Traveling-Wave Membrane Photomixers

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1. Motivation

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

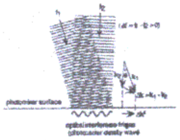
The four topics we will address in detail are:

- 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 design above 1.5 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 fringe matches the group velocity of the generated RF wave along the photomixer surface (*Appl. Phys. Lett.* **74**, 2872 (1999)).



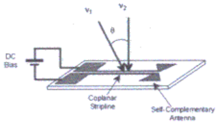
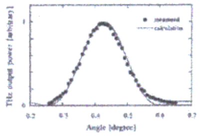


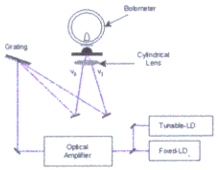
Illustration of the first implementation of a traveling-wave photomixer. The photomixing takes place in the gap of a coplanar stripline. The RF radiation was launched using a broadband bowtie antenna.



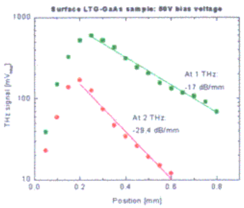
The Graph to the left shows the experimentally determined emitted RF power as the angle between the pump lasers is varied. Phase-matching occurs when the velocities are matched and is well-described by the theoretical expression:

$$\text{Phase Match} \propto \frac{\sin^2\left(\dfrac{\Delta k^1 L}{2}\right)}{\left(\dfrac{\Delta k^1 L}{2}\right)^2} \qquad L\text{: Length of gain region}$$

The angle must be carefully controlled to obtain optimal phase-matching. In the experimental setup we first assured perfect mode-matching of the pump lasers by seeding a single optical amplifier with two laser diodes. The wavelengths are then split using a grating and separate mirrors control the final incident angles. This arrangement works but is a bit cumbersome since the angle is optimal for only a single output frequency.

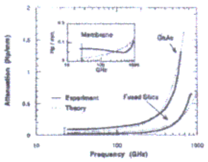


3. RF losses and solution



Due to the thick underlying GaAs substrate, the RF losses along the coplanar striplines are large and increase as $\propto f^3$. Illustration on the left shows this loss for our geometry.

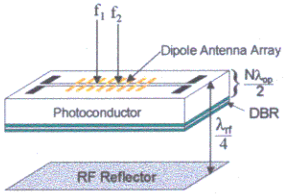
The high frequency loss can be dramatically reduced when the underlying substrate is thinned (see Fig. on the right). This poster will show how we implemented membrane photomixer devices.



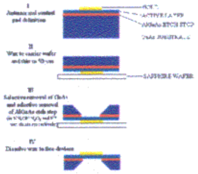
H.-J.Cheng, *et al.*, IEEE Trans. MTT-42, 2399 (1994).

4. Membrane device design

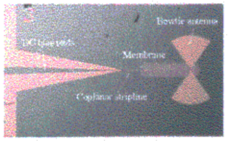
Implementation of a membrane supported traveling-wave photomixer requires several changes in design. Maximum absorption of the optical pump is achieved by using a thickness resonant with the wavelength and a DBR below the active region. Broadside RF emission can be achieved by placing a reflector behind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



4.1 GaAs membrane

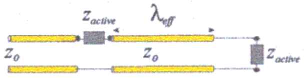


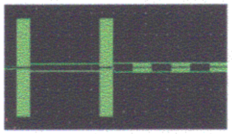
Process flow (left) and photograph of prototype device (below) with membrane below the CPS and center of bowtie antenna.

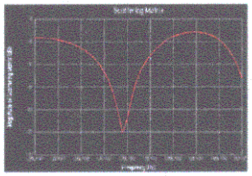


4.2 RF design

In the RF design shown below the distributed gain region is a coplanar waveguide and the planar antenna is implemented as slots. Since the impedance of slot, operated at the second resonance, is smaller than achievable with a CPW, we used two slots seperated 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 grounf plane. This permits DC biasing of the photomixer material.

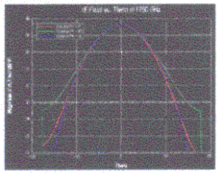






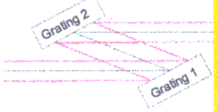
Left: S11 of left input port

Right: Far-field antenna radiation pattern on resonance.



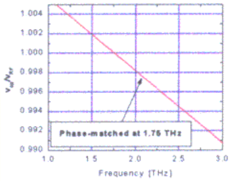
4.3 Phase-matching

With the use of a matched grating pair, the lateral offset of two colinearly propagating optical rays can be adjusted to achieve phase-matching throughout a large frequency range. Mismatched of less than 1% are obtained for bandwidths in excess of 2 THz. No mechanical tuning is required of the optical components.



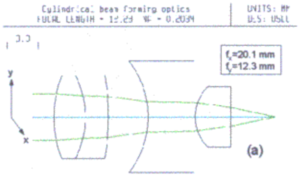
Grating Equation:

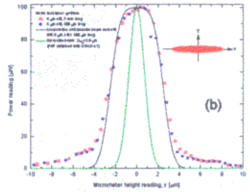
$G\lambda = \sin(\alpha_L + \Delta\alpha_i) + \sin(\alpha_L - \Delta\alpha_r)$
G : Grating period (lp/m)
α_L : Littrow angle
$\Delta\alpha_i, \Delta\alpha_r$: Angle offsets

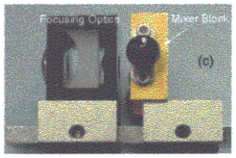


4.4 Optical and RF beam shaping

A four element (doublet and two cylindrical lenses), Fig. (a), are used to form the cylindrical beam used to excite the photomixing media. Figure (b) shows the beam profile in the narrow direction, the FWHM along the wide dimension is approximately 300 µm.

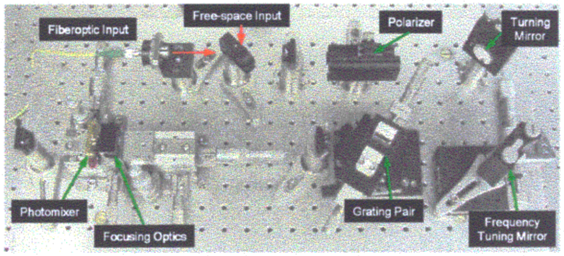






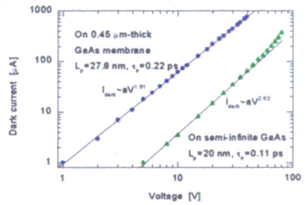
Photographs (c) and (d) show the lens assembly and mixer block. The device is held at the focal point of a parabolic mirror by a metal bridge. The parabola has a focal length of 3 mm.

4.5 Experimental setup



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 5× after taking into account the difference in carrier lifetime of the photomixing material. Carrier excitation by stray light incident from the rear side may be the cause of the lower resistance.



5. Summary

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

R. A. Wyss, *et al.*, 12th Int. Symp. of Space THz Technology, San Diego, CA, February 14-16, 2001.