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ADVANCED ELECTROOPTIC COMPONENTS FOR SATELLITE/SUBMARINE OPTICAL COMMUNICATIONS SYSTEMS

John B. Marling, Frederick T. Aldridge, Lowell L. Wood

30 September 1976

Prepared for The Naval Systems Division, Office of Naval Research
Arlington, Virginia
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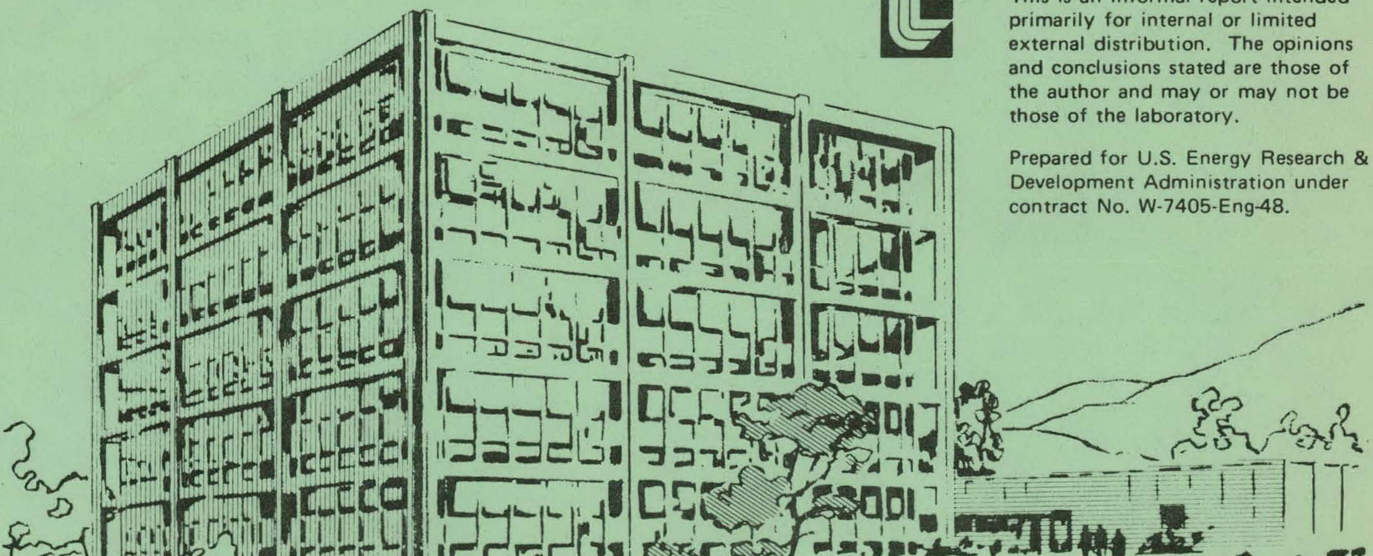

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Interim Report on Research Work on Ultra-High Brightness Blue-Green Laser Technology

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ADVANCED ELECTRO-OPTICAL COMPONENTS
FOR
SATELLITE/SUBMARINE OPTICAL COMMUNICATIONS SYSTEMS

Funding for Phys. Prop. 76-102, submitted to ONR in March, 1976, was anticipated to commence early in Spring, 1976, but did not do so until late June, 1976. This progress report thus summarizes results for the three-month period comprising FY76T. During this brief period, significant progress was nevertheless made on identification and acquisition of optical components for an ultra-high brightness weakly tunable blue-green beam generator. Limited performance validation of key system design concepts was achieved, and significant progress was made in improved optical design for more efficient generation of ultra-high brightness, tunable blue-green radiation. These results are detailed below.

I. Identification of Laser and Optical Components

After considerable examination of alternatives, the neodymium-YAG laser was chosen as the best first generation choice for a high power, high brightness blue-green beam generator. Specifications supplied by the LLL Project were satisfactorily implemented by a commercial supplier of neodymium laser systems. Delivery and final adjustments for operation were achieved in mid-FY76T. The primary thrust of this present investigation is determination of the potential for frequency tunability and high spectral brightness beam generation in a neodymium-YAG laser system. The necessary optical components were identified and received in FY76T, as well as the non-linear crystals required for frequency up-conversion. Optics for tuning consisted primarily of narrow-gap Fabry-Perot etalons for selection among the several available Nd-YAG emission lines, and higher resolution Fabry-Perot etalons for achieving the frequency aspect of high spectral brightness. These were placed inside the laser cavity and tuned by orientation change. In addition, a high resolution scanning monochrometer was available for monitoring wavelength tunability over broader spectral ranges.

II. Performance Validation of High Brightness Green Coherent Beam Generator

A. Optical Performance

The neodymium-YAG laser consisted of a low power oscillator operating in the lowest order transverse mode (TEM_{00}), followed by a double pass amplifier. Output was determined to meet beam quality specifications, and a pulse energy of 50 millijoules was obtained at 1.06 microns with a diffraction-limited beam divergence of about 0.001 radian. Peak output power was 3 megawatts.

Frequency up-conversion to the green was achieved in a deuterated CDA (cesium dideuterium arsenate) crystal heated to 104° C to achieve non-critical frequency doubling to 0.532 microns. Even without attempting to optimize the non-linear frequency conversion, a peak green output of about 1 megawatt in the green at 532 nm was achieved. Operation with a telescope for optimally collimated green output beam generation was not attempted during the FY76T effort.

B. Spectral Performance and Frequency-Tunability

Relevant measurements of the frequency tunability of the neodymium-YAG laser system were performed to more effectively evaluate the potential of this laser in satellite-submarine communications systems. Significant wavelength tunability was achieved by varying crystal temperature, as indicated in Figure I. Figure I shows the tuning range of two Nd-YAG emission lines as the YAG crystal temperature was varied from 0-100° C.

By extrapolating to -40° C crystal temperature (previously demonstrated to be effectively attainable), one projects tunability over 4Å for the 1.0615 micron line, and a tunability of 6Å over the 1.0641 micron transition. This represents a total tuning range of 260 gigahertz, and corresponds to tunable green emission over the range of 5306.65Å to 5308.75Å for the shorter wavelength 'line' and tunable green emission over the range 5319.05Å to 5322.40Å for the "normal" blue-green emission 'line' from the frequency-doubled Nd-YAG laser output.

Insertion of an etalon into the Nd-YAG oscillator narrowed the emission linewidth to less than the resolution of the spectrometer used for wavelength measurement. This linewidth was estimated to be about 0.01Å. Insertion of a second etalon decreased linewidth to that of one longitudinal cavity mode, or about 10 megahertz, comparatively close to the Fourier transform limit. However, the instrumentation for verification of this ultra-high brightness operation was not received in FY76T. Such a linewidth of course implies the availability of about 3 x 10^4 discrete wavelength 'bands' within the demonstrated temperature tuning range of the Nd-YAG laser 'lines,' an enormous number of discrete channels for communications purposes.

C. Optical Design for Improved Harmonic Generation

Optical conversion to green emission was achieved by placing the second harmonic generating crystal outside the laser cavity. It is well known that intracavity frequency doubling can yield higher conversion efficiency. Furthermore, recent papers[1,2] have presented the advantages of double pass second harmonic generation[1] and double pass two-branch oscillator design[2]. These concepts were combined to yield efficient optical designs for intracavity second harmonic and third harmonic generation. These designs allow use of both polarizations of the Nd-YAG laser and compensate for thermally-induced crystal depolarization at high average laser power levels. They also provide for two traversals of the nonlinear crystal as well as four traversals of the Nd-YAG rod for each photon round-trip in the laser cavity. Similar designs were developed for intracavity third harmonic generation.

High efficiency third harmonic generation will permit the Nd-YAG to be a long-life, reliable high power pump source for the tunable blue-green dye lasers. Dye laser systems will also permit wavelength operation over the band of maximum ocean transmissivity, as well as frequency-matching to very high background rejection resonance filter detector systems. Optical components to implement these designs have been ordered and will be received in early FY77, when performance evaluation of this high efficiency blue-green generation technique will commence.

SUMMARY

In spite of the late Project commencement resulting in significant research endeavor only during FY76T, blue-green coherent beam generator components were procured and integrated, and preliminary performance evaluation begun. Very high spatial and spectral brightness outputs from these systems were both achieved, as well as relatively very large wavelength tunability. Use of the Nd-YAG laser as the primary source of coherent radiation admitted a total of 260 GHz of frequency tunability by varying crystal temperature from -40° C to +100° C, corresponding to 5 Angstroms of tunability in the blue-green spectral region on the two 'lines' near 5307Å and 5320Å. These attainments substantially overfulfilled the Project's FY76/76T Work Statement.

Optical design for high efficiency intracavity harmonic conversion was completed in FY76T, and necessary components ordered. This aspect of the Project was substituted for design commencement of a 1% scale experiment for submarine detection, which became less appropriate due to an ONR-directed focussing of Project attention on optical communication. Efficient second harmonic generation will provide blue-green light directly near 532 nm, while such third harmonic generation will permit use of the Nd-YAG laser as a very high quality pump source for blue-green dye lasers frequency-tunable over the 470-530 nm region of maximum ocean transmissivity, and potentially having the ultra-high brightness characteristics demonstrated for frequency-doubled Nd-YAG.

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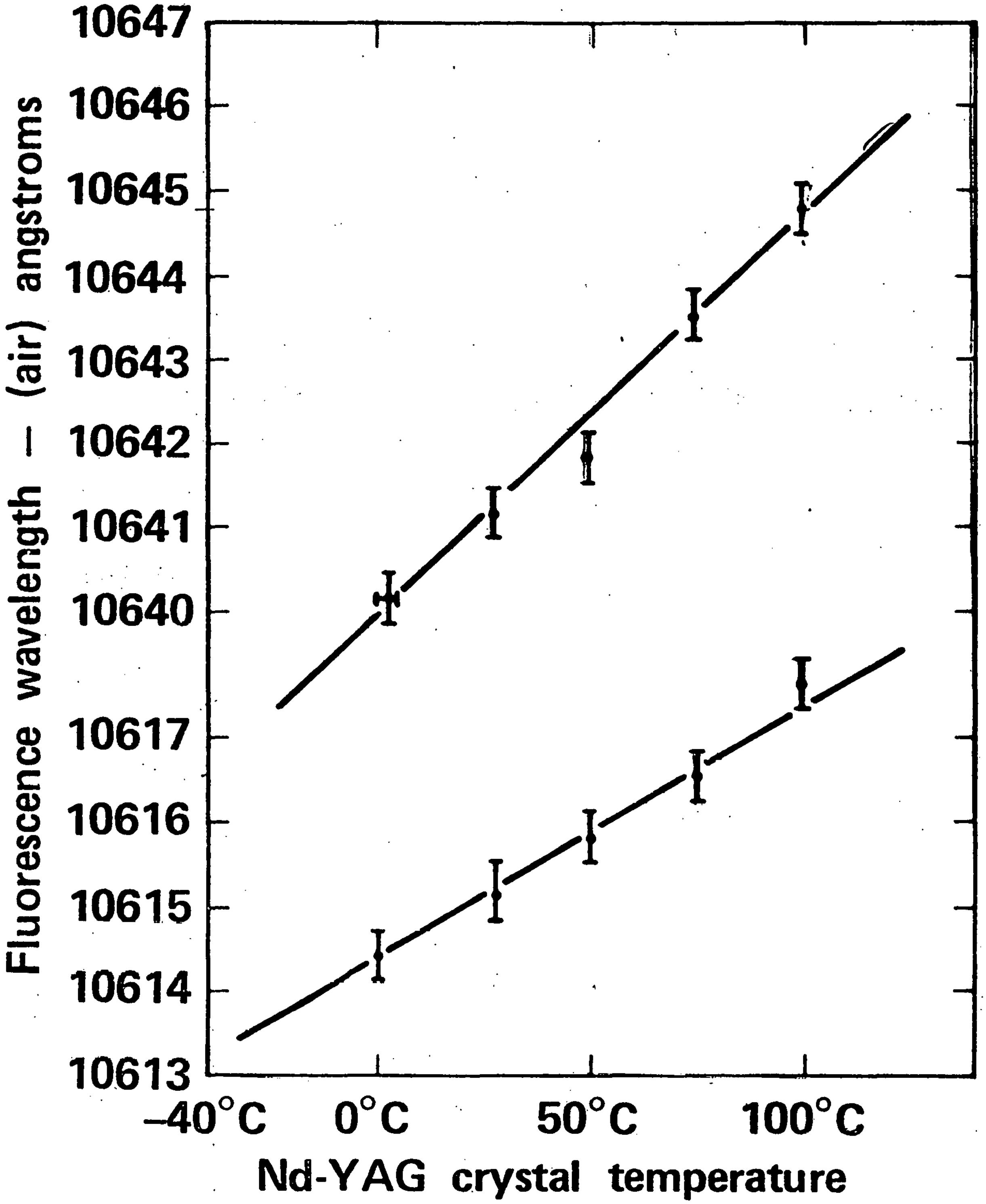
TUNING OF Nd-YAG ACHIEVED BY CHANGING CRYSTAL TEMPERATURE



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