NOTES

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Electronically tunable fiber laser for optical pumping of ^{3}He and ^{4}He

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We present in this paper a low threshold, highly stable, integrated fiber laser cavity that uses an electronically tunable internal Bragg grating. The fiber laser produced over 5 mW with a spectral width of about 5 GHz at 1083 nm. The laser was used to achieve 30% polarization of the $2\,^3S_1$ metastable states of ^{4}He in a weak rf discharge cell. © *1996 American Institute of Physics.* [S0034-6748(96)01601-3]

Fiber lasers have considerable potential as sources for laser spectroscopy. Multilongitudinal-mode Nd-doped fiber lasers have been used for spectroscopy of Sr^+ at 1092 nm,[1] ^{4}He at 1083 nm,[2] Yb^+ at 935 nm,[3] and for atmospheric absorption spectroscopy in the range of 1065–1145 nm.[4] Single-longitudinal-mode Er-doped fiber lasers operating near 1530 nm have been used in spectroscopy of C_2H_2 (Ref. 5) and Rb.[6] These fiber laser systems used bulk tuning elements such as diffraction gratings, prisms, Lyot filters, and etalons. The bulk elements can be replaced with Bragg reflection gratings in the core of optical fiber,[7] making an all-fiber laser cavity.[8] These lasers have lower losses and should be relatively insensitive to vibration.

The Schearer Laser Laboratory at the University of Missouri has been developing Nd-doped bulk laser systems operating at 1083 nm for optical pumping of the ^{4}He and ^{3}He metastable states.[9] Recently this laboratory has been investigating the miniaturization of such laser systems for their operation in ^{3}He magnetometers and have shown that fiber lasers are capable of tuning over the He transitions of interest.[2] However, in that series of experiments the fiber laser was tuned with the use of an external cavity and therefore was not a serious contender for use in He magnetometers. We present in this paper the first use of a Nd-doped fiber laser incorporating an internal Bragg grating for the optical pumping of ^{4}He and ^{3}He metastable states. This laser offers considerable cost reduction and has higher stability than the diode-pumped Nd:LMA solid state lasers commonly used.

We used a 60 cm length of a SiO_2–GeO_2 fiber containing Nd.[10] The core diameter was approximately 3.5 μm with a NA of 0.21; the absorption of the fiber at the 810 nm pumping wavelength was approximately 1.96 dB/m. As shown in Fig. 1, a 1-mm-thick mirror, antireflection coated for the pumping wavelength and >99% reflectance at the lasing wavelength, was butted against the fiber to form the rear of the cavity. The output reflector of the cavity was a 6-mm-long fiber Bragg grating. The grating was written directly into the Nd-doped fiber using UV interference.[11] Continuous-wave UV light was produced at 244 nm by frequency-doubling argon-ion laser light in an external resonant cavity. The UV light was split into two beams and recombined to form an interference pattern in the fiber. Exposing the fiber for 23 min to an intensity of 44 W/cm^2 produced a Bragg grating of 70% reflectance with a full width at half-maximum bandwidth of 0.3 nm. The peak of the reflectance was positioned 1 nm below the wavelength of the He metastable transitions to allow tuning of the fiber laser by stretching the grating with a PZT translator.

The pumping source used in the experiment was an 810 nm diode laser (1×3 m emitter) capable of producing 100 mW of output power. The diode laser light was collimated with a 6 mm focal length lens, and the ellipticity of the beam was corrected using an anamorphic prism pair. After collimation, the pump beam was launched into the fiber laser cavity using a 25.6 mm focal length lens and −150 mm focal length steering lens combination.

Before the Bragg grating was written into the fiber, a different laser configuration using an output coupler consisting of a collimator and a 93% reflectance mirror was investigated. The spectrum of this laser had a 16 nm bandwidth consisting of a large number of modes operating simultaneously. In contrast to this, the fiber laser bandwidth after the grating was written into the fiber core was less than the 0.04 nm resolution of the monochrometer. Even at maximum pumping, the fiber laser developed no satellite modes and was extremely stable in both power output and wavelength. The spectral output of the fiber was further investigated using a Fabry–Perot spectrum analyzer. This revealed that the fiber laser was operating in many longitudinal modes separated by approximately 170 MHz.

Figure 2 shows a plot of the fiber laser output power versus diode laser (pump) output power. The maximum output power of the fiber laser was over 5 mW when the output of the pump laser was 100 mW. Based on measurements

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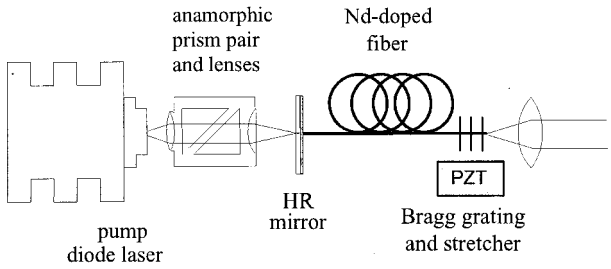

FIG. 1. Experimental setup of the Nd-doped fiber laser with an internal, tunable Bragg grating.

made with a similar undoped fiber, we estimate that the overall coupling efficiency of the diode laser pump light into the fiber was about 22%. Due to the high reflectance of the Bragg grating and the very low additional loss in the laser cavity, the fiber laser began lasing when the diode laser reached threshold.

Tuning of the fiber laser was achieved by gluing a 17 mm section of the fiber laser containing the Bragg grating to a custom designed translator that used both a manual micrometer for rough stretching and a PZT capable of 30 μm expansion for fine tuning. Voltage was applied to the PZT with a single power supply or a computer-controlled voltage source. Since the peak wavelength of the unstretched Bragg grating was just below the He resonance lines, the fiber needed to be stretched less than 30 μm to achieve the 1 nm wavelength shift required. Figure 3 shows a plot of the fiber laser wavelength as a function of PZT position. The fiber laser tuned smoothly without significant power fluctuations over the entire 1 nm range.

The output from the fiber laser was collimated and sent through a 2.5-cm-diam, 3-cm-long rf ^{4}He discharge cell driven at 25 MHz. The pressure in the cell was about 133 Pa (1 Torr). The fluorescence of the discharge cell was monitored with a silicon photodetector and an oscilloscope. A large, stable signal was produced when the fiber laser was tuned through the He transitions D_0, D_1, D_2 at wavelengths of 1082.908, 1083.025, and 1083.034 nm, respectively. A complete scan through the He transitions showed that the linewidth of the fiber laser was greater than the 1.5 GHz

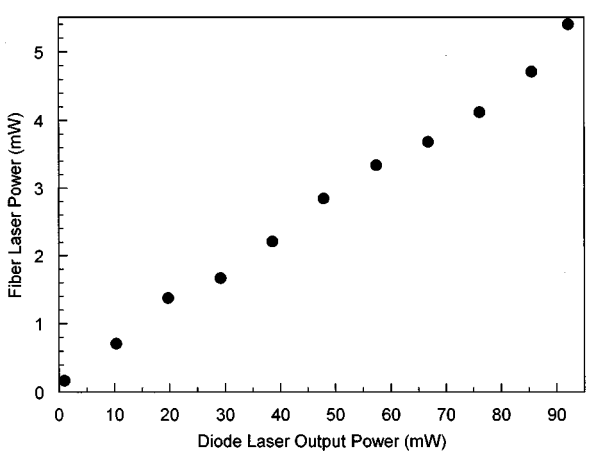

FIG. 2. Plot of fiber laser output power as a function of diode laser output power.

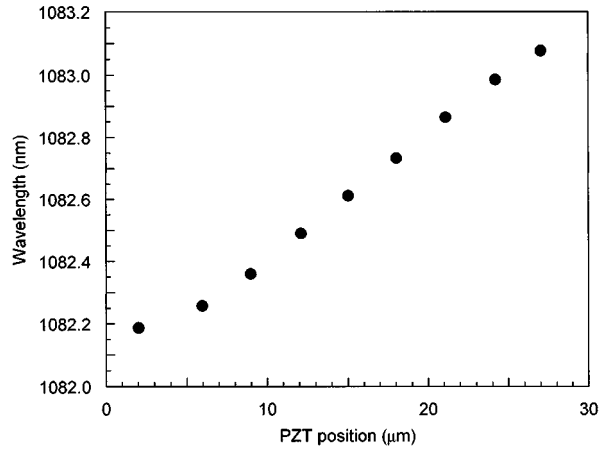

FIG. 3. Plot of fiber laser wavelength as a function of PZT position.

Doppler-broadened He transitions, since the D_1 and D_2 lines were not resolved. The wavelength span was calibrated using the known separation between the transitions. From the width of the D_0 line, the spectral width of the fiber laser was determined to be approximately 5 GHz.

The optical pumping capabilities of the fiber laser were investigated by inserting a linear polarizer and quarter-wave plate combination to produce right-circularly polarized light. The fiber laser was then tuned to the D_0 transition and a uniform magnetic field was applied along the direction of laser beam propagation. By monitoring the change in fluorescence while switching the magnetic field on and off, we determined that 30% polarization of the ^{4}He metastable states was achieved using this system.

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