Traveling-Wave Membrane Photomixers

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1. Motivation

Traveling-wave photomixers have superior performance compared to lumped area photomixers in the 1 to 3 THz frequency range. Their large active area and distributed gain mechanism ensure high thermal damage threshold and elimination of the competitive frequency roll-off. However, the losses experienced by the RF wave traveling along the coplanar strip waveguide (due to underlying semi-insulating GaAs substrate) were serious drawbacks. In this poster, we present device designs and an experimental setup that make possible the realization of photomixers on membranes which eliminate the losses.

The four topics we will address in detail are:
- Membrane device design, material design and processing
- Planar RF antenna design
- Broadband phase-matching of optic pump to traveling-wave gain region
- Optic and RF beam shaping

2. Traveling-wave photomixer

We have demonstrated that a traveling-wave photomixer design is capable of generating an order of magnitude more power than earlier small-area devices above 1 THz. This is because the RC-time constant associated with the interdigitated electrode structure is eliminated.

The traveling wave requires the two incident wavelength optical beams to be incident at a slight angle, such that the velocity of the optical interference fringes matches the group velocity of the generated RF wave along the waveguide surface (Appl. Phys. Lett. 74, 2672 (1999)).

The above diagram illustrates the first implementation of a traveling-wave photomixer. The photomixing occurs in the gap of a coplanar dipole. The RF radiation was launched using a broadband bowtie antenna.

The graph to the left shows the experimentally determined output RF power as a function of the angle between the pump beams as varied. Phase-matching occurs when the velocities of the two waves are matched and is well-described by the theoretical expression

\[ \frac{\Delta \phi}{\lambda} = \frac{2 \pi}{2 \pi} \]

where \( \Delta \phi \) is the phase difference and \( \lambda \) is the wavelength of the light.

3. RF losses and solution

Due to the thick underlying GaAs substrate, the RF losses along the coplanar strip are large and increase as the thickness increases. This loss is shown on the left.

The high frequency RF losses can be dramatically reduced by using a substrate that is thinned (see Fig. on the right). The poster will show the results of implementing membrane photomixer devices.

4. Membrane device design

Implementation of a membrane-supported traveling-wave photomixer requires several changes in design. Maximum absorption of the optical pump is achieved by using a thickness resonant with the wavelength and a DBR below the active region. Broadband RF emission can be achieved by placing a reflector behind the membrane and a properly designed antenna array. Both requirements are satisfied by the design shown on the right.

4.1 GaAs membrane

Process flow (left) and photograph of prototype device (below) with membrane below the GSP and center of bovine antenna.

4.2 RF design

In the RF design shown, below the distributed gain region is a coplanar waveguide and the planar antenna is implemented as slots. Since the incidence of light operated at the second resonance, the RF is absorbed by a CPW, we used two slots separated by the effective wavelength of the CPW. The design also includes a filter on the right to obtain an RF short while electrically isolating the center conductor from the surrounding ground plane. This permits DC biasing of the photomixing material.

4.3 Phase-matching

With the use of a matched grating pair, the lateral offset of two collinearly propagating optical rays can be adjusted to achieve phase-matching throughout a large frequency range. Misfitting of less than 1% are obtained for bandwidths in excess of 3 THz. No mechanical tuning is required of the optical components.

4.4 Optical and RF beam shaping

A four element (doublet and two cylindrical lenses) Fig. (a), are used to focus the cylindrical beam used to excite the photomixing media. Figure (b) shows the beam profile in the narrow direction, with the FWHP full width at half maximum.

4.5 Experimental setup

Figure (c) shows the lens assembly and mirror block. The device is held at the focal point of a periscope mirror by a metal bridge. The device has a focal length of 3 mm.

5. I-V Measurements

Figure on the right shows the first dark current measurement of membrane photomixers. The resistance turned out to be smaller for the membrane devices, by a factor of 5x after taking into account the difference in carrier lifetime of the photomixing material. Carrier excitation by alias light incident from the rear side may be the cause of the lower resistance.

5. Summary

- An novel design of a traveling-wave photomixer has been discussed
- RF antenna designs have been presented and analyzed which radiate broadband
- Implementation of optics and RF components have been shown that allow broadband operation
- First measurement results of membrane devices are discussed