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High Bandwidth Metal-Semiconductor-Metal Photodiodes with Integrated Fabry-Perot Resonator for WDM Receivers

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Metal-semiconductor-metal photodetectors operating at light incidence normal to the surface are reported. Wavelength demultiplexing of closely spaced channels is attained by integration of a Fabry-Perot resonator. The optical bandwidth of 1 nm at a contrast ratio exceeding 10:1 is promising for application in WDM receivers. Frequency limits exceeding 35 GHz are observed by illumination with HF sinusoidally modulated light. From the dark current of less than 30 pA results a high receiver sensitivity.

1. Introduction

The integration of a planar metal-semiconductor-metal (MSM) structure with a monolithically integrated Fabry-Perot resonator combines the advantages of these both concepts: low device capacitance, low dark current, process compatibility with MESFETs, operation at incidence normal to the surface and extension to two-dimensional arrays [1]. Because of the remarkable features of planar MSM devices they have attained considerable importance for photodetection [2] and electrooptical modulation [3] in multigigabit optical transmission systems. Monolithical integration of multilayer reflectors and Fabry-Perot (FP) resonators epitaxially grown by MBE opens up new concepts of surface operating optoelectronic devices such as vertical cavity lasers [4], modulators [3], filters, and wavelength selective photodetectors.

2. Device Structures

Monolithically integrated FP structures can be fabricated by solid source MBE in the AlGaAs/GaAs system for near infrared applications at 800 nm and in the InGaAlAs/InP system for 1.3 μm and 1.55 μm wavelength [5].

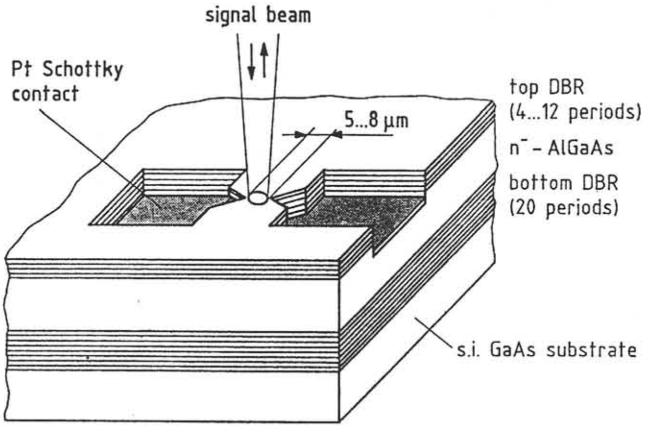

Fig. 1: Design of wavelength selective MSM photodetector with integrated Fabry-Perot resonator.

Fig. 1 shows an AlGaAs/GaAs MSM photodetector. It consists of two integrated Bragg reflectors (DBR) separated by an AlGaAs absorption layer. Its bandgap wavelength is adjusted to the the test wavelength to obtain optimum absorption and to avoid reflections into the system.

The bottom DBR is composed of 20 periods of AlAs and $Al_{0.14}Ga_{0.86}As$ quarterwavelength layers whereas the number of periods in the top DBR is varied from 4 to 12. The absorption of the DBR layers is negligible. The top reflector has to be removed underneath the Pt Schottky electrodes before contact deposition because the heterointerfaces drastically increase the resistance and reduce the frequency limit.

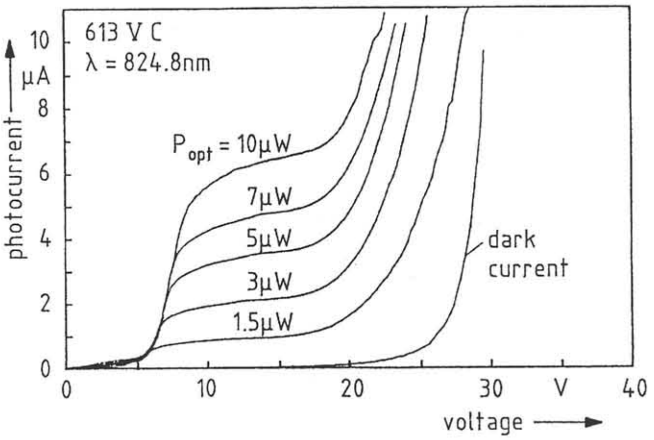

Fig. 2: Current-voltage characteristics at different optical power levels.

The current-voltage characteristics at optical power levels from 0 to 10 μW are shown in Fig. 2. A bias voltage of about 5 V is necessary to extend the depletion region into the optical focus. Beyond 20 V strong carrier multiplication is observed. The dark current at a bias voltage of 10 V is less than 30 pA resulting in a dark current density $J(10\ V)<10^{-6}$ A/cm^2. This result is promising for high receiver sensitivities.

3. Wavelength Demultiplexing

As indicated in Fig. 1 and mentioned in the introduction the integrated FP resonator is composed of two monolithically integrated DBRs. The reflectivities of multilayer structures composed of 20 to 30 periods surpass 99 % facing air [5]. Whereas a number of 20 periods in the bottom DBR is chosen, the number of periods is reduced in the top DBR (4 to 12 periods) to adjust finesse and optical bandwidth (2 nm to 0.2 nm) of the FP resonator to the channel spacing.

As an example the current-wavelength characteristics of a device with 7 periods in the top reflector and 20 periods in the bottom DBR is shown in Fig. 3. A resonator bandwidth of 1.0 nm and a contrast ratio of more than 10:1 are achieved. Bandwidth and contrast ratio easily can be adjusted by a variation of the number of periods in the DBRs. For experimental investigation we have prepared and characterized photodetectors which have 4 to 12 periods in the top reflector. As shown in Fig. 4 the experimentally determined bandwidths (●) are in good agreement with the calculated curve (——).

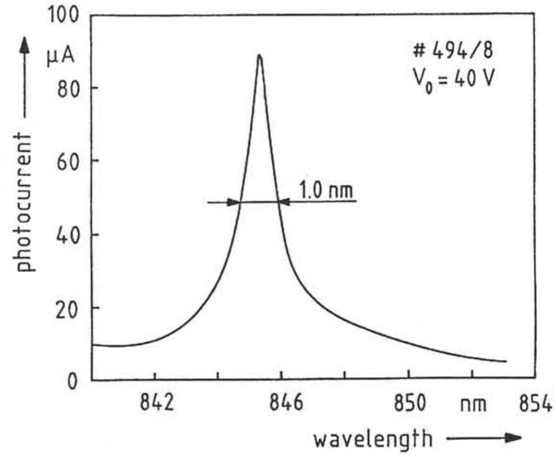

Fig. 3: Photocurrent-wavelength characteristics of a wavelength selective MSM photodetector (top DBR: 7 periods, bottom DBR: 20 periods).

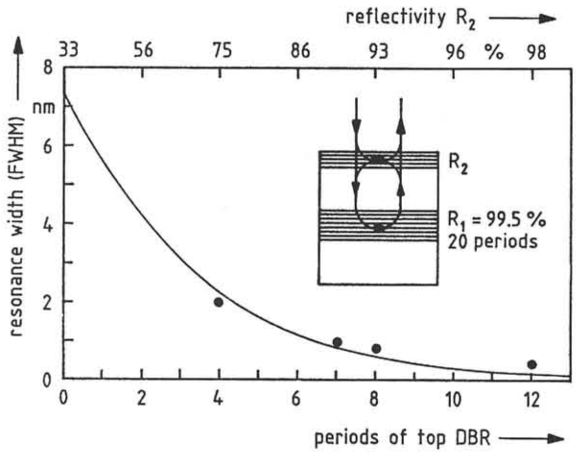

Fig. 4: Resonance width in dependence on the number of periods in the top DBR, exp. (●) and calc. (——) results.

4. Frequency Characteristics

For high frequency operation the MSM photodetectors are mounted onto 2.4 mm flanges and partially are provided with fiber pigtails. The frequency characteristics of the devices is derived by illumination with HF sinusoidally modulated light. Modulation of the output power of a commercial laser diode by current modulation hardly exceeds 20 GHz. In our experiments HF modulation of the incident test light is attained by beam superposition of two external cavity semiconductor lasers. A wavelength of about 830 nm close to the gap wavelength is used. Microwave spectra are free of jitter at a linewidth of about 20 MHz. Because of the nearly unlimited tuning range of this HF source investigations of frequency characteristics are limited by the microwave spectrum analyzer only. Verly low power levels can be detected since no crosstalk of a microwave generator is limiting these experiments. The frequency limit, indicated in Fig. 5, exceeds 35 GHz and is predominantly caused by parasitic inductance of the detector package.

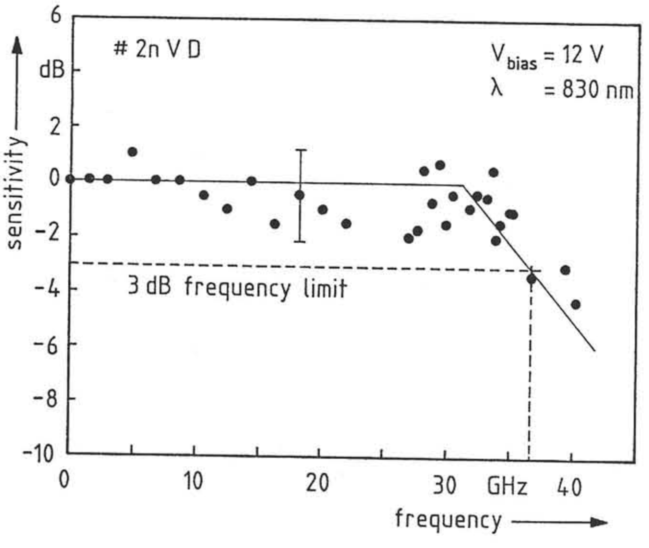

Fig. 5: Frequency characteristics of a resonant MSM photodetector mounted onto a 2.4 mm flange.

5. Summary

In conclusion, we reported design considerations and experimental investigations of wavelength selectice MSM photodetectors with monolithically integrated Fabry-Perot resonator. The optical bandwidth is adjusted by the design of the distributed bragg reflectors of the Fabry-Perot resonator. Using 20 periods in the bottom reflector and 7 periods in the top reflector results in an optical bandwidth of 1 nm. The contrast ratio exceeds 10:1. The frequency limit of MSM devices mounted onto 2.4 mm flanges is about 35 GHz. This result is confirmed by detection of short optical pulses generated by a mode locked laser. The high sensitivity, the promising frequency characteristics, and the process compatibility to electronic circuits are remarkable features for applications in WDM transmission systems

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6. References

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