Continuous-wave mirrorless lasing for directional laser guide stars and remote magnetometry

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The commonly used laser guide star (LGS) method developed for image correction in optical astronomy is based on the detection of near-isotropic fluorescence from the mesospheric sodium layer [1]. Even with the great recent progress in the LGS techniques, there is a widely recognized need for stronger return signals that could make image correction faster and more accurate. Low-divergence downward-directed emission generated in the sodium layer could constitute a solution to the problem. Backward cooperative emission from dense Na vapours in a cell was demonstrated using an femtosecond laser [2]; however, here we suggest an alternative approach based on continuous-wave (cw) mirrorless lasing in mesospheric Na atoms.

We report on a study of the spectral and spatial characteristics of directional emission from alkali vapours two-photon excited with cw resonant laser light in the sub-100 mW power range. In atomic media excited by cw resonant light, new optical fields can be generated by nonlinear processes such as parametric four-wave mixing (FWM) and amplified spontaneous emission (ASE) [3], [4].

First, we conducted a detailed study of new-field generation in Rb vapours revealing important properties of the ASE radiation on the $5D_{5/2}$ - $6P_{3/2}$ transition at 5.23 μm.

- Depending on the excitation geometry, the ASE radiation could be spectrally and spatially distinguishable
- Both the FWM and ASE processes could be effectively switched off by an additional resonant laser field
- We find the optimal conditions for generating spatially and temporally coherent backward-directed radiation.

The mechanism of mirrorless lasing investigated in Rb vapours has been extended to Na. A scheme of relevant energy levels of Na is shown in Fig. 1 (a). Directional emission at 2.20 μm that is equally intense in the forward and backward directions has been obtained for Na vapours excited by co-propagating laser fields at 589 and 569 nm. Its directionality, as well as the threshold-like number-density and laser-power dependences (Fig. 1b), are consistent with the mechanism of ASE. The divergence of mirrorless lasing is determined by the aspect ratio of the interaction region and can be as small as 6 mrad (Fig.1c).

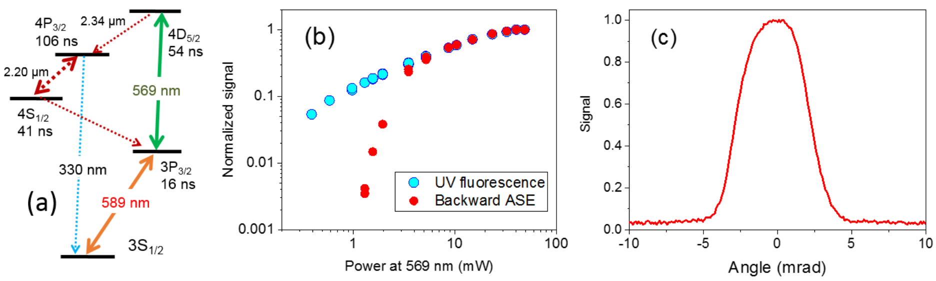

Fig. 1: (a) Relevant energy levels of Na atoms. (b) Backward emission at 2.20 μm and isotropic fluorescence at 330 nm as a function of laser power at 589 nm. (c) Spatial profile of **backward-directed lasing** at 2.20 μm.

We find that the intensity of mirrorless lasing strongly depends on the polarization of the applied laser light and magnetic field in the cell. Under the present experimental conditions, the backward ASE generated by linearly polarized laser light is approximately ten times weaker than the ASE generated by circularly polarized light. This effect, as well as its possible application for remote magnetometry, is the subject of our current study.

The presented results could decisively inform the prospects for achieving directional return from mesospheric sodium atoms that would be beneficial for remote magnetometry and may enable dramatic improvement of the LGS technique.

References

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