REACTIVELY MATCHED OPTOELECTRONIC TRANSCEIVERS ON InP SUBSTRATE FOR 6 GHz OPERATION

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ABSTRACT

We present the monolithic integration of optoelectronic devices with microwave impedance matching networks. Those are a GaInAs photodiode and a GaInAsP Buried Ridge Stripe structure laser emitting at 1.3 µm; both are fabricated on semi-insulating InP substrate. The matching networks, constituted of reactive components, have been designed to match these devices to 50 Ω at 6 GHz with a bandwidth close to 10%. Compared to an unmatched link, an improvement of 12 dB at 6 GHz is theoretically obtained; experimentally, it has been measured to 11.4 dB at 5.6 GHz.

INTRODUCTION

The quite high microwave signal loss (≈ 30 dB) of a classical optical link could be roughly attributed to three main sources: (i) optical losses (misalignments, connectors, propagation loss), (ii) optoelectronic device efficiencies, (iii) microwave electrical mismatch of optoelectronic devices. This work is focused on this last point.

Usually, matching of optoelectronic devices is resistive. Besides their simplicity, these solutions have the advantage of offering broadband operation which is appreciated in high bit rate digital communications. This necessity disappears for analog transmissions where narrow bandwidth operation is often used. Moreover, these resistive matches improve the input and output return losses but do not maximize the power transfer between RF generator and laser diode and between photodiode and load. The use of reactive matching networks can fulfill the requirements of improving return losses and reducing insertion losses as well (1-5); however, broadband operation is then more complicated to achieve.

Nevertheless, parasitic elements, due to bonding and packaging, reduce the capability of the matching as frequency increases. The use of chip components overcomes case parasitics but bonding ones are only cancelled by monolithic integration. This is the reason why we monolithically integrated optoelectronic devices with passive reactive networks. This first demonstration has been made for a 6 GHz work frequency.

TRANSCEIVER CONCEPTION

First, discrete optoelectronic devices have been fabricated on semi-insulating InP substrate. The epitaxial growth used is MOCVD for the emitter and LPE for the receiver, the use of semi-insulating substrate is more appropriate for the fabrication of the matching networks. The main characteristics of discrete devices are summarized below:

emitter: (400 µm long, 1.5 µm wide stripe)
- threshold current: 20 mA
- maximum output power: > 10 mW
- external efficiency: 0.12 W/A (per facet)
- bandwidth: >16 GHz

receiver: (30 µm diameter active area)
- dark current: < 10 nA (@ -10V)
- capacitance: 0.13 pF (@ -10V)
- responsivity: 0.7 A/W
- cut-off frequency: > 20 GHz (on 50 Ω)

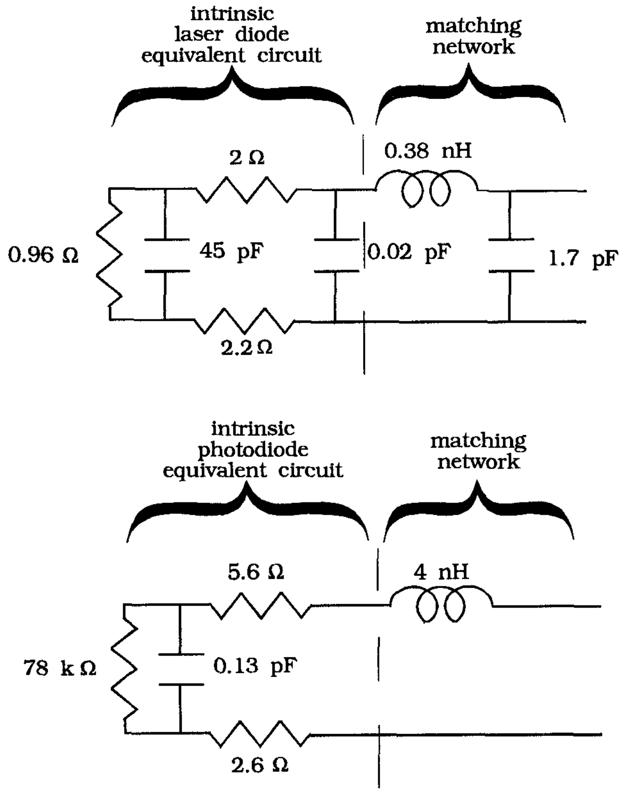

***Fig.1:** Equivalent circuits for integrated emitter (above) and receiver (below)*

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The S parameter of each device is measured in the 100 MHz - 10 GHz frequency range. An equivalent circuit is de- duced from the de-embedded data since only the intrinsic part of the devices will appear in the monolithic integration scheme. On these equivalent circuits (see Fig. 1) the contribution of both contacts ,N and P, (due to the planar processing of the devices) is shown separately; this has not, of course, any influence on the electrical circuit behavior.

The impedance matching networks are then calculated (6) in order to match the link at 6 GHz. These matching networks are constituted of spiral inductors and MIM capacitors. For the emitter, we have to match the low impedance of the laser diode (few ohms) to the 50 Ω of the RF generator. This is made using a single reactive cell including a 0.38 nH inductor and a 1.7 pF capacitor (see Fig.1). The use of a series inductor in the matching circuit easily permits the DC bias of the laser diode via an external bias tee. For the receiver, the current generator of the photodiode equivalent circuit must be loaded by the highest possible impedance in order to increase the power transfer of the link. This is done using an impedance transformer which will transform the 50 Ω load impedance in a highest one, close to 500 Ω in our case. This value is limited, on the one hand, by the value of the intrinsic capacitance of the photodiode and, on the other hand, by the value of the inductor which cannot reasonably reach large value (5 to 6 nH seems the maximum one) for integrated devices due to the increase in size and series resistance. In our case, the limit is due to the capacitance of the photodiode. The matching circuit, then, only needs an inductor of 4 nH to perform the matching at 6 GHz.

The microwave power transfer of an optical link using such matched devices instead of unmatched ones will theoretically be improved by 11.7 dB at 6 GHz. These are spread into 3.5 dB for the emitter and 8.2 dB for the receiver. These results include the effect of parasitics encountered in the monolithic fabrication process, in particular the inductor sheet resistance which is evaluated to 2 Ω for the 0.38 nH inductor and 12 Ω for the 4 nH one.

TRANSCEIVER FABRICATION

Discrete (unmatched) and integrated (matched) lasers and photodiodes are fabricated simultaneously (7) in order to easily compared their performances. Except the specific steps concerning the fabrication of spiral inductors and MIM capacitor, the technological process is the same as for the discrete device fabrication. The transmitter inductor (0.38 nH) has a 145 μm diameter, 20 μm conductor width, 5 μm conductor gap and 1.5 turn; the capacitor (1.7 pF) is 90 μm square with a 1700 Å thickness of SiO_2. The receiver inductor (4 nH) has a 225 μm diameter, 5 μm conductor width and gap and 3.5 turns. Their fabrication needs four extra technological steps for the emitter and two for the receiver. Fig.2 shows photograph of each of these transceivers.

TRANSCEIVER CHARACTERIZATION

Identical characteristics are obtained on both kinds of devices (discrete and integrated) showing that no major influence on optoelectronic properties has been produced due to the matching network fabrication. Integrated and discrete laser diodes have been mounted on a microwave submount allowing light emission while photodiodes have been directly bonded to a 50 Ω line on RT Duroid 6010 substrate. The laser diode and photodiode biases are respectively 80 mA and - 5V which allow to reach intrinsic cut-off frequencies much higher than the intended work frequency. Free air optical propagation is used; in order to avoid direct microwave coupling between the two transceivers, they are taken away from each other and focusing lenses are inserted in the optical path to minimize link optical losses which are, so, close to -4 dB.

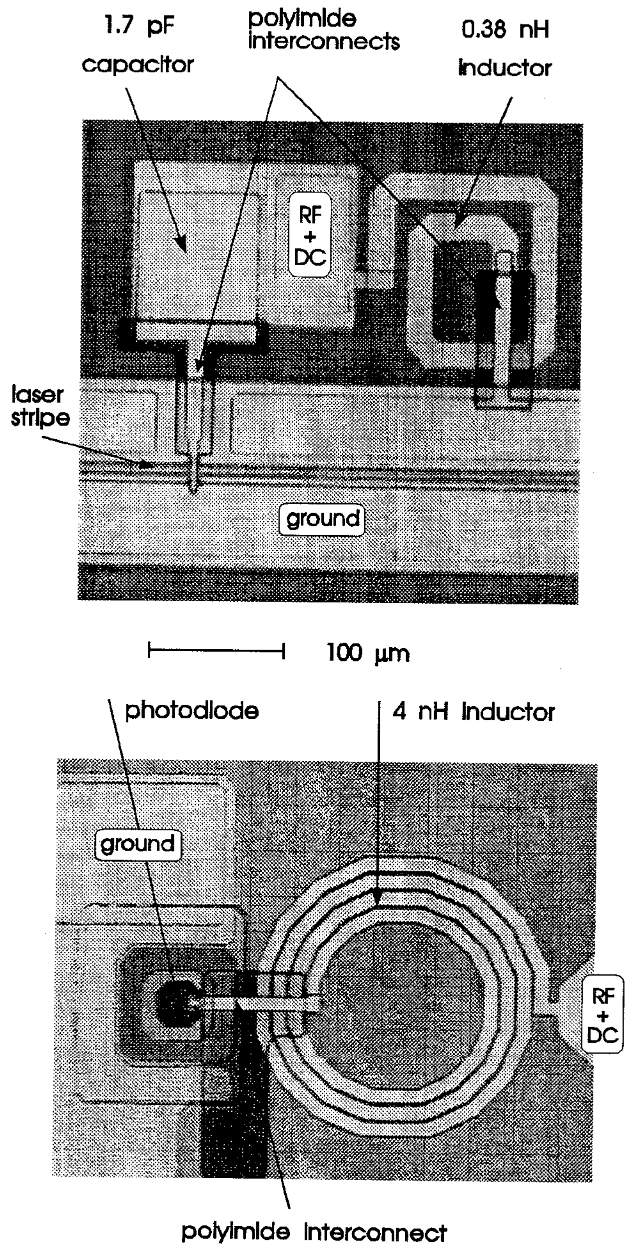

***Fig.2:* Integrated emitter (above) and receiver (below)**

The measurement set-up is composed of a Wiltron

6659B sweeper and a 562 scalar network analyser. the characterization of the link has been carried out in three successive steps. First, both emitter and receiver are unmatched (discrete devices); the link response is used for comparison with the next measurements. Second, only a matched emitter is used. A maximum of -17.5 dB in the transmission is obtained at 5.6 GHz. Compared to the previous experiment which shows -21.7 dB at this frequency, an improvement of 4.2 dB is obtained by the matching of the laser diode, theoretical one was 3.5 dB at 6 GHz. Third, both emitter and receiver are matched. A maximum of -10.3 dB at 5.6 GHz is obtained showing an overall improvement of 11.4 dB compared to the unmatched link (Fig. 3). Photodiode matching brings then 7.2 dB improvement in the power transfer of the link at 5.6 GHz; theoretical one was 8.2 dB at 6 GHz. The -3 dB bandwidth of the link is close to 600 MHz. So, the insertion loss is close to -10 dB at 5.6 GHz including the -4 dB optical loss.

The main difficulty for this experiment is to obtain simultaneously the same resonance frequency for the two transceivers; the result of a discrepancy in their value is a change in the achievable power transfer improvement. Moreover some influence of the bonding can still be observed. In our case, this is specially the case for the receiver bonding because its inductance adds directly to the one of the matching inductor. Nevertheless, this additional inductance (in case, it can be evaluated before the conceiving step) can be taken into account in the model in order to be an integral part of the matching inductor.

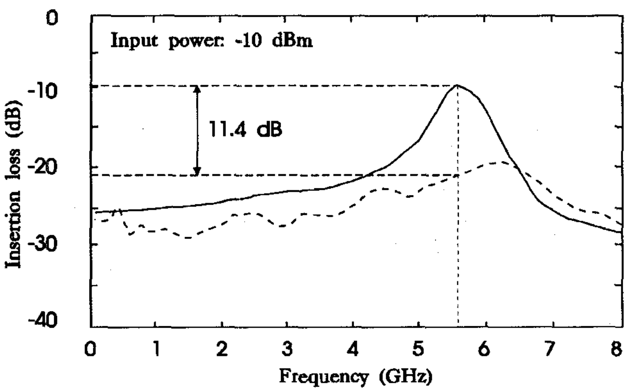

***Fig.3:* Insertion loss of matched (__) and unmatched (- -) links**

The compression point is reported on Fig.4 for the matched and unmatched links. It is close to -18 dBm for the unmatched link against -12 dBm for the matched one. By comparison between the different results that we have obtained, two remarks can be made; first, the matching of the receiver brings directly its improvement on the signal transmission (≈ 7 dB) to the value of the compression point. Second, it seems that the matching of the emitter does not affect the compression point value but only decreases the value of the corresponding input power from an amount which would correspond to the improvement in signal transmission (≈ 4 dB), but this assumption has not been clearly pointed out.

The 3rd order intercept point has been measured on the unmatched link close to -11 dBm. The noise level, measured in a 1 MHz bandwidth is close to - 78 dBm. The compression dynamic range and the spurious free one are then respectively close to 60 dB.MHz and 46 dB.MHz$^{2/3}$ (Fig.5). The same experiment has been made on the matched link.

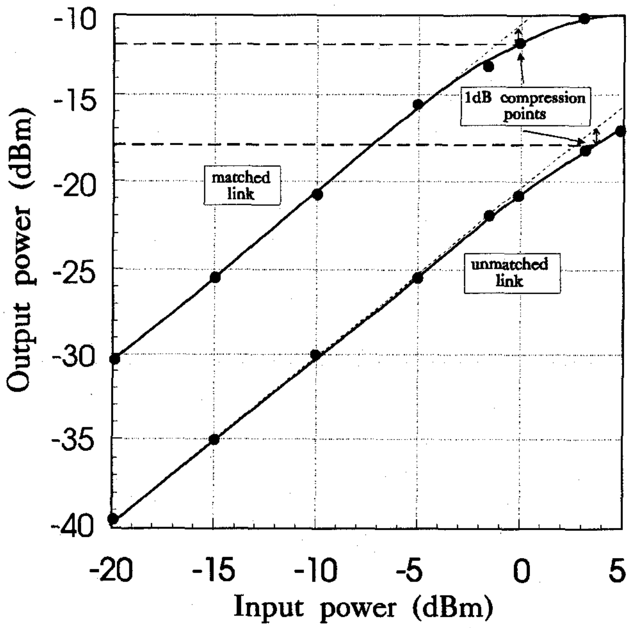

***Fig.4:* Compression point for the matched and unmatched links (I/Ith = 2.2; Frequency: 5.6 GHz)**

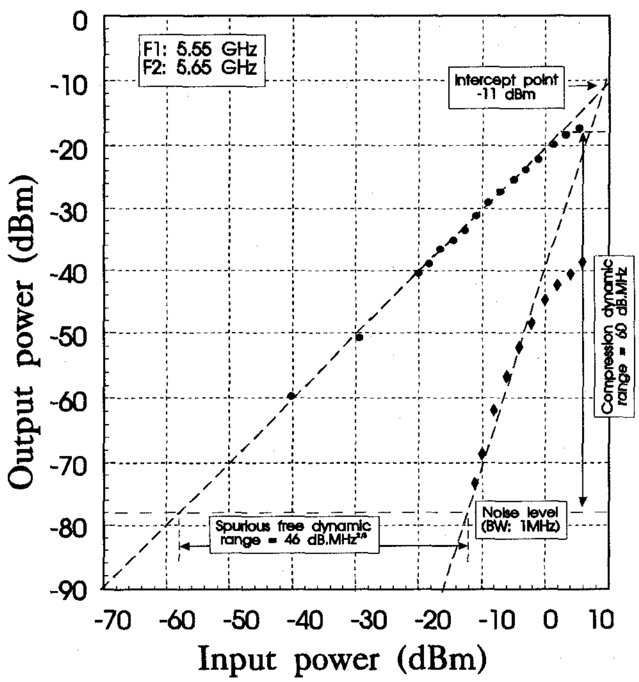

***Fig.5:* Dynamic ranges and intermodulation product for the unmatched link (I/Ith = 2.2).**

No major difference in the value of the compression and spurious free dynamic ranges has been noticed, since both signal and noise levels have shown a closely identical increase The 3rd order intercept point is then close to - 5dBm.

CONCLUSION

We have shown the first demonstration of the monolithic integration of optoelectronic devices with reactive impedance matching networks on semi-insulating InP substrate. The addition of these matching networks will theoretically improve the insertion loss of the link by 12 dB at 6 GHz.

The matching networks are constituted of MIM capacitors and spiral inductors and are made on the semi-insulating substrate. Although the technological process is more complicated, the intrinsic performances of the optoelectronic components (BRS laser and PIN photodiode) are closely the same that for discrete devices.

The characterization of the link has shown an improvement of 11.4 dB at 5.6 GHz in a -3 dB bandwidth of 600 MHz. This improvement is spread into 7.2 dB for the receiver matching and 4.2 dB for the emitter one. The -1dB compression point is -18 dBm and -12 dBm for, respectively, the unmatched and matched link. This would tend to show that receiver matching brings the same improvement on the insertion loss value than on the compression point one. The compression dynamic range of the link is close to 60 dB.MHz whether it is matched or not.

This experiment shows that monolithic integration can be an attractive solution for high frequency analog optical links The fabrication of such kind of microwave optoelectronic monolithic integrated circuits could be extend up to X-band or more, the limitation is then the intrinsic limitation of the optoelectronic components. It is yet necessary to define suitable packaging in order to observe the microwave and optical requirements.

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