in the scattered signal intensity when the idler frequency approaches the lattice absorption bands in these materials. Two explanations for this effect have been proposed.[1,2,3] They have been interpreted as contradictory,[2,3,5] and this has led to some controversy and confusion in the published literature.

In the first interpretation[1] the decrease in signal intensity has been attributed to (2 phonon) lattice absorption at the idler frequency, which limits the effective interaction length in the crystal. Over the frequency ranges studied, this interpretation was in excellent agreement with the experimental results.

Subsequent measurements by Klyshko *et al.*[2] showed that the signal intensity again increases as the idler frequency is tuned farther into the absorption region. These authors pointed out that idler absorption alone cannot explain this increase. In order to explain their observations, they assumed that idler absorption is completely negligible and have attempted to describe the observed dip and subsequent increase in signal intensity solely in terms of dispersion in the nonlinear susceptibility which arises from resonant contributions from the lattice in the absorbing region. We feel that a proper description of the parametric scattering should include the effects of both idler absorption and dispersion in the nonlinear susceptibility.

Our experiments enable us to determine quantitatively the role of each of these phenomena in the parametric scattering process. Using an argon ion laser operating at 4880 Å, a tandem double monochromator, and synchronous photoelectric detection, and using angular frequency tuning to achieve phase matching, we measure the frequency dependence of the spontaneous scattering intensity at a fixed temperature. A complete set of such measurements in both the absorbing and nonabsorbing regions is made at several temperatures between 25 and 250°C. From these measurements, the known lattice absorption spectrum,[6] and the known temperature dependence of this absorption,[1] we quantitatively determine the effect of idler absorption on the scattered signal intensity. Having thus included the effects of absorption, we can determine the dispersion in the nonlinear susceptibility due to lattice contributions.

Our measurement techniques compensate for any small effect of temperature on the electronic contribution to the susceptibility. Any temperature dependence of the lattice contribution is included in our analysis by using the measured temperature dependence of the LO and TO phonon Raman scattering.

Our results show that a consistent description of the experimental data is possible when both idler absorption and dispersion in the nonlinear susceptibility are included. This work should resolve the controversy now present in the literature.

[6] A. S. Barker and R. Loudon, *Phys. Rev.*, vol. 158, p. 433, 1967.

L.9 CdSe Infrared Parametric Oscillator, R. L. Herbst and R. L. Byer, *Microwave Laboratory, Stanford University, Stanford, Calif.*

We have obtained single resonant parametric oscillation in the infrared at 2.2 μ and 9.6 μ using CdSe as the nonlinear crystal. A *Q*-switched Nd:YAG laser operating at 1.833-μ pumps the oscillator which has a threshold of 660 W.

Phase matching for positive birefringent CdSe is Type II with the pump and idler an ordinary wave and the 2.2-μ signal an extraordinary wave. The oscillator may be angle tuned over the 2–2.2-μ and 9.6–14-μ region.[1] The present oscillator operates at the 90°-phase-matched orientation. To prevent feedback at the idler and also provide output coupling at 9.6 μ, a fused silica Brewster angle plate is inserted in the oscillator cavity. With a pump power of 2.4 kW in the crystal, 40 percent pump depletion was seen. Using the Manley–Rowe relations, the available power at the 9.6-μ nonresonant idler is 180 W.

Experiments are in progress and results for tuning, bandwidth, and crystal quality will be discussed. Surface damage is a problem in some crystals, and work is continuing toward an understanding of the damage problem.

The simplicity of construction together with room temperature operation and the availability of high quality CdSe crystals make this oscillator an attractive tunable source in the middle infrared.

[1] R. L. Herbst and R. L. Byer, "Efficient parametric mixing in CdSe," *Appl. Phys. Lett.*, vol. 19, p. 527, 1971.

L.10 Coherence and Efficiency in Nonlinear Optical Processes, B. Crosignani, P. DiPorto,[1] U. Ganiel,[2] S. Solimeno[3] and A. Yariv.[4]

A remarkable difference between linear and nonlinear processes lies in the fact that the efficiency of the latter depends on the coherence properties of the electromagnetic field (pump) from which the process is driven. In this frame, the trend toward a decrease in the energy exchange rate with increasing of pump incoherence has been suggested.[5] A fairly complete detailed analysis is presented here for the specific case of optical parametric amplification (PA) and frequency conversion (FC). The dynamic models have the formal features which are common to a large class of problems. Their analytic behavior cannot, in general, be deduced by extrapolation of the existing theory for ideally coherent pump, but has to be investigated resorting to more sophisticated methods of statistical physics.

We consider some of the effects of this limited coherence on the efficiency and the statistical properties of both the parametric amplification and frequency conversion processes. We assume the interaction process to be driven by an external, stochastic, centered field of constant amplitude, as the one associated with a real laser operating well above threshold. The two limiting situations are treated in which the coherence time of the pump is large or small compared with the characteristic time of the PA and FC processes, when driven by a perfectly coherent field.

The lack of coherence of the pump in parametric amplification is shown to induce significant changes with respect to the ideal situation. Specifically, the growth rate of the processes is always reduced, the degradation becoming extreme in the case of strongly incoherent pump.

In the case of the frequency converter, even the qualitative nature of the interaction is changed from that of the ideal case. The most striking departure concerns the gradual deterioration and eventual disappearance of the periodic energy exchange between the low and high frequency fields in the frequency converter. This is shown qualitatively. In the fast-fluctuating pump case (dashed line), the periodic nature of the exchange process is completely damped out: In the other case (dotted-dashed line), the modification depends on the detailed nature of the correlation function of the frequency fluctuations, and it is less relevant. The continuous line represents the ideal coherent pump case. The lack of coherence leads to an eventual (average) equal number of photons in the signal and idler channels.

[1] B. Crosignani and P. DiPorto are with Fondazione Ugo Bordoni, Istituto Superiore P.T., Rome, Italy.
[2] U. Ganiel is with the Weizmann Institute of Science, Rehovot, Israel.
[3] S. Solimeno is with the Istituto Electtrotecnico, Universita di Napoli, Naples, Italy.
[4] A. Yariv is with the California Institute of Technology, Pasadena, Calif. 91109.
[5] B. Crosignani, U. Ganiel, S. Solimeno, and A. Yariv, *Phys. Rev. Lett.*, vol. 27, p. 237, 1971.

SESSION M

Wednesday, May 10, 1972

8:30 A.M.–12:00

Spectroscopy II

M.1 High-Resolution Infrared Spectroscopy of Gases,[1] V. J. Corcoran, J. M. Martin, and W. T. Smith, *Martin-Marietta Corporation, Orlando, Fla. 32805.*

The spectrometer has been developed which uses the signal generated by mixing a CO_2 laser and a millimeter wave klystron in a gallium arsenide loaded waveguide as a source.[2] This spectrometer has the tuning range of the klystron and the resolution of the CO_2 laser. Since the frequencies of the CO_2 laser and the klystron can be measured, the tunable

[1] This work was supported by the Air Force Office of Scientific Research, under Contract No. F44620-70-C-0101.
[2] V. J. Cocoran and W. T. Smith, "Laser-millimeter wave techniques," presented at the 1971 IEEE/OSA Conf. Laser Engineering and Applications, Paper 6.7, June 1971.