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A tunable fiber laser for application to helium optically pumped magnetometers

A. LE GARREC, J.M. LÉGER, D. PUREUR*, M. DOUAY*, P. BERNAGE*, P. NIAY* and E. DELEVAQUE**

LETI, CEA-Technologies Avancées, DSYS-CEN/G, 85 X, 38041 Grenoble cedex

* Laboratoire de Dynamique Moléculaire et Photonique, URA 0779 du CNRS, Université des Sciences et Technologies de Lille, UFR de Physique, Bât. P5, 59655 Villeneuve d'Ascq cedex, France

** CNET Lannion, route de Trégastel, BP. 40, 22301 Lannion cedex, France

INTRODUCTION

The replacement of helium discharge lamps by lasers emitting at 1083 nm has significantly improved the helium 4 optical pumping efficiency. Over the last few years, numerous lasers have been developed, most of them being tunable solid state lasers. However, applications of helium optically pumped magnetometers require lasers with low power consumption, a compact design and flexibility. The most critical point is the laser wavelength control which is very difficult due to the temperature sensitivity of the cavity components. In this article, we first present briefly the helium 4 optical pumping process. We then compare the efficiency of singlemode and multimode lasers for magnetometry applications. Finally, we describe the performance of an integrated Nd^{3+} fiber laser, and the first tests carried out to determine whether it is well adapted for magnetometry applications.

HELIUM 4 OPTICAL PUMPING PROCESS

Optical pumping is a powerful technique to create an electronic spin polarization of the 2^3S_1 metastable state of helium 4 resulting from the interaction between these atoms and resonant light at 1083 nm. It induces a new distribution of the atomic population within the three Zeeman sublevels, hence a possible alignment of the metastable state. The result of the pumping cycle depends essentially on the beam source characteristics (intensity, polarization and wavelength). Three resonant transitions, labeled D_0 , D_1 and D_2 , are involved in the process. Figure 1 presents the relevant energy levels of helium 4.

Figure 1 : ^4He energy levels

It has been demonstrated that the traditional helium optical pumping by a spectral lamp is quite inefficient because only about 10% of the emitted light -fraction corresponding to the D_0 transition- contributes to the orientation build-up of the metastable state. The D_1 and D_2 components have an opposite polarity and nearly equal intensity, so that their effects cancel each other [1]. Moreover, due to their very small wavelength difference, the three transitions can not be separated by an interference filter. Laser pumping, which allows single line excitation, therefore leads to a much better orientation, up to the 90 % of the helium metastable state for an equivalent intensity. Nevertheless, the orientation build-up resulting from optical pumping depends on the spectral linewidth of the laser sources.

We have developed a numerical simulation to estimate the laser bandwidth influence on the metastable state alignment [2]. To achieve this, the metastable atoms are divided into two groups depending on whether they are directly in resonance with the laser or not. The two groups are coupled by velocity exchange collisions ($P=1$ Torr). The resolution of the evolution equations taking into account the different phenomena to which the metastable atoms are submitted allows an evaluation of the 2^3S_1 alignment for lasers presenting different spectral profiles.

Figure 2: Alignment for different laser width

Figure 2 illustrates typical simulation results. It shows that the alignment of both the metastable atoms in resonance and those out of resonance with the laser increases significantly for laser exhibiting a broader spectral profile. This can be explained by the fact that the broadband pumping light matches the Doppler absorption profile. On the contrary, for narrow singlemode lasers, only a very small fraction of metastable atoms are directly in resonance with the laser. It follows that most metastable atoms are only indirectly aligned by collisions with the metastable pumped atoms and the process is therefore less efficient. These results are in good agreement with previous evaluations of the optical pumping efficiency for helium 3 [3] and cesium [4].

Until now, the need for a compact laser implied a narrow singlemode operation, as far as solid state lasers are concerned. But with the advent of fiber lasers and the development of compact lasers, emission on a large spectral profile is henceforth possible. This justifies the great interest in fiber lasers in magnetometry applications.

LASER PERFORMANCES

Several lasers have been produced at the LPDM laboratory at the Lille university. The laser cavity consists of a 3-meter-long Neodymium doped fiber. The glass fiber obtained from the CNET-Lannion has a $1.8 \mu\text{m}$ core diameter and a $125 \mu\text{m}$ cladding. The originality of these lasers lies in the fact that the usual cavity mirrors are replaced by

Bragg gratings acting as wavelength filters. These gratings are photoinduced by U.V irradiation within the core of the Nd doped fiber [5]. The gratings are a few millimeters long. The reflectivities at 1083 nm of these filters are of about 99% for the high reflector and 30% for the output coupler. The cavity is pumped by a 100 mW laser diode SDL5412 emitting around 815 nm, which corresponds to an absorption band of Neodymium. The coupling between the diode and the fiber core is made by a pair of lenses. The experimental set-up for measurements is described on figure 3.

Figure 3: experimental set-up

Figure 4 shows the total output power at 1083 nm versus the injected pump power. The quantum efficiency approaches 70%, close to the theoretical efficiency. One can also notice the very low pump threshold-2 mW- a common property of fiber lasers. Low power laser diodes delivering for instance 25 mW would thus be sufficient to align efficiently the metastable state whereas it is not even sufficient to reach the threshold current of solid state lasers.

The laser spectral bandwidth is principally dependent on the Bragg grating characteristics. Our laser typically exhibits about 100 modes with a 3 GHz overall width (fig5). The mode spacing, determined by the fiber length, is close to 30 MHz. It should however be possible to produce lasers with a spectral width of 1,7 GHz.

Figure 4: laser quantum efficiency

Figure 5: laser spectrum

To achieve wavelength tuning, only the gratings periodicity has to be controlled. This means that only a single element must be adapted making it very simple compared to other lasers. This adjustment is obtained by stretching the gratings using a piezoelectrical microdisplacement platform. A wavelength span of several nanometers has been obtained for a fiber stretch of a few millimeters.

These lasers have been successfully used for helium 4 optical pumping. Figure 6 shows the absorption and the fluorescence when the laser is tuned to the D_0 , D_1 and D_2 transitions.

Figure 6
Laser wavelength tuning
to the 2^3S_1 - 2^3P helium transitions

CONCLUSION

A new generation of lasers presenting low threshold and very high quantum efficiency has been developed for helium optical pumping. Due to their compactness, their flexibility of use and their multimode operation, they present an attractive alternative to solid state lasers for specific applications. Preliminary magnetometry experiments have been carried out. The first results are very encouraging and more extensive characterizations are being performed.

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