by usual photolithography technique and it includes devices with different metal electrode spacing (3 and 4 μm). The active area dimensions are defined as 20 μm x 20 μm, 40 μm x 40 μm and 100 μm x 100 μm. Fig. 1 shows the scanning electron microscope (SEM) image of a fabricated device.

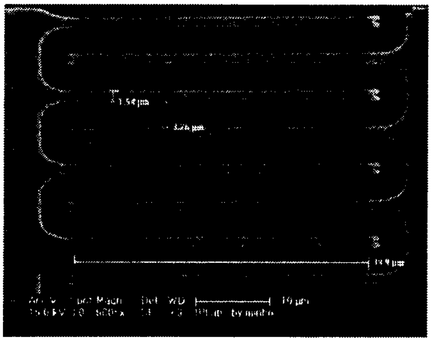

Fig 1. Fabricated device with active region of 40 μm x 40 μm

2.2 Characterizations

The device characterizations were done by DC and RF measurement. The DC responsivities are measured as a function of bias voltage and optical power using a 850 nm CW laser light input. The response speed of the devices are assessed by measurements in the time domain. A 850 nm gain-switched injection laser with a pulse duration of 40 ps FWHM was used for this purpose. The impulse responses were measured on the wafer using a 40 GHz microwave probe in conjunction with a 50 GHz sampling oscilloscope. The On-wafer S-parameter measurements were performed in the frequency range of 100 MHz-40 GHz using a vector network analyzer. The MSM detectors used in our measurements were well light-screened and a bias voltage varied from 5 V to 15 V. The devices have 40 μm x 40 μm active regions with 2 μm width of metal electrodes and 3 μm inter-electrode spacing. The equivalent circuit was derived by the S-parameter measurements.

3. Results and Discussion

Table 1 summarizes the DC responsivities and dark currents of various devices. These results are relatively high and comparable to the early reported data.

Table 1. DC responsivity and dark-current of the devices

Active area	Responsivity	Dark current at 10V
20 μm x 20 μm	0.282 A/W	3.83 nA
40 μm x 40 μm	0.451 A/W	6.32 nA
100 μm x 100 μm	0.455 A/W	11.7 nA

Fig. 2(a) and (b) show the results obtained with various optical power levels between 0 and 0.25 mW. Figs. 2(c) and (d) shows impulse responses of 40 μm x 40 μm active region with 2 μm metal finger width and 3 μm metal finger spacing depends on the bias voltage and metal electrodes gab respectively.

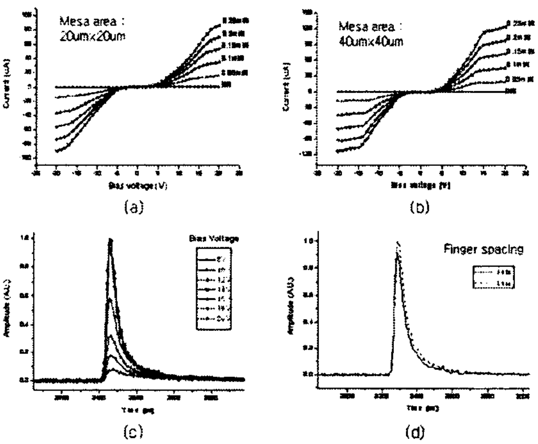

Fig 2. DC and RF measurements. (a), (b) Photocurrents and dark-currents of 20 μm x 20 μm and 40 μm x 40 μm active area. (c), (d) Temporal responses depending on bias voltage and metal finger spacing respectively.

Rise time technique was used to estimate the device bandwidth. The relations between rise time(Tr) and bandwidth(f_{3dB}) describes as[3]

$$T_r = (\tau_{tr} + \tau_{RC})\ln 9 \quad \text{and} \quad f_{3dB} = [2\pi(\tau_{tr} + \tau_{RC})]^{-1} \qquad (1)$$

where τ_{tr} is the transit time, and τ_{RC} is the RC-time constant. Measured rise time was Tr =21.81 ps and its bandwidth was 16.02 GHz by (1). The reported bandwidths of MSM PD with electrode spacing of 1-3 μm are 1.3-11 GHz. The device in this paper shows higher bandwidth compared with conventional MSM devices which have large metal electrodes spacing (2-3 μm). 2DEG effects due to the AlGaAs/ InGaAs/ GaAs heterostructures further enhance the barrier height results in the reduction the dark-current and add in transport of photogenerated carrier by internal field [4]. Fig. 3(a) shows the Smith-chart representation of S_{11} parameters measured up to 40 GHz. Various impedance values were estimated combining these parameters to a known circuit topology for typical inter-digital heterojunction structures [5,6]. Fig. 3(b) shows the derived equivalent circuit of the MSM detector. Small value of capacitance of the device implies its potential for high speed operation. Since the interdigitated MSM PD structure possesses a low capacitance and resistance, the speed limitation is primarily due to the transit time of the photogenerated carriers in the MSM PD and not the RC time constant[7]. The maximum 3-dB bandwidth calculated from this circuit is 15 GHz, comparable to the previously measured value.

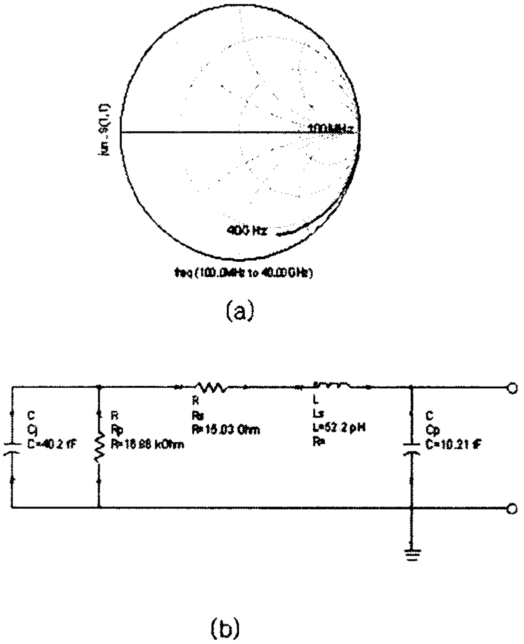

Fig. 3. (a)Measured S(1,1) parameter represented in Smith-chart. (b)Equivalent electric circuit model of MSM photodetector. The values of the parasitic elements are obtained by fitting to the S11 parameters.

4. Conclusion

We have fabricated and characterized an MSM photodetector on a AlGaAs/InGaAs Quantum Well FET wafer with simple processing steps. DC and RF characteristics show we can achieve relatively high device performance without complex submicron lithograph technique. The typical device with 2 μm finger width and 3 μm finger spacing shows the reasonable good DC responsivity such as 0.451 A/W and the low dark-current such as 6.32 nA at 10 V bias. The bandwidth of 16.02 GHz at 15 V bias is one of the largest among the 3 μm device. Equivalent circuit model, derived using S-parameters which representing the parasitic properties of the detector, confirms the high RF performances and provides the useful informations in matching with other device. The device can be directly integrated with QW-FET or HEMT amplifier to make a front-end of a receiver circuit.

[References]

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