# INFRARED PARAMETRIC AMPLIFICATION USING A QUASI-MICROWAVE APPROACH TO PHASE-MATCHING*

by

D. B. Anderson and J. D. McMullen

Autonetics
A Division of North American Rockwell Corporation, Anaheim, California

Current nonlinear optical experiments employ birefringence to compensate for the refractive index dispersion to increase the constructive interaction length. Most of the semiconductors have large nonlinear susceptibility coefficients; however, lack the necessary birefringence. Their use has been inhibited by the lack of means to satisfy the phase-match condition for efficient nonlinear interactions. A quasi-microwave[1] approach for the optical region is reported as a means to fulfill the phase-match condition. This approach employs a nonlinear dielectric transmission line with dimensions comparable to the wavelength wherein control of the polarization, kind and order of mode is exercised.

The experimental demonstration of infrared parametric amplification using GaAs as a nonlinear medium and a quasi-microwave approach to phase-matching is reported. Infrared lower sideband parametric upconversion from 3.50 to 1.64μ has been realized using a He/Ne gas laser pump at 1.117μ. The pump power incident on the GaAs waveguide from a Cassegrainian reflective objective input coupling was 240 mw. The pump power density incident on the waveguide is in the region of $10^6$ watts/$cm^2$. The experiment utilized a Xe gas laser as the signal at 3.5μ with a power of 150 microwatts incident on the GaAs waveguide. A 2% conversion efficiency was observed which exceeds the results obtained using birefringent crystals.[2-5]

NOTES

From the computations of the dispersion of dielectric waveguide,[6] phase-matching of pump, signal, and idler fields was achieved by selecting the mode kind, order, and orientation to fulfill the conservation of momentum condition. A representative, small section of the Brillouin diagram for the first nine mode orders used to solve the phase-matching condition is shown in Figure 1 for the pump refractive index of 3.45. The coordinates are given in terms of waveguide thickness normalized to the free space and guide wavelengths. The constraints upon and method of fulfilling the phase-match condition will be described.

The GaAs dielectric waveguide has a cross section of 4 x 10μ with a length of 500μ formed from an ultra-thin slab in the (001) plane to maximize the interaction. The signal (3.5μ) was excited as a $TE_0$ mode oriented in the $\langle\bar{1}10\rangle$ direction and propagating in the $\langle 110\rangle$ direction. The pump electric field was oriented in the $\langle 001\rangle$ direction as a high order TM mode. This configuration of field orientations in the GaAs crystal eliminates pump depletion due to second harmonic generation.[7] The resulting upconverted signal appears as a high order TE mode. The pump power distribution emerging from the parametric interaction region is shown in Figure 2. Unfortunately, the high order spatial mode cannot be resolved by the closed circuit television system used to obtain Figure 2.

The input/output coupling to the GaAs waveguide interaction region mounted in the infrared microscope is shown in Figure 3. Polarization, spectral, and spatial filtering was used to extract the lower sideband upconverted output (1.64μ). The spatial filter, a refractive objective, was responsive only to the bound waveguide modes.

*This work has been supported in part by the Night Vision Laboratory, Ft. Belvoir, Virginia.

1. D. B. Anderson, R. R. August, and W. A. McDowell, "Enhancement of Optical Nonlinear Interactions by a Quasi-Microwave Technique," Fourth International Quantum Electronics Conference, April, 1966.

2. J. E. Midwinter and J. Warner, "Up-Conversion of Near Infrared to Visible Radiation in Lithium-meta-Niobate," J. Appl. Phys., 38, 2, p. 519 (February 1967).

3. J. Warner, "Photomultiplier Detection of 10.6μ Radiation Using Optical Up-Conversion in Proustite," Appl. Phys. Letters, 12, 6, p. 222 (15 March 1968).

4. L. Gampel and F. M. Johnson, "IR Image Detection by CW Parametric Up-Conversion to the Visible," 1968 International Quantum Electronics Conference, May 14-17.

5. G. D. Boyd, T. J. Bridges, and E. G. Burkhardt, "Up-Conversion of 10.6μ Radiation to the Visible and Second Harmonic Generation in HgS," IEEE J. Quantum Electronics, Vol. QE-4, No. 9, p. 515 (September 1968).

6. D. B. Anderson and C. B. Shaw, Jr., "Dielectric Waveguide for Infrared Wavelengths," 1968 IEEE GMTT International Microwave Symposium, May 20-22.

7. J. Ducuing and N. Bloembergen, "Observation of Reflected Light Harmonics at the Boundary of Piezoelectric Crystals," Phys. Rev. Letters, 10, 11, p. 474 (June 1, 1963).

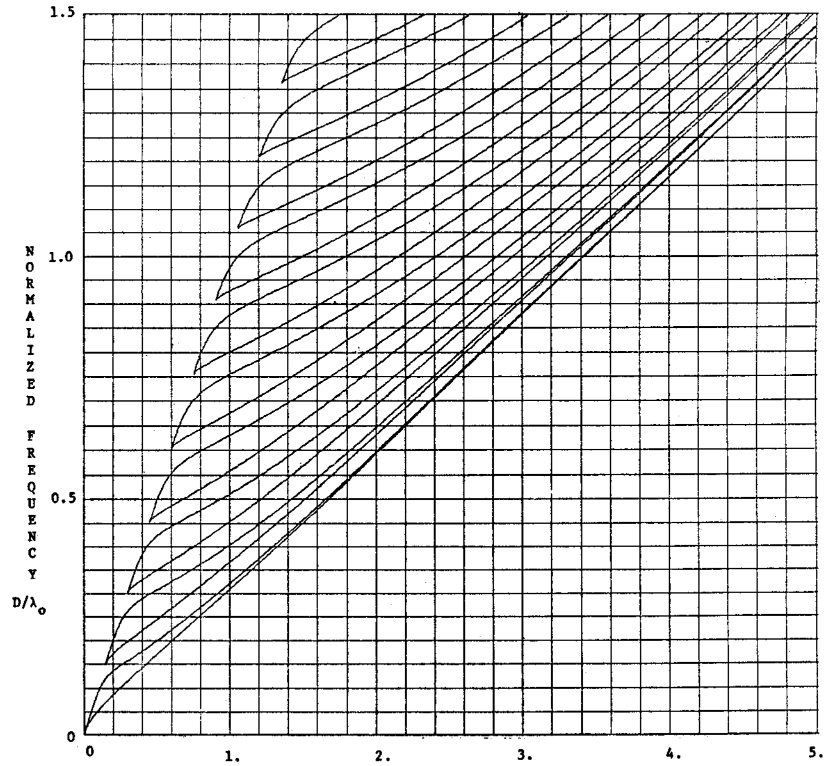


**Figure 1. Brillouin Diagram of Dielectric Waveguide Dispersion; Refractive Index, 3.45**

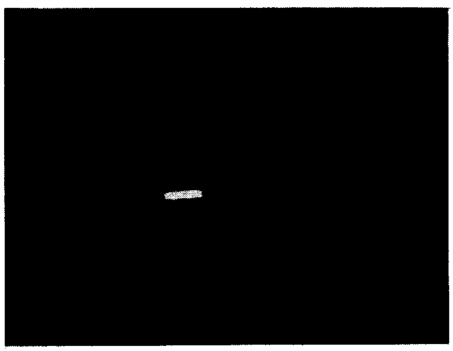

**Figure 2. Pump Power Distribution in GaAs Waveguide**

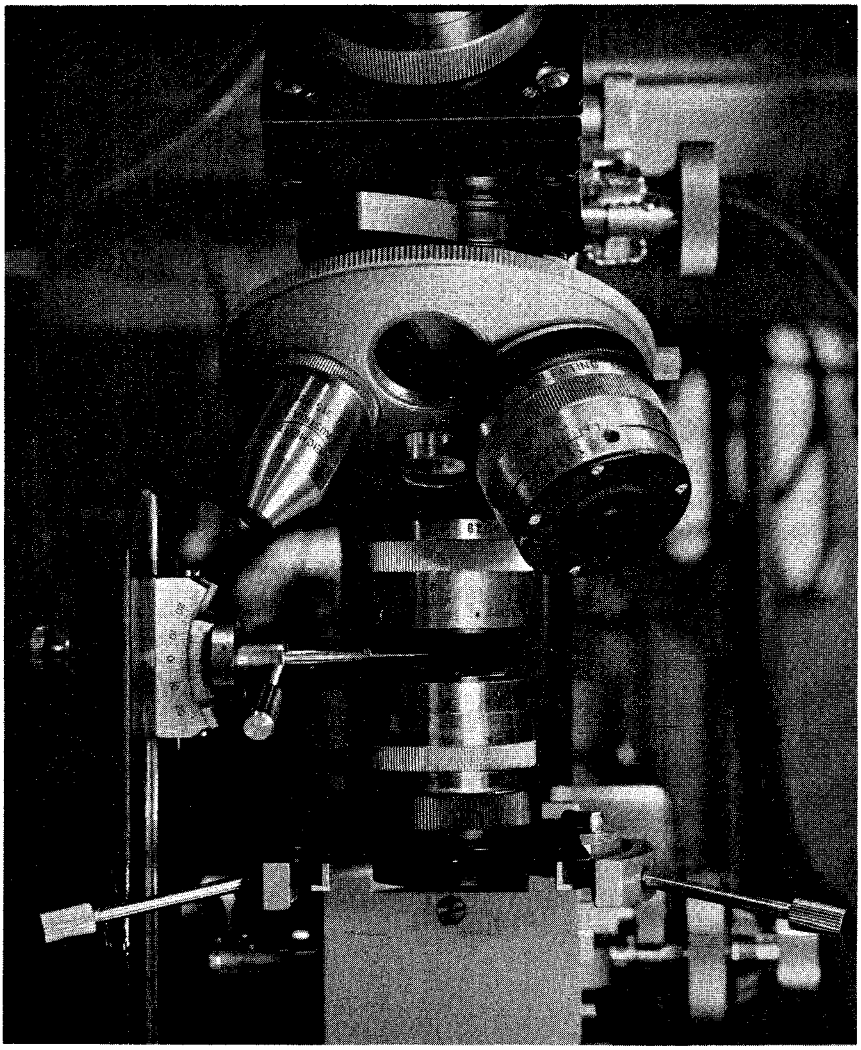

Figure 3. Input-Output Coupling to Parametric Interaction Region in Focal Plane of Microscope