Integrated Photonics for MWP

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Abstract: We address microwave signal generation utilizing the heterogeneous photonic integration platform, highlight the benefits of such approach and show preliminary results from a heterogeneously integrated photonic microwave signal generator. We address in detail narrow-linewidth tunable lasers as one of key components.

1. Motivation

Frequency agile microwave and millimeter wave microwave sources at frequencies from 1 to 300 GHz are necessary for a variety of military and commercial applications [1]. Generating, testing and measuring such signals is challenging. Conventionally signal generation at millimeter-wave frequencies is done by using frequency up-conversion. For higher frequencies electronic circuitry with many stages of frequency doubling is needed to achieve the desired frequency. The use of additional hardware that is bulky, fragile, expensive and difficult to operate, makes finding an alternative approach beneficial. Another difficulty is the distribution of such very-high frequency signals, as signals in electrical domain encounter high transmission losses in distribution lines, such as a coaxial cable.

Alternatively, signals may be generated optically. Photonic techniques for generating millimeter-wave frequencies provide some key advantages, one being broad tunability and another being ultra-low propagation loss in optical fiber for signal distribution. There are a number of techniques to generate continuous wave RF signals [2], but we will concentrate on using laser outputs that are combined and detected on a high-speed photodetector to generate a heterodyne beat tone at the frequency difference between the laser outputs. At least one of the lasers may be discretely or continuously tuned. The optically generated heterodyne beat tone can be swept over a very wide range of frequencies exceeding hundreds of gigahertz.

Photonic integration brings a promise of significant cost, power and space savings compared to bulk optics approaches. Silicon photonics offers many advantages for microwave photonics, such as large, low cost wafers, low cost processing in volume, better process control, and low optical loss, to name a few. One serious limitation of silicon photonics is the light generation, and we solve that using heterogeneous integration. Recent developments have shown that heterogeneous integration not only allows for a reduced cost due to economy of scale, but also allows for same or even better performing photonic devices than what has previously been demonstrated utilizing only III-V materials [3].

2. Microwave generator

A photonic microwave generator based on laser heterodyning, in its basic configuration, comprises of two lasers, at least one of which is tunable, a coupler that combines these two signals and a fast photodetector. One can increase performance and functionality by including booster semiconductor optical amplifiers (SOA) and high speed amplitude and phase modulators. We show a microscope image of an exemplary microwave generator in Figure 1.

For optimal performance one requires narrow-linewidth lasers as the width of RF signal generated by beating the two lasers will be equal to the cross-correlation of the two linewidths. The underlying waveguide platform should be low-loss. A booster SOA should have high-output saturation powers and the photodetector should be high-power and high-speed. The heterogeneous platform allows for independent optimization of all the components. The Si or Si3N4 waveguide platform provides low loss. Multiple thin-film epitaxial layers provide optimized gain, modulation and detection performance. The ability to individually change the widths of the Si waveguides and III-V mesa allows for gradual change of confinement factor.

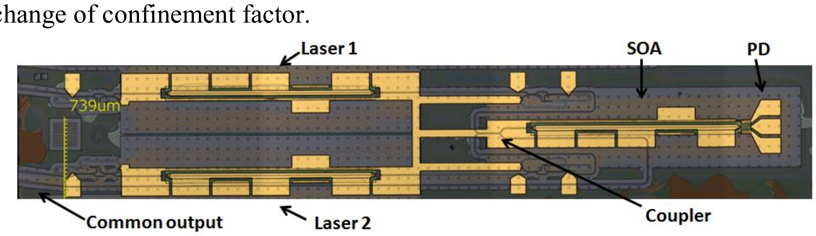

Fig. 1 Microscope image of the photonic microwave generator comprising of two tunable lasers, a coupler, booster semiconductor optical amplifier (SOA) and photodetector (PD). One arm of the 2x2 coupler goes to SOA and PD, other arm goes to the edge facet (common output).

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3. Narrow-linewidth laser design

The linewidth of semiconductor lasers is inherently broader than e.g. that of solid-state lasers. In a semiconductor laser there are two mechanisms broadening the linewidth: (1) the spontaneous emission which alters the phase and intensity of lasing field and (2) the linewidth enhancement factor α that characterizes the coupling between intensity and phase noise and is specific to semiconductor lasers due to carrier density fluctuations. The heterogeneous silicon photonics platform opens up a new possibility in improving the coherence by providing a mechanism to separate the photon resonator and highly-absorbing active medium [4]. The III-V active medium allows for efficient electrical pumping, while the low loss silicon waveguides allow for an increased total Q of the laser cavity. Lower losses reduce the number of excited carriers needed to reach threshold, which combined with the confinement factor optimization can reduce the spontaneous emission into the lasing mode. The transverse confinement is controlled by changing the widths of Si and III/V waveguides, and by changing the number of quantum wells in the active region. The longitudinal confinement is controlled by adjusting the length of passive section inside the cavity.

Passive microring-resonator-coupled semiconductor lasers were proposed in 2001. In such a structure, an active region in the conventional Fabry–Perot cavity is coupled with a passive ring resonator. This is different from conventional ring lasers, where the active traveling wave ring resonator replaces the standing wave Fabry–Perot cavity. The ring inside the cavity improves side mode suppression ratio, linewidth, and decreases the frequency chirp. The concept can be extended to two or more rings, significantly improving the single-mode tuning range by utilizing the Vernier effect [5]. Using rings inside the cavity benefits the linewidth in two ways: (1) increasing the photon lifetime due to effective cavity length enhancement, and (2) providing negative optical feedback by slight detuning from the ring (resonator) resonance. Both mechanisms cannot be maximized at the same time, but there is an optimal point where the combined influence is maximized [6].

4. Semiconductor optical amplifier

Tunable lasers benefit from the addition of an SOA, since it allows the laser bias condition to be optimized for emission wavelength and side mode suppression ratio independently from the output power. Another advantage of introducing SOAs for microwave generator is the control and boosting of optical power before the detector providing higher RF powers. A key benefit of heterogeneous silicon photonics for this application is the ability to control the confinement factor by changing the width of underling Si waveguide. With increase in confinement factor, the gain is increased, while with reduction, output saturation power is increased. The confinement factor also influences the spontaneous emission into the laser mode. As the confinement can gradually be controlled, a single optimal amplifier can be made. We have demonstrated unsaturated gains of 25.5 dB, input saturation power of 4.25 dBm, 65 nm of 3 dB bandwidth and 16 dBm of maximum output power [7].

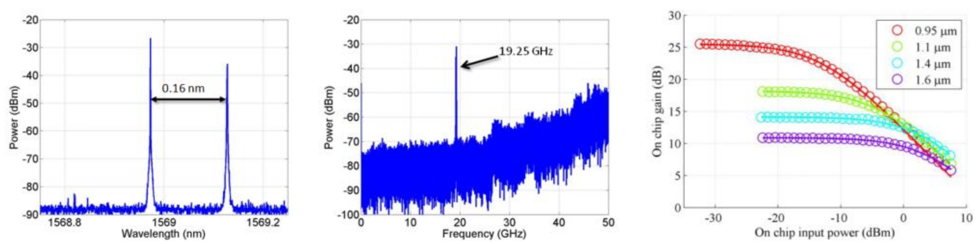

Fig. 2. (left) Optical spectra of two lasers comprising a photonic microwave generator (captured with high-resolution 20 MHz optical spectrum analyzer) (center) RF beat tone after high-speed detector (right) Gain versus input power measurements (circles) and fit (lines) for various Si waveguide widths directly influencing the confinement factor [7]

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4. References

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