A BROAD BAND GaAs MICROSTRIP MODULATOR AT 16 GHz FOR CO_2 LASER RADIATION *

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Abstract

A 16 GHz microstrip modulator, fabricated on a thin slab of GaAs 25 microns thick, has been developed for CO_2 laser radiation. An instantaneous bandwidth of 1 GHz and a single optical sideband conversion efficiency of 0.7 percent has been obtained with 20 watts of microwave driving power.

Introduction

Wide band modulation of CO_2 laser beams (infrared radiation) is required for high data rate communications and high resolution imaging radar. This can be accomplished in a modulator using a microwave subcarrier and GaAs as the nonlinear medium. Efficient power conversion to an optical sideband that becomes the new carrier is also a requirement. A solution for these problems, presented here, uses Integrated Optics techniques to realize a waveguiding structure which is common to both the ir and the microwaves and in which both electromagnetic radiations are confined to the smallest practical common cross section.

The modulation of the ir beam is produced by a non-linear electro-optic effect in single crystal GaAs that results in a phase shift.[1] In the common waveguide the electric fields for the microwaves and ir beam are orthogonal. Since the degree of phase modulation is proportional to the microwave electric field strength, for a given power level the most efficient modulation is obtained when the interaction cross section is made as small as possible and within this region both the optical and the microwave energy are perfectly overlapped. In this work the thickness of the GaAs slab is only 25 μm (10^{-3} inches) and the width of the guided ir beam is 1 mm. From the microwave aspect of the problem it is desirable to produce modulation bandwidths exceeding 1 GHz at 16 GHz center frequency and to feed microwave power levels up to 100 watts into the thin GaAs slab. The optical aspects require good beam quality and efficient transmission of the ir laser beams corresponding to 50% transmission for input power levels up to about 15 watts.

The microwave frequency modulation introduces another restriction because a substantial interaction length is required to produce the desired level of phase modulation[2]. At 16 GHz as many as 12 wavelengths are needed; this requires a traveling wave type of interaction. For efficient traveling wave interaction, the phase velocity must be close to that of the guided ir beam.[1]

Description of the Modulator

Two structures were considered for the modulator, a mini-gap ridge waveguide[3] and a microstrip transmission line. In both cases the electrode configuration confines the microwaves to the desired small cross sectional area. However, the microstrip configuration has proved to be the best choice in terms of reproducibility and reliability, but requires more sophisticated fabrication techniques. The microwave losses dictated that metallic electrodes must be used rather than heavily doped GaAs substrates. Such substrates with epitaxially grown, thin, active layers have commonly been used as excellent optical waveguides.

Efficient optical coupling techniques using grating and prisms were considered and explored in great detail for infrared radiation.[4] Both techniques have in common a coupling mechanism for launching the guided ir wave that is similar to directional coupling over extended regions in microwave waveguides. The most efficient optical coupling was realized with prisms because an optimum interaction length with gratings would have required a beam diameter too large to be useful for efficient microwave modulation. For a given grating the larger the beam diameter, the longer is the coupling region.[4]

The essential details of the modulator configuration are sketched in Figure 1. The couplers are selected so that the ir laser beam excites preferably a TE_0 or TE_1 mode in the GaAs optical waveguide. The particular mode being selected depends on the angle of incidence.[5] The GaAs slab is bonded to the metal base which also serves as a water cooled heat sink. Microwaves are excited in the microstrip transmission line; however, only the synchronous wave modulates the ir beam.

The microwave microstrip circuit is shown in more detail in Figure 2. The electrode is center-fed through a microstrip impedance transformer from a microstrip launcher. The launcher, a standard design, was modified to have a longer finger (center conductor) and shield. This allowed the pressure from the finger to be distributed over a wider area

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on the GaAs so as to prevent damage to the thin GaAs crystal slab. The wider contact area for the microwaves also provided some tuning capability. At the operating frequency the electrical distances were integral numbers of half wavelengths from the feedpoint to the open circuited ends. Although this configuration may seem narrow band, this is not necessarily the case. For example, if the feed line from a matched generator is also well matched to the net characteristic impedance of the two lines in parallel, then the amplitudes of the synchronous components of the standing wave are independent of frequency. Because broad band microwave TWT amplifiers at cw power levels ranging from 20 to 100 watts require circulators for protection, the resultant reflected power is conveniently absorbed. Under these conditions, the operation is almost equivalent to that of a two port modulator with both input and output ports matched. The most efficient modulation condition, of course, occurs when the net input resistance is transformed so that an impedance match exists at the input port of the modulator. Under these matched conditions the power in the sidebands is derived to be:[4]

$$P_{SB} = \left(\frac{\Delta\phi}{2}\right)^2 P_0 \tag{1}$$

in which the phase shift $\Delta\phi$ is

$$\Delta\phi = \frac{k}{4} r_{41} n^3 \left(\frac{2P\ \eta L}{tw\alpha}\right)^{\frac{1}{2}} \tag{2}$$

where $r_{41} = 1.2 \times 10^{-10}$ cm/volt, n is the index of refraction, $k = 2\pi/\lambda$, P is the microwave power, α is the microwave attenuation coefficient in Nepers, η is the free space characteristic impedance, t is the slab thickness and W is the width of the microstrip line, and L is the length.

Experimental Results

The electrical parameters of the microstrip line were verified experimentally from measurements on long straight sections. The resonant frequencies, the input impedances at resonance, and calculated values of z_o were used to establish the following values for a modulator line 25 microns thick and 1 mm wide: $z_o = 2.7$ ohms, attenuation = 0.75 dB/cm and ineffective index of refraction = 3.5. These values were used for broad band design purposes and computer modeling.

In our present modulation experiments the laser carrier power output from the modulator is about 4 watts and the applied microwave power is 20 watts. However, the structure has been operated with up to 80 watts of microwave power. The side band signals are displayed by using an electronically scanning Fabry-Perot filter. A typical signal from the scanning filter is shown in Figure 3 together with the scanning voltage which is approximately proportional to frequency. The spacing between the two peaks corresponds to 32 GHz and the full scan is 50 GHz. A set of data for different frequencies was used to determine the optical signal frequency response that is shown in Figure 4. The 3 dB bandwidth is 700 MHz; however, more than 1000 MHz has been obtained with another similar structure. Some bandwidth was sacrificed since the device was adjusted to give maximum conversion efficiency. These results correspond to 0.7% conversion efficiency from optical carrier power to side band power and represent good agreement with theoretical predictions.

Conclusions

This work shows that the generation of substantial levels of optical side band power from an ir laser is now possible with frequencies programmable over a range of 1 GHz on a 16 GHz subcarrier. The integrated optics, common ir/microwave waveguiding approach is seen to provide an efficient use of microwave power. Our goal of reaching several hundred milliwatts sideband power with a bandwidth of 1 GHz is within reach with practical increases of microwave and optical power levels and some circuit improvement.

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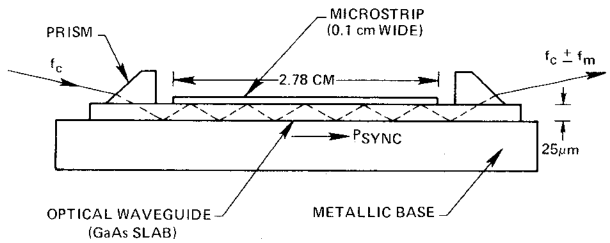

Figure 1. Infrared Microwave Modulator

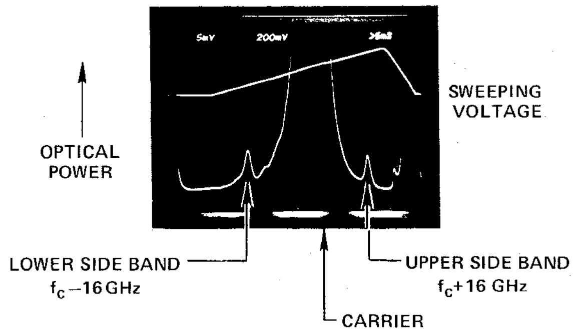

Figure 3. Optical Signal From Swept Fabry-Perot Filter

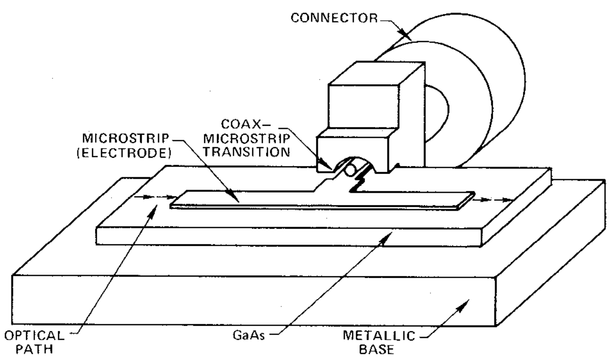

Figure 2. IR Modulator - Microstrip Microwave Section

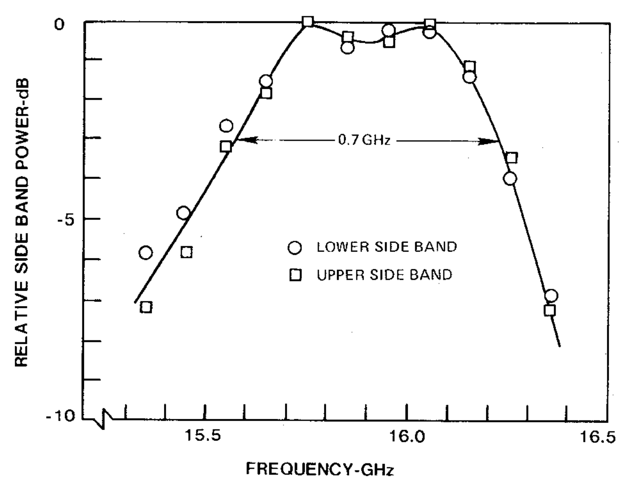

Figure 4. Modulator Frequency Response