Towards self-referenced lasers for cold-atom technologies

Doppler-free Laser Spectroscopy of Iodine around 689nm

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Introduction

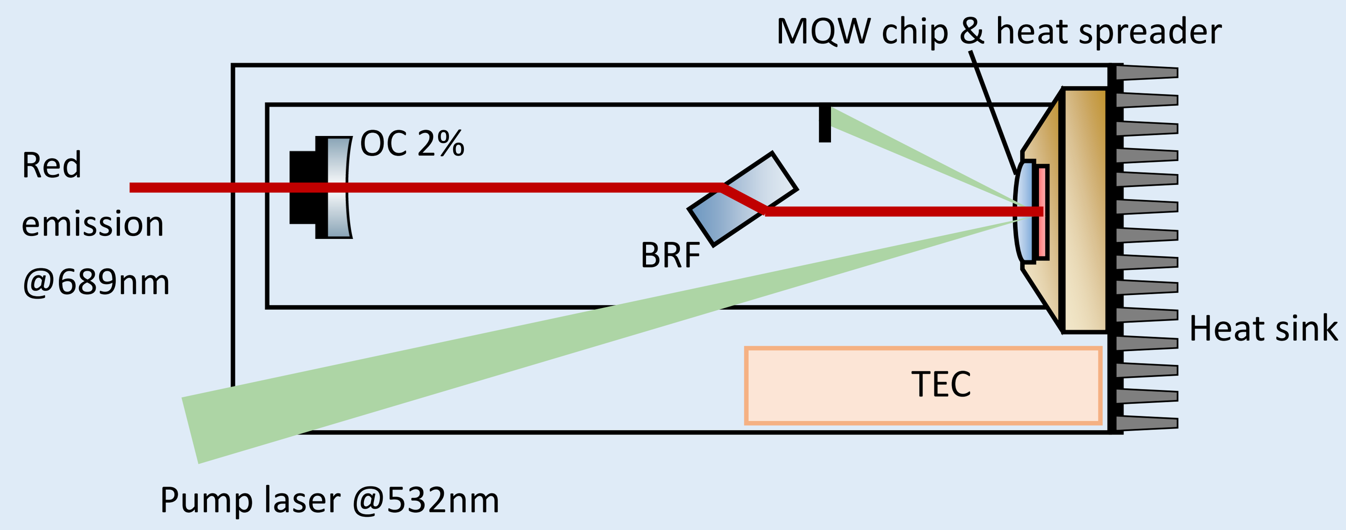
Frequency stabilized lasers underpin many cold atom technologies [1], making them vital in quantum sensing and metrology applications such as the Sr atomic clock [2]. In this example, the visible-wavelength edge-emitting semiconductor lasers used for cooling, trapping, re-pumping, and probing the transitions of Sr atoms [3] are robustly frequency stabilized to high-finesse Fabry-Perot reference cavities to narrow the laser linewidth as required.

Reference cavities alone cannot serve as absolute frequency references, but when combined with a spectroscopic reference an absolute laser lock can be established.

In the case of Sr spectroscopy atoms must be heated to high temperatures (up to 530 °C) and contained in an inert metal chamber [4] to maintain a suitably large population for a signal to be derived. Where field-deployable compact Sr clock development is concerned this presents a significant challenge, in addition to other constraints on compactness following from the use of edge-emitting lasers, such as beam correction optics and amplifiers.

As an alternative we propose spectral referencing to iodine vapour, which has many transitions in the red and infrared wavelength regions [5]. Here we present preliminary spectroscopy of Iodine vapour using a vertical external cavity surface-emitting laser (VECSEL), which is described at right.

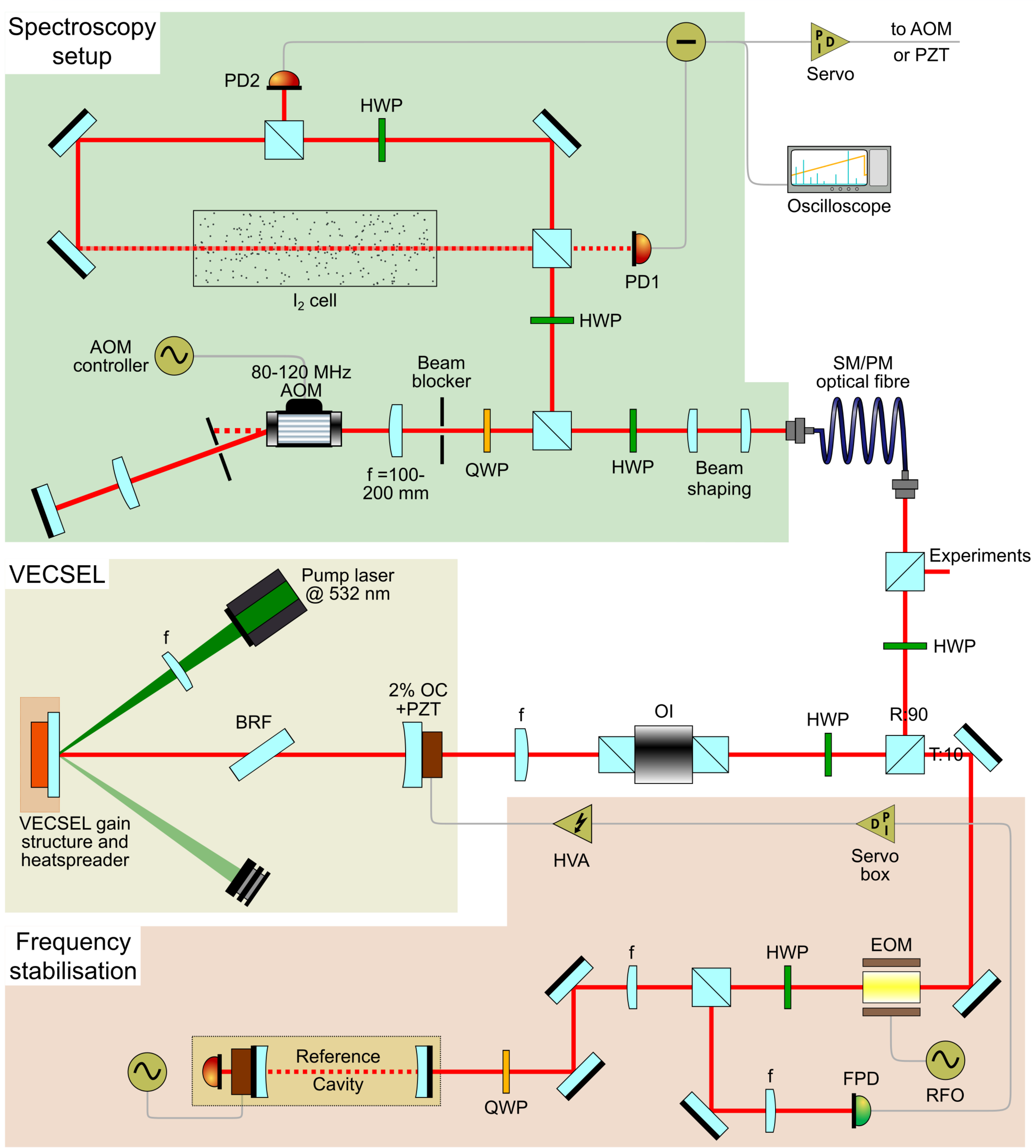
Vertical External-Cavity Surface-Emitting Lasers (VECSELs)



- Green pump laser (Coherent VERDI G5 or InGaN diode for compact embodiments) is focussed onto a highly-reflective semiconductor gain mirror.
- Resonantly positioned multiple GaInP quantum wells (MQWs) generate surface-emitting light at 689nm.
- External resonator (few cm) is formed with 2% transmitting output coupler, birefringent crystal (BRF) placed intracavity to produce single-frequency tunable light.
- VECSEL enclosed in temperature controlled metal box for thermal management and to minimise airflow disturbances.

Methods

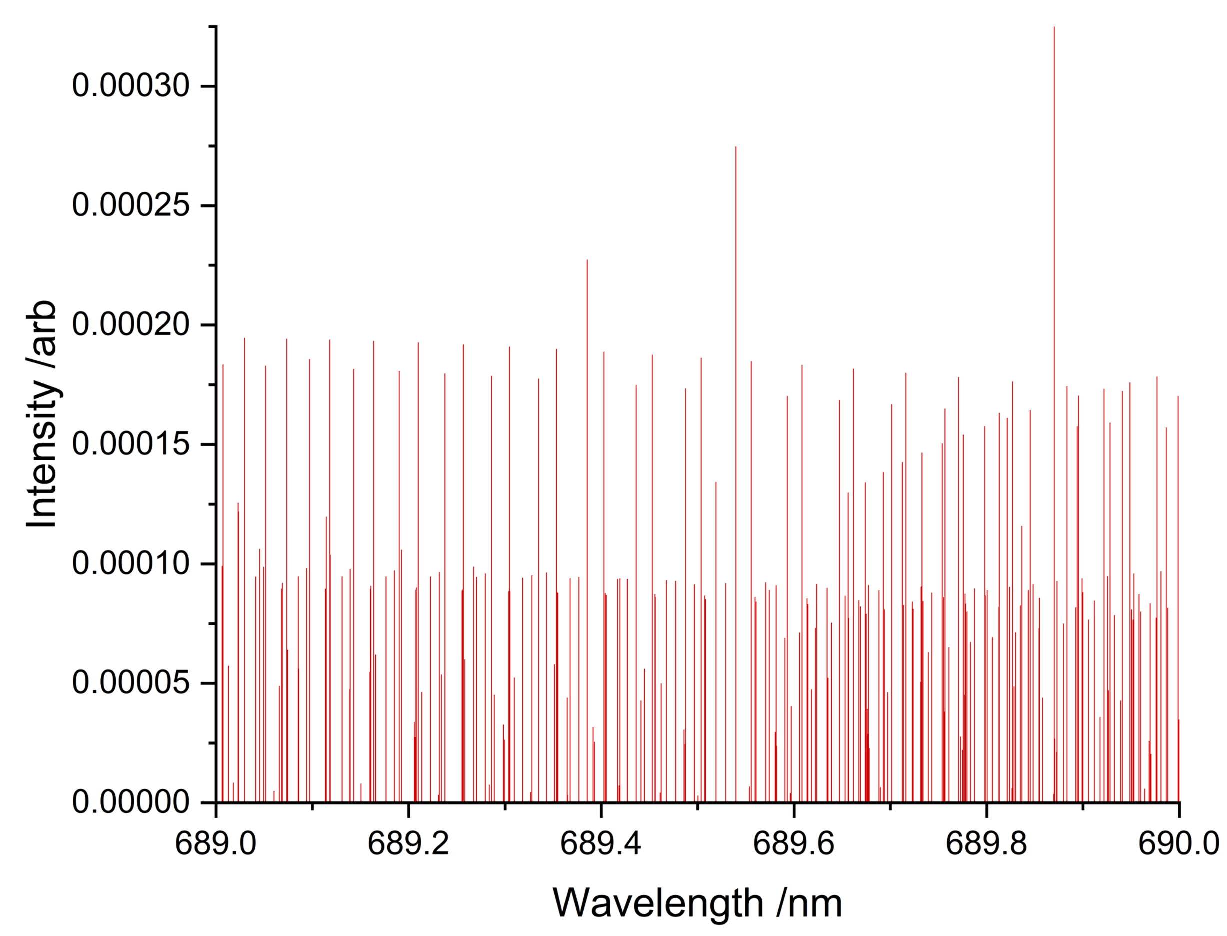
To resolve hyperfine features of iodine in our target wavelength region we use saturated absorption spectroscopy. In this method the VECSEL output is divided into a sufficiently bright pump beam and weaker probe beam that counter-propagate through a vapour cell. The pump beam interacts strongly with atoms in one direction, saturating them, and the probe beam interacts less strongly in the opposite direction. When the light frequency matches that of a hyperfine feature, the pump and probe beams address the same velocity class of atoms — the atoms are fully saturated by the pump beam, and the probe beam is allowed to pass without absorption. By scanning the VECSEL frequency the hyperfine spectrum can be recorded without a Doppler background.



Spectroscopy experiment. VECSEL light passes through an optical isolator (OI) and is fibre-coupled to spectroscopy and Pound-Drever-Hall frequency stabilization stages. In the former an acousto-optic modulator (AOM) is used in double-pass configuration to scan pump and probe beam frequency. Our iodine cell is 19cm in length. N.B. Our preliminary results will be completed without the use of the frequency stabilization set-up shown above.

Preliminary analysis

A ‘stick diagram’ (right) is simulated from rovibrational constants supplied in [5]. The lines indicate transitions in molecular iodine, and do not show their hyperfine structure components. We will attempt to view the hyperfine structure in our work.



The configuration of the hyperfine components we observe will indicate the source transition. We will fit saturated lineshapes to the spectra to estimate parameters that inform on suitability of iodine for further frequency stabilization work.

Conclusion

We have presented our spectroscopy experiment and discussed the structures we expect to observe. We have described the anticipated form of our spectra and the planned method of analysis. We expect our first results in the next quarter.

References:

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[3] N. Poli et al, 2006, *Spectrochimica A,* **63** 981.
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[5] S. Gerstenkorn & P. Luc, 1985, *J. Phys. France,* **46** 867.

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