A Frequency-Stabilised Diode Laser and its Application to Atomic Spectroscopy of Caesium

A thesis presented in partial fulfilment
of the requirements for the degree of

PhD in Physics

at

Massey University

Peter Saunders

1993

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Abstract

This thesis examines the hypothesis that a commercially available single-chip AlGaAs diode laser can be rendered suitable for atomic physics research through the addition of external circuitry alone. This circuitry is discussed and the frequency-stabilised laser is applied to some interferometric and spectroscopic studies. These studies also include the development of theoretical models.

The design and construction of an ultra-stable constant current source is discussed, along with an evaluation of its effectiveness. The current source is capable of supplying up to 100-mA dc with the addition of a ramp current of up to 20 mA to allow frequency scanning of the laser, and exhibits short-term fluctuations of ±8 μA with a drift of less than 2 μA in ten hours. A temperature controller, capable of both heating and cooling the laser, is described. This can maintain temperature stability to ±1 mdeg. A data acquisition and control unit is designed and constructed to enable the interfacing of both the laser and other measurement apparatus to a micro-computer.

A system for automatically measuring wavelength maps as a function of injection current and laser temperature is developed, utilising the data acquisition and control unit in conjunction with a grating spectrometer. This is applied to four diode lasers. Linearity measurements are made of the frequency scan with injection current. The linewidth of one laser is measured as a function of its output power by heterodyning its output with that of a second laser operated at fixed injection current and temperature, and observing the beat note on a rf spectrum analyser. The linewidth can be reduced to below 10 MHz. The absolute frequency stability of the laser is measured by monitoring the change in absorbed power over time when the laser is tuned to the D_2 transition of caesium. The drift is measured to be 10 kHz/s over five hours, and is attributed largely to temperature drift.

An analysis is presented which allows the spectral linewidth of a light source with a Lorentzian or Gaussian profile to be calculated from the measured fringe visibility of the transmission fringes of a high-finesse scanning Fabry-Perot interferometer when these fringes are not fully resolved. The method is also applied to truncated spectral profiles, which may provide a more appropriate model for the spectral profile of some lasers, and the differences are characterised. The analysis is then extended to interferometers with low finesse and also to include the Voigt profile. An experimental verification of the analysis is made using a diode laser whose spectral profile is demonstrated to be Lorentzian in shape.

The frequency-stabilised diode laser is applied to the study of saturated absorption spectroscopy of the caesium D_2 line at 852.1 nm. Both single-beam and two-beam experiments are performed using an absorption cell containing caesium vapour with no buffer gas. A theoretical model is developed, based on rate equations for the population densities of the 48 sublevels involved in the transition, including a rate for ground state relaxation due to transit of atoms through the laser beam. The model facilitates the analysis of the effects of optical pumping and extent to which the ground state relaxation rate limits the optical pumping. For the medium-resolution single-beam experiments the laser is shown to be a suitable source for resolving the Doppler-broadened transitions, and good agreement is obtained with the model for sufficiently low laser powers. However, for the sub-Doppler two-beam experiments the limited frequency stability is revealed. An analysis of the lock-in detection process for the two-beam experiments is made, emphasising the relationships between the detection frequency, the ground state relaxation rate, and the shape of the detected signal. It is discovered that if the detection frequency is of the order of the ground state relaxation rate then a simple subtraction of the Doppler-broadened background from the probe absorption signal does not adequately model the lock-in detection process. A technique is described to experimentally determine the ground state relaxation rate from the detected signal as a function of the lock-in phase.

Acknowledgements

First and foremost I wish to thank Dr Deborah Kane, my original supervisor, for her enthusiasm and inspiration which motivated me to undertake this project, for her active role as instructor and mentor in the development stage, and for her continued interest in the project despite the many obstacles that have arisen.

I would like to thank Associate Professor Neil Pinder for the unfaltering support and encouragement he has shown, and also Dr Robert O'Driscoll for his helpful advice and support.

I gratefully acknowledge the assistance of the staff of the Electronics and Mechanical Workshops at Massey University in the construction of many pieces of apparatus. In particular, I am indebted to Robin Dykstra for many hours of stimulating discussion and for much advice concerning the electronic content of this thesis.

I thank Professor Wes Sandle for the critical contribution he has made towards the completion of this work, and the other staff, in particular Dr Don Warrington and Dr Rob Ballagh, and graduate students of the Atomic Physics Group at the University of Otago for their assistance and kind hospitality during my several visits to Dunedin. I am grateful to Robin Gledhill for the construction of the caesium cells.

I would like to express much appreciation to Diane Reay for her unfailing encouragement and for her well-informed advice concerning the layout of the thesis.

I wish to thank my parents, Bryan and Denise Saunders, for their constant encouragement throughout this project.

Thanks to the staff and graduate students of the Department of Physics and Biophysics at Massey University for their advice and help when needed, and for maintaining a friendly working environment.

Among the many unaware contributors, I would to like to express thanks to David Bowie for providing much inspiration, and to Roger Waters and *Pink Floyd* for helping to maintain my sanity.

Finally, I am grateful to the former NZ University Grants Committee for providing financial assistance and for the Massey University Vice-Chancellor's PhD study award.

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