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6. AUTHOR(S)

Prof. Mikhail Gubin

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Lebedev Physics Institute
53 Leninsky Prospekt
Moscow 117924
Russia

8. PERFORMING ORGANIZATION REPORT NUMBER

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This report results from a contract tasking Lebedev Physics Institute as follows: Collaborate with Phillips Lab to produce a continuous wave (cw) color center laser (CCL) of wavelength 3-3.3 micron with laser diode pumping.

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TO EUROPEAN OFFICE OF AEROSPACE RESEARCH AND DEVELOPMENT

ATTENTION: Professor John K. McIver

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Special Project SPC-94-4087

"Optical Frequency Standard Based On Diode-Pumped Solid-State Laser With Methane Absorption Cell"

Final Report

for Research Period 1 October 1994 to 30 September 1995

CW operation of a color center laser (CCL) with a RbCl:Li crystal has been obtained under pumping by a red laser diode (LD). It was an InGaAlP/GaAs laser (AOC 670-400-T3 from Applied Optronics Corp.) delivered by Phillips Lab.

For the CCL with a 2% transmission output mirror pump power at threshold was $P_{th} = 90$ mW. With a diffraction grating as an output coupler (300 lines/mm, 85% efficiency) this CCL can be tuned from 2.84 to 2.98 microns. With an additional selective element - an air-spaced Brewster-cut intracavity etalon - the CCL operated in a single longitudinal mode. Pump power at threshold in that case was about 160 mW.

Study of the far field energy distribution showed that the laser operated on the main spatial TEM_{00} mode.

Two pump sources -LD and Kr-ion laser -were compared. With the Kr-ion laser as the pump source for the same CCL cavity configuration, we had $P_{th} = 115$ mW (instead of 160 mW for LD pumping). The Kr+ laser operated on the TEM_{00} mode. It should be noted that spectral and spatial characteristics of CCL radiation did not depend on the specific pump source (LD or Kr-ion laser) but was determined by cavity design of the CCL (though maximum pump power did not exceed 300 mW).

The noise level of the LD output intensity in the frequency range up to 40 kHz is at least 20-30 dB lower than that of the Kr-ion laser (spectrum analyzer bandwidth is 30 Hz). The resulting noise of LD-pumped CCL is close to the level

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of PbS detector noise and is about 15 dB lower than the noise of the CCL with the Kr-ion laser pumping. Such low amplitude pump noise should facilitate realization of a narrow linewidth CCL.

Application of a more powerful LD and optimization of the RbCl:Li crystal and other optical elements of the CCL cavity will lead to an improvement of tuning range and output power of our CCL. Application of this laser to methane ν_3-band high resolution spectroscopy followed by stabilization of the CCL frequency to one of the ν_3-band methane transitions should be possible.

The work in this direction is still in progress. A new scheme of LD pumped CCL is under consideration now. It includes a powerful (2 watts at 682 nm) laser diode array (LDA) as a pump source for the RbCl:Li CCL. A power supply for this array has been made and tested. A special collimating optical system is designed to match LDA output radiation with the input parameters of the CCL cavity.

The experiments with the RbCl:Li CCL pumped by the Kr ion laser are going on also. By means of the single frequency CCL with an intracavity absorption cell the subDoppler resonances of saturated absorption were obtained for the first time on different components of the methane ν_3-band R(0) - R(10) lines. The estimated spectral width of the resonances was about 300 kHz and was determined primarily by the CCL linewidth and time-of-flight broadening. To reduce time-of-flight broadening and to utilize a sensitive double-mode technique of detection narrow resonances of saturated dispersion a scheme for a two-mode CCL with the intracavity absorption cell and a telescope for beam expanding was developed.

Two types of double mode regime were considered: with orthogonal mode polarization and with parallel mode polarization. Two special CCL vacuum chambers for each type of double-mode regime were designed and fabricated. Double-mode operation for both types of mode polarization was obtained. But in case of perpendicular mode polarization the pump power at threshold was too high to tune the laser to the methane absorption lines (ν_3 band, R-branch). Such high threshold is due to large intracavity losses. These losses arise from the deficiency of the special intracavity optical elements needed for wavelength tuning and mode selection in the case of perpendicular mode polarization.

The scheme with parallel mode polarization has no such limitations (it is similar to the scheme of single mode laser), but it requires a fast ($\geq$100 MHz) mid-infrared (3.0 - 3.4 μm) photodetector. In that scheme tunable two-mode operation of the CCL with adjustable intermode spacing (100-400 MHz) in the spectral region of interest (3.0-3.3 μm) was obtained and a beat signal was detected.

The obtained results were reported on the 5th Symposium on Frequency Standards and Metrology (October 15 - 19, 1995, Woods Hole, Massachusetts, USA). This work was appreciated and discussed with the leading specialists and the proposed approach towards the creation of the optical frequency standard in the mid-infrared spectral region was considered to be perspective.

On this Symposium a new concept of a two - range (optical - microwave) frequency standard was also proposed. The scheme is based on a high - precise methane optical frequency standard stabilized over the strong rotational - vibrational transitions of the ν_3 band ($\lambda = 3.3\ \mu m$) with cryogenic cooled methane cell. The scheme implies using the "reference comb" of these strong CH_4 lines.

The advantage of this scheme is based on two points:

- high correlation of the "physical" shifts of two practically identical lines (the only difference is the rotational number J), and

- high correlation of the "methodical" shifts and technical fluctuations of the frequencies of the two adjacent modes of the same resonator.

As a result the reproducibility and accuracy distinguished at the optical frequencies (for the both modes) can be transferred without considerable loss to the beat signal at microwave domain in spite of the fact that a ratio of the carriers (optical/microwave) is high enough (90 THz / 300 GHz = 300).

The concept allows to consider the "optical / microwave double-mode double-line" methane frequency standard as a device providing the reproducibility 10^{-15} - 10^{-14} at microwave frequencies via the standards on optical transitions without touching the complicated problem of a compact radio-optical frequency chain.

Mikhail Gubin
Dr.of Science
Head of Frequency Standards Laboratory
P.N.Lebedev Physics Institute
20 November 1995