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Innovationen mit Mikrowellen & Licht

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Forschungsberichte aus dem

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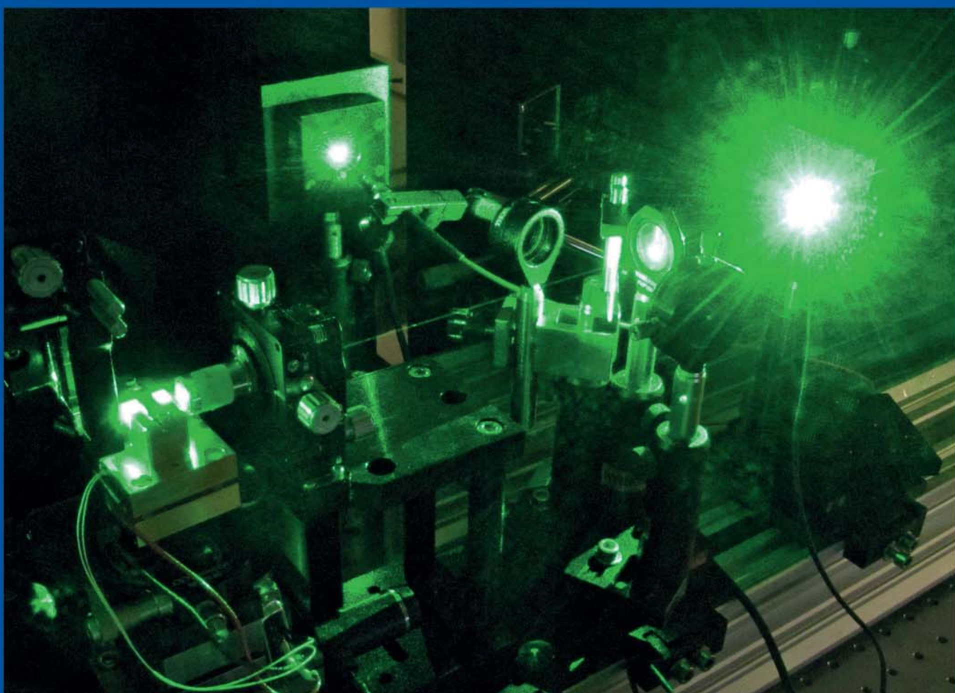
Efficient frequency doubling of near-infrared diode lasers using quasi phase-matched waveguides



Daniel Jedrzejczyk

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Efficient frequency doubling of near-infrared diode lasers using quasi phase-matched waveguides

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Innovations with Microwaves and Light

Research Reports from the Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik

Preface of the Editors

Research-based ideas, developments, and concepts are the basis of scientific progress and competitiveness, expanding human knowledge and being expressed technologically as inventions. The resulting innovative products and services eventually find their way into public life.

Accordingly, the *"Research Reports from the Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik"* series compile the institute's latest research and developments. We would like to make our results broadly accessible and to stimulate further discussions, not least to enable as many of our developments as possible to enhance everyday life.

Frequency doubling of diode lasers in nonlinear crystals enables the miniaturization of visible laser systems based on second-harmonic generation (SHG). In order to reach high conversion efficiency, periodically poled waveguide structures can be applied instead of bulk crystals. In this report, SHG with diode lasers in ridge and planar waveguide structures is studied in depth by means of simulations and experiments. The completion of the system of coupled equations with terms describing nonlinear absorption as well as structural and thermal inhomogeneity allows to indicate the causes for the experimentally observed temperature tuning spectra and the saturation of the second-harmonic power. In addition, results achieved with diode lasers in this work are comparable to state-of-the-art results reached, for example, with solid-state lasers as pump sources.

We wish you an informative and inspiring reading

Prof. Dr. Günther Tränkle
Director

Prof. Dr.-Ing. Wolfgang Heinrich
Deputy Director

The Ferdinand-Braun-Institut

The Ferdinand-Braun-Institut researches electronic and optical components, modules and systems based on compound semiconductors. These devices are key enablers that address the needs of today's society in fields like communications, energy, health and mobility. Specifically, FBH develops light sources from the visible to the ultra-violet spectral range: high-power diode lasers with excellent beam quality, UV light sources and hybrid laser systems. Applications range from medical technology, high-precision metrology and sensors to optical communications in space. In the field of microwaves, FBH develops high-efficiency multi-functional power amplifiers and millimeter wave frontends targeting energy-efficient mobile communications as well as car safety systems. In addition, compact atmospheric microwave plasma sources that operate with economic low-voltage drivers are fabricated for use in a variety of applications, such as the treatment of skin diseases.

The FBH is a competence center for III-V compound semiconductors and has a strong international reputation. FBH competence covers the full range of capabilities, from design to fabrication to device characterization.

In close cooperation with industry, its research results lead to cutting-edge products. The institute also successfully turns innovative product ideas into spin-off companies. Thus, working in strategic partnerships with industry, FBH assures Germany's technological excellence in microwave and optoelectronic research.

Efficient frequency doubling of near-infrared diode lasers using quasi phase-matched waveguides

vorgelegt von

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Abstract

Single-pass frequency doubling of near-infrared (NIR) diode lasers in quasi phase-matched nonlinear bulk crystals represents a straightforward approach to realize efficient and compact green emitting lasers in continuous-wave (CW) operation with a high output power and a nearly diffraction-limited beam quality [19, 20]. In this thesis, the application of waveguide structures, instead of bulk crystals, is investigated theoretically and experimentally with the objective of increasing the efficiency of such laser systems. In particular, a complemented study of second-harmonic generation (SHG) in periodically poled MgO-doped lithium niobate (MgO:LN) ridge and planar waveguides is conducted in order to identify all benefits and limitations for both geometries with respect to maximum conversion efficiency and accessible power in the green spectral region.

In the first part of this work frequency doubling of a DBR ridge waveguide diode laser in a periodically poled MgO:LN ridge waveguide is studied. In particular, the influence of structural imperfection, optical absorption and subsequent heat generation on the conversion efficiency of the nonlinear interaction is investigated in-depth by means of experiments and numerical simulations.

In the second part of this work frequency doubling of a DBR tapered diode laser in a periodically poled MgO:LN planar waveguide is investigated. Prior to high-power experiments, a comprehensive experimental study of the normalized SHG conversion efficiency in planar waveguides as a function of spatial diode laser beam parameters is carried out in order to provide optimum values with corresponding tolerances for subsequent experiments.

The application of periodically poled MgO:LN waveguide structures for frequency doubling of NIR diode lasers results in this thesis in a distinct improvement of the opto-optical conversion efficiency. An increase from approx. 20 % in a bulk crystal to almost 30 % in a planar waveguide and approx. 40 % in a ridge waveguide is achieved. However, unlike in a bulk crystal, the maximum generated power is limited in both waveguide geometries. In a ridge-waveguide the maximum second-harmonic (SH) power of nearly 0.4 W is limited due to its gradual saturation with increasing NIR pump power accompanied by an increase in the propagation loss, which is attributed to nonlinear absorption. The nonlinear absorption affects the SHG process starting from an SH wave intensity of approx. 1.7 MW/cm^2. Above an SH wave intensity of approx. 3.1 MW/cm^2 a saturation of the SH output power can be observed. In a planar waveguide the maximum generated SH power of approx. 1.2 W is limited due to its gradual

saturation with increasing NIR pump power. However, unlike in case of the ridge waveguide, no distinct increase of loss in the investigated power range can be determined. In addition, the maximum SH wave power density is determined here to 0.3 MW/cm^2, which is one order of magnitude lower compared to the maximum SH wave intensity in the ridge waveguide structure. Therefore, the experimentally observed power limitation in a planar waveguide is attributed to thermally induced quasi phase-matching distortion, caused by waveguide cladding material not suitable for high power operation. Higher maximum output power is expected for improved planar waveguide structures.

The generated laser radiation in the green spectral range is characterized by a single-frequency spectrum and nearly diffraction-limited beam quality and is therefore well suited for applications in the fields of bio-medicine, bio-technology and spectroscopy.

Kurzfassung

Frequenzverdopplung von nah-infraroten (NIR) Diodenlasern im einfachen Durchgang durch nichtlineare, periodisch gepolte Volumenkristalle stellt eine einfache Anordnung dar, um effiziente und kompakte, grün emittierende Laserstrahlquellen mit hoher Ausgangsleistung im Dauerstrichbetrieb und annähernd beugungsbegrenzter Strahlqualität zu realisieren [19, 20]. Im Rahmen dieser Arbeit wird die Verwendung von Wellenleiterstrukturen anstelle von Volumenkristallen theoretisch und experimentell mit dem Ziel betrachtet, die Konversionseffizienz solcher Lasersysteme zu steigern. Insbesondere wird die Erzeugung der zweiten Harmonischen in periodisch gepolten Rippen- und Planarwellenleitern aus MgO-dotierten Lithiumniobat (MgO:LN) ausführlich untersucht, um die Vorteile und Grenzen beider Strukturen bezüglich der maximalen Konversionseffizienz und der maximal erreichbaren Ausgangsleistung im grünen Spektralbereich zu finden.

Im ersten Teil dieser Arbeit wird die Frequenzverdopplung der Strahlung eines DBR-Rippenwellenleiterlasers in einem periodisch gepolten MgO:LN-Rippenwellenleiter betrachtet. Insbesondere wird dabei der Einfluss der Strukturinhomogenität, der optischen Absorption und der daraus resultierenden Wärmeentwicklung auf die Konversionseffizienz dieser nichtlinearen Wechselwirkung sowohl experimentell als auch durch numerische Simulationen ausführlich untersucht.

Im zweiten Teil dieser Arbeit wird die Frequenzverdopplung der Strahlung eines DBR-Trapezlasers in periodisch gepolten MgO:LN-Planarwellenleitern dargelegt. Zur Vorbereitung auf die Hochleistungsexperimente wird zunächst die normierte Konversionseffizienz in planaren Wellenleitern als Funktion von räumlichen Strahlparametern ausführlich untersucht, um die optimalen Werte und die dazugehörigen Toleranzen zu finden.

Die Verwendung von periodisch gepolten MgO:LN-Wellenleiterstrukturen für die Frequenzverdopplung von NIR-Diodenlasern führt in dieser Arbeit zu einer verbesserten opto-optischen Konversionseffizienz. Deren Erhöhung von ca. 20 % in Volumenkristallen [9, 10] auf hier nahezu 30 % in einem planaren Wellenleiter und auf ca. 40 % in einem Rippenwellenleiter wird beobachtet. Im Gegensatz zu Volumenkristallen ist die maximal erreichbare Ausgangsleistung in beiden Wellenleiterstrukturen jedoch begrenzt. In einem Rippenwellenleiter ist die maximale Leistung der zweiten Harmonischen auf nahezu 0,4 W begrenzt, und zwar durch die mit steigender NIR-Pumpleistung graduell auftretende Sättigung. Gleichzeitig wird eine Erhöhung der Ausbreitungsverluste beobachtet, die

auf die nichtlineare Absorption zurückzuführen ist. Die nichtlineare Absorption beeinflusst den nichtlinearen Prozess der Frequenzverdopplung ab einer Intensität der zweiten Harmonischen von ca. 1,7 MW/cm^2. Oberhalb einer Intensität der zweiten Harmonischen von ca. 3,1 MW/cm^2 ist eine Sättigung der Leistung der zweiten Harmonischen zu beobachten. Für den Planarwellenleiter ergibt sich eine Leistungsgrenze für die zweite Harmonische von ca. 1,2 W, wiederum verursacht durch die mit steigender NIR-Pumpleistung graduell auftretende Sättigung. Jedoch kann im Gegensatz zum Rippenwellenleiter in den planaren Wellenleitern keine deutliche Erhöhung der Ausbreitungsverluste festgestellt werden. Des Weiteren wird hier die maximale Intensität der zweiten Harmonischen zu einem Wert von 0,3 MW/cm^2 bestimmt, welcher im Vergleich zu der maximalen Intensität im Rippenwellenleiter um eine Größenordnung kleiner ist. Folglich ist die im Planarwellenleiter experimentell beobachtete Leistungsbegrenzung auf eine thermisch verursachte Störung der Quasi-Phasenanpassung zurückzuführen, die durch das für hohe Leistungen nicht geeignete Mantelmaterial des Wellenleiters verursacht wird. Höhere Ausgangsleistungen sind für optimierte planare Wellenleiterstrukturen zu erwarten.

Die erzeugte Strahlung im grünen Spektralbereich ist durch ein einmodiges Emissionsspektrum und durch eine nahezu beugungsbegrenzte Strahlqualität gekennzeichnet. Sie ist deswegen für die Anwendungen im Bereich der Biomedizin, Biotechnologie und Spektroskopie gut geeignet.

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