The diode-pumped continuous-wave Raman laser : classical, Quantum, and thermo-optic fundamentals
by Peter Aaron Roos

A thesis submitted in partial fulfillment of the requirements of the degree Masters of Science
Montana State University

Abstract:
This thesis describes the creation and development of far-off-resonance diode-pumped cw Raman lasers using high-finesse cavity enhancement from both theoretical and experimental standpoints. Comprehensive theoretical models are developed for the cw Raman system in the classical and quantum mechanical domains. The classical treatments include two separate derivations of the time-dependent cw Raman equations (one as an appendix), derivations of the analytical steady-state threshold power, impedance-matching power, all emitted powers, and conversion efficiency, as well as the system optimization with respect to every parameter available, and a useful frequency tuning picture (as an appendix). An entire chapter is devoted to the classical treatment of thermo-optic effects in this laser system including mode pulling and thermal lensing.

The quantum mechanical treatment uses the Heisenberg/Langevin approach to derive the Stokes output noise spectra analytically for this system. Subsequent analysis reveals the possibility of approaching perfect photon statistics transfer from the pump to the Stokes and generating nonclassical photon number statistics. An interesting and useful connection to the nondegenerate optical parametric oscillator is uncovered. The quantum mechanical approach is also used to show that a similar system can generate efficient cw anti-Stokes emission.

The process of constructing these laser systems and the subsequent measured behavior comprise the experimental component of this thesis. Diode laser frequency locking for this system is treated thoroughly as an exercise in precision frequency stabilization and control theory. The optimal designs of the diode laser pump source, the high-finesse Raman laser cavity, and the electronic servo are discussed. The use of injection locking and passive optical frequency stabilization are also addressed.

Using these construction and locking techniques, the results from diode-pumped cw Raman laser experiments in diatomic hydrogen gas are provided and are shown to compare favorably with the theoretical predictions. The results include steady-state data obtained from the first diode-pumped cw Raman laser, the first high efficiency cw Raman laser, a cw Raman laser pumped by an injection-locked diode laser, and the first cw Raman ring laser. Data confirming the effects of thermal mode pulling and lensing are also provided.

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APPROVAL

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Peter Aaron Roos

This dissertation has been read by each member of the dissertation committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies

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CHAPTER 1

INTRODUCTION

Stimulated Raman Scattering: A Brief Review

The stimulated Raman effect was discovered in 1962 [1], shortly after the advent of the laser. One can view this two-photon process most simply as an exchange of "pump" photons for lower energy "Stokes" photons through a stimulated interaction with a Raman-active medium as illustrated in Fig. 1. The energy difference between the incident pump and stimulated Stokes photons resides within the Raman medium after the interaction, often in the form of a molecular vibration.

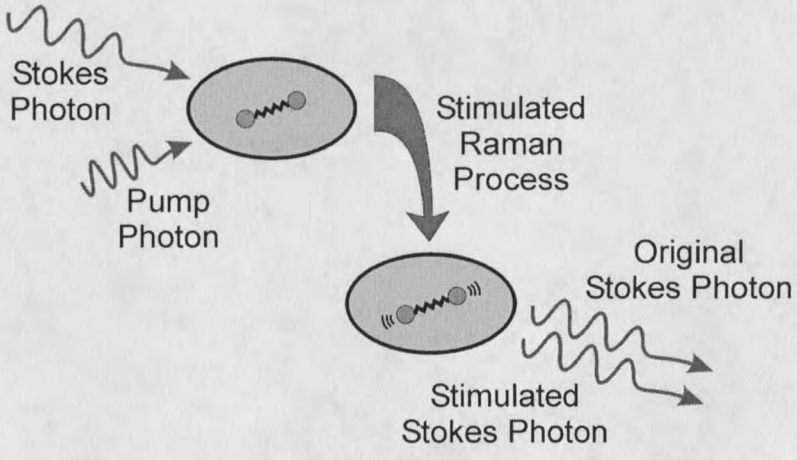

Figure 1. Simple picture of the stimulated Raman process. An incident pump photon is converted to a lower energy (longer wavelength) stimulated Stokes photon and the leftover energy remains in the Raman medium.

This process can result in exponential growth (amplification) of input Stokes light at the expense of the input pump light. But even when there is no input Stokes, the process can be initiated by spontaneous emission alone. In other words, by simply directing an intense pump laser through a Raman medium, some of the pump light will be converted to the Stokes frequency, as shown in Fig. 2. Stimulated Raman scattering (SRS) therefore provides, among other things, a valuable method of down-shifting the frequency of laser light. However, this stimulated process differs from parametric conversion processes in that the phase of the generated Stokes light doesn't directly depend on that of the pump. Due to this phase-insensitive amplification, the system shown in Fig. 2 is often considered to be an optically-pumped laser; more specifically, a Raman laser.

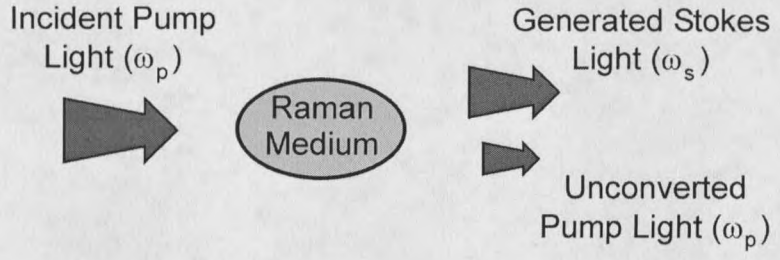

Figure 2. Frequency downconversion using the stimulated Raman process. Because this involves phase insensitive amplification of the Stokes light, the system shown is often called a Raman laser. The laser action is initiated by spontaneously emitted Stokes photons.