DESIGN AND CONSTRUCTION WDM TYPE TRIPLEX OPTICAL RECEIVER MODULE USING SYSTEM MULTIMODE POLYMERIC PLC HYBRID INTEGRATION TECHNOLOGY

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Abstract: We report about more detail design and constructions of the WDM triplex optical receive part of the triplex transceiver module for subscribe part passive optical network PON-FTTH. The triplex optical receiver module consists of a epoxy novolak resin polymer or a microoptic planar lightwave circuit (PLC) made by hybrid integration technology with volume holographic grating triplex filter VHGT and surface-illuminated photodetectors in SMD package. The hybrid PLC has composed from two parts – a microoptical or polymer planar optical waveguide including VHGT filter section and an optoelectronic microwave section. The both parts are placed on the composite substrate.

Key-Words: Hybrid integration, optical transceiver, WDM triplex optical receiver, planar lightwave circuit, volume holographic grating triplexer, surface-illuminated photodetectors

1 Introduction
We report about design, simulation and construction of the WDM type triplex optical receiver module using multimode polymer planar lightwave circuit (PLC) hybrid integration technology, which enables us to construct component by combining PLC with passive function (collimation lens, fiber and planar optical waveguides) and active optoelectronics devices (laser diodes, optical amplifiers and photodiodes) hybridized on a PLC [1]. The WDM type triplex receiver is part of transceiver for subscriber part of the passive optical network PON for a fiber to the home FTTH topology. The WDM optical receiver module used a PLC hybrid integration technology consist of the system polymer planar waveguides, volume holographic grating triplex filter VHGT, surface-illuminated photodetectors (SI-PD) and collimating lenses. For multimode system polymeric waveguides was used epoxy polymer resist SU-8 2000 or PMMA (polymethylmetacrylate). As for selected theoretical issues dealing with preparation of the planar photonic hybrid integrated circuits, the works take up previously discovered major dependence of the index of refraction of selected polymeric thin layers on the electric field [2] and using of this phenomenon at the production of planar channel waveguides.

2 Design and results of the optical part
In the first part of the optoelectronic WDM receiver module design was determined basic geometrical parameters of the system multimode polymeric waveguides and VHGT for wavelength 1310, 1490 nm and 1550 nm by Beam Prop simulation programs. The design respect the geometrical parameters of the photodetectors and laser diode SMD curriers.

In the second step of the research the minimal diameter far-field beam and angle of diffraction of the VHGT was determined from far-field measuring of the SM fiber, collimation lens and VHGT set by Beam Profiler BP 104-IR from Thor Labs. The light power from the single mode optical fiber (SMF), which had a thickness core of 3.5 µm with a thickness cladding layer of 125 µm, the NA = 0.14 and collimation lens with 1.8 mm diameter and 2 mm length was coupled to the VHGT element (2x1x1mm) by a piezoelectrically driven micromanipulator with Beam Profiler head to acquire sufficient position accuracy in the alignment process.

The VHGT filter is diffractive element with volume holographic gratings, which containing volume periodic changes index of refraction. When optical radiation incidents on holographic grating, and satisfy Bragg phase condition, then happen to diffraction optical radiation for wavelength \( \lambda_B \) of the transmission grating (1)

\[ \lambda_B = 2\Lambda \sin \theta \]
where $\lambda_B$ is Bragg wavelength, $\Lambda$ is grating period and $\theta$ is angle of the diffraction. On the basis formula (2) was derived grating period $\Lambda = 2.388 \ \mu$m. The simple schema of the VHGT filter is given on the Fig.1

Fig. 1: Simple schema of the VHGT filter arrangement

The diffraction angle of the VHGT filter was measured by the beam analyzing system Beam Profiler BP 104-IR from Thor Labs. The diagram of the diffraction angle measuring, which was determined as the radiation spot deflection in X-axis for the wavelength 1490 nm and 1310 nm, deflection left, 1310 nm and 1550 nm, The diagram of the diffraction angle measuring, which was determined as the radiation spot deflection in X-axis for the wavelength 1490 and 1310 nm, deflection left, 1310 nm and 1550 nm, deflection right. The difference in Z-axis was 2 mm, difference in X-axis was 0.69 mm, after it diffraction angle was 19.1 degree for wavelength 1490, 1550 nm and zero degree for 1310 nm.

The basic problem was design of the optical alignment between VHGT element and the planar optical multimode waveguides system. The diameter of the optical spot behind the VHGT had to be 50 µm, if the enough diffraction efficiency would be received. After it the multimode wide diameters optical planar waveguides we had to use. The optical waveguides power transition and waveguides topology was simulated in Beam Prop program for optimal dimension of the multimode waveguides cross section and minimal attenuation Fig.2.

Fig. 2: BMP simulation of the TE 01 mode in the multimode planar polymer waveguide width 50 µm, $\lambda = 1310$ nm

The simulated coupling efficiency for direct coupling between the input facet of the optical polymer waveguide (SU8-2000) with the ridge width 50 µm and thickness 50 µm and the VHGT filter at 1310 nm and 1550 nm wavelength was 25 %, for fundamental mode $TE_{01}$.

In the next step was designed and fabricated the platform technology for hybrid PLC to match numerical aperture the waveguides made by organic polymer and PIN photodetectors of the optoelectronic WDM receiver. WDM receiver was created by the SI-PD PIN InGaAs photodetector on the alumina submount and electrical microwave part of the WDM receiver create by the HBT amplifier. The photodetectors was placed in the groove for elimination height offset of a from composite HF material Rodgers substrate. The optimum distance among optical waveguides facet on base polymer SU8-2000 and optical fiber or photodetector in the receiving part was specified by BMP program and measuring at 180 µm.

## 3 Design and results of the microwave electrical part

Our work was concentrated on design and construction of a microwave hybrid optoelectronic receiver [3], where the PIN photodiode was connected by microstripe line to input of the HBT amplifier. All parts are placed on the composite material substrate. The theoretical analysis describes the microstrip connection between the PIN photodiode and the input of the HBT amplifier by the small signal equivalent circuit. For frequency response analysis we used the small signal equivalent circuit of the OE receiver input Fig. 3.

Fig. 3: The small signal equivalent circuit of the PIN photodiode with SMD assembly and input of the HBT amplifier

where

- $i_p(\omega)$ – PIN photodiode photocurrent source
- $C_D$ - capacitance of depletion layer 0.5 pF
- $C_S$ - stray capacitance 1 pF
$R_s$ - series resistance 10 Ω
$R_D$ - dynamic resistance of the PIN photodiode 1 kΩ
$L$ - inductance generated by the photodiode SMD carrier
$R_V$ - thin film resistor for reverse bias voltage 2 kΩ
$R_A$ - input impedance 50 Ω of the ideal amplifier

The PIN photodiode (C30606ECER from Judson Technologies) chip connection to the microstrip waveguide is composed from compensation inductance made by gold microstrip on the alumina carrier $L_1$ and gold wire connection $L_2$. For calculation frequency response limit it was counted inductance $L$ given by (2).

$$ L = L_1 + L_2 $$

(2)

For the cutoff angle frequency $\omega_T$ of the module complex transition $Z_T$ impedance characteristic (3) was derived

$$ |Z_T| = \frac{R_pR_s}{\left[ R_D + R_s - \omega^2LC_D R_s \right] + \omega^2 \left[ (L + R_DRC_D + RL_R C) \right] }^{1/2} $$

(3)

The cut off angle frequency $\omega_T$ was derived as root of the transcendent equation (4)

$$ |Z_T(\omega_T)| = \left| Z_T^e \right| / 2^{1/2} $$

(4)

here $\left| Z_T^e \right|$ is module of the impedance for $\omega = 0$, $R_p$ is parallel $R_s$ and $R_D$ combination.

The limit frequency $f_T$ received by solve equation (4) was $f_T = 2.78$ GHz. The module $\left| Z_T^e \right| = 46.07 \Omega$, $C_T = 1.5$ pF and $L = 4.5$ nH.

The optimum value of the inductance $L_{opt}$ for maximally flat transition impedance $Z_T$ characteristic is given after [4] as (5)

$$ L_{opt} = 0.4R^2_C \times 1.85nH $$

(5)

The cut off frequency for optimum value $L_{opt}$ was calculate $f_T = 3.25$ GHz.

The small signal equivalent circuit presented in the Fig. 4 was implemented for simulation in Win Mide program. The capacity of depletion layer $C_D$ is a function of reverse bias voltage and for 5 V is catalog value 0.50 pF. $C_s$ is stray capacity signal connection PIN photodiode SMD assembly. For good high frequency response it is essential to be $C_D$ and $C_s$ kept as low as possible. After that it is necessary to reduce $R_A$ or to provide high-frequency equalization. The inductance and capacity generated by the photodiode SMD carrier was simulated to analyze its influence on the device. The measured and simulated results at the frequency range 0.1 – 3.5 GHz is shown in the Fig.4.

The simulation and measurement of $S_{21}$ modulation characteristic reveal that the limit frequency $f_T$ of the OE receiver was 2.5 GHz. The bandwidth of the OE receiver is limited by the capacity depletion layer $C_D$ of the photodiode and $C_s$ stray capacity of the contact spots. The inductance distributed along the signal way between PIN photodiode and input of the HBT amplifier shift the bandwidth of the OE receiver from 1.91 GHz to 2.5 GHz with reasonable ripple 3 dB.

4 Conclusion

In this paper were report about design and construction of a WDM triplex optical receiver, which is receiving part of transceiver module TRx for subscribe part passive optical network PON-FTTH using polymer PLC hybrid integration technology. We presented the diffraction angle measuring results of the VHGT filter between 1310 nm and 1550 nm wavelength which was 19.1 degree. The simulated coupling efficiency for direct coupling to the input facet of the optical polymer waveguide (SU8-2000) with the ridge width 50 µm and thickness 50 µm from the VHGT filter at 1310 nm and 1550 nm wavelength was 25 %, for fundamental mode TE01. In the second step of our work was designed and measured the optoelectronic and microwave part of the hybrid WDM triplex optical receiver with a polymer optical waveguide, InGaAs p-i-n photodiode and integrated HBT amplifier. The results of the $S_{21}$ modulation characteristic measuring and simulations were in good agreement. The bandwidth of the OE receiver was 2.5 GHz for compensation inductance value $L_S = 4.8$ nH. When the inductance $L_S$ will drop to optimal value $L=1.85 \times 10^{-3}$, the bandwidth will shift to...
3.25 GHz but for PON-FTTH application was $L_S = 4.85 \text{nH}$ more suitable special from noise point of view. The simulation reveals that the bandwidth was limited by the capacity depletion layer $C_D$ of the PIN photodiode and stray capacity $C_S$ of the contact spots. The resonance of the lumped compensation inductance $L_S$ in the signal way make the peaking effect in the $S_{21}$ modulation characteristic shift the bandwidth of the OE receiver to high level with acceptable ripple. Further work will be concentrated on design and construction of optoelectronic WDM transmitting part and microoptic WDM optical receiving part, which will be fabricated by use existing technology with bandwidth 2.5 GHz as the main optoelectronic part of the hybrid PLC integrated microwave transceiver TRx for the FTTH topology optical PON networks.

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References: