where $\Psi = \xi^2 - \zeta^2$ and $\phi = 2\zeta \xi$. Since, for a chiral material, there exists an extra complex parameter $\zeta$ in addition to the usual parameters ($\varepsilon$ and $\mu$) of conventional materials, electromagnetic properties of such a medium can be controlled and tailored with increased flexibility. From a mathematical point of view, one might anticipate the usefulness of chiral material for zero reflectivity by noting that extra degrees of freedom are available for impedance matching as compared to the achiral case. From a more physical viewpoint, we note that the chirality admittance fine-tunes the offset between the permeability and permittivity ratios which would be optimum for matching in conventional materials. Explicitly, $\xi$ and $\zeta$ can remove this difference in value between $\varepsilon'$ and $\mu'$, and $\varepsilon'$ and $\mu'$ inherent in today's materials, and consequently achieve perfect impedance matching. Because note that the above result is indeed used for the achiral case. However, we reiterate that these results come from the solution of the complete boundary-value problem displayed in Fig. 1, and that all of the chirality information and complexity has been embedded in the chirality impedance $\zeta$. Nowadays, conventional materials used for RCS reduction are composite materials that are in general lossy and anisotropic. The anisotropy poses problems in the design, manufacture, and application of such materials. In addition, the complex electromagnetic parameters of these materials may exhibit extreme frequency sensitivity. Chirosoft, owing to the above advantages, is a strong candidate for effective RCS management.

One way of making Chirosoft is by embedding randomly oriented identical chiral microstructures, such as microhelices, in an isotropic host medium. Geometric dimensions and density of the chiral microstructures will determine constitutive parameters ($\zeta$, $\xi$, $\mu$) of the chiral medium, and can be tailored to satisfy eqn. 4, as will be detailed in forthcoming papers.

In summary, we have introduced a novel synthetic material named Chirosoft which is invisible to electromagnetic energy and has properties which are independent of polarization in the backscatter direction. The introduction of electromagnetic chirality to the problem of RCS reduction has added extra flexibility through the chirality admittance $\zeta$. We have shown that by properly choosing the chirality admittance, one can achieve zero reflectivity.

D. L. JAGGARD
N. ENGHETA
Moore School of Electrical Engineering
University of Pennsylvania
Philadelphia, PA 19104, USA

References

SECOND-HARMONIC GENERATION OF GREEN LIGHT IN PERIODICALLY POLED PLANAR LITHIUM NIOBATE WAVEGUIDE

Indexing terms: Optics, Optical waveguides, Integrated optics, Nonlinear optics

A periodically poled, planar waveguide in lithium niobate was used to generate 532 nm radiation at room temperature by continuous-wave frequency-doubling with a conversion efficiency of 5% per W cm$^{-2}$. The quasi-phase-matching allowed generation of the second harmonic using the $d_{33}$ nonlinear coefficient.

Introduction: Frequency doubling in a lithium niobate optical waveguide is an attractive method for generating coherent visible radiation. To date, such devices have involved birefringent phase-matching, modal dispersion or the Cerenkov effect. An alternative method for compensating refractive index dispersion in nonlinear optical interactions is quasi-phase-matching (QPM). Periodic reversal of the sign of the nonlinear coefficient of the material at odd integer multiples of the coherence length prevents the accumulation of phase mismatch between the interacting waves. QPM can be used for nonlinear interactions which cannot be birefringently phase-matched owing to the material, wavelengths or nonlinear coefficients involved. In the present work, QPM enables the use of the $d_{33}$ coefficient for an interaction between $z$-polarized fields in lithium niobate. The use of $d_{33}$ is desirable because it is seven times larger than the $d_{43}$ coefficient used in birefringently phase-matched interactions. A periodic reversal of the nonlinear coefficient for quasi-phase-matched bulk interactions has been accomplished using stacks of oriented plates, rotationally twinned layers, periodically poled crystals, and more recently periodically poled single-crystal fibres. The prospect of a guided-wave device using QPM is attractive because it combines the flexibility of QPM with the efficiency of waveguide interactions. We report a technique for patterning the nonlinear coefficient at the surface of a lithium niobate substrate, and quasi-phase-matched frequency-doubling in a waveguide in such a substrate. The high conversion efficiency resulting from the use of the $d_{33}$ coefficient in a guided-wave geometry is demonstrated in a device fabricated with commonly used materials and processes.

Poling process: The signs of the nonlinear coefficients in lithium niobate are linked to the direction of the spontaneous ferroelectric polarization. Periodic reversal of the ferroelectric polarization in the crystal (periodic poling) thus periodically reverses the signs of the nonlinear coefficients. It is known that titanium diffusion into the +c face of a lithium niobate wafer causes ferroelectric domain reversal at the surface of the wafer. We employ this effect to create patterned domains at the surface of a lithium niobate substrate. Lithographic is used to pattern a Ti layer. A subsequent heat treatment in the 1000-1100°C range produces domain reversal in the patterned areas. We have produced domain patterns with periods ranging from 5 to 50 μm. Fig. 1 shows a periodic domain structure created by patterned Ti indiffusion.

Device technology: For the initial optical demonstration, the +c face of a 0.5 mm thick lithium niobate substrate was patterned with four Ti gratings, each about 1 mm long, with...
periods ranging from 15 to 22 μm. The gratings were comprised of Ti lines 4 μm wide and 5 nm thick. The grating periods were chosen so the resulting domains would be about three coherence lengths long for doubling 1.06 μm radiation. The gratings were arranged so that a light beam would traverse all four gratings before exiting. The heat treatment consisted of a 2 h ramp-up from room temperature to 1100°C, and a 30 min soak at 1100°C, after which the oven was turned off and allowed to cool to room temperature. The oven had an initial cooling rate of 8 K/min. To prevent oxidization of lithium oxide from the sample during the poling process, the substrate was placed in a closed alumina boat filled with congruent lithium niobate melt. After the heat treatment, we made a planar annealed proton-exchange waveguide in the substrate. This involved a 30 min soak in pure benzoic acid at 200°C followed by a 4 h anneal in flowing oxygen at 550°C. The resulting waveguide had a single TM mode at 1.06 μm.

Fig. 1 Periodic ferroelectric domains on c-face of lithium niobate wafer revealed by etching with HF acid
Period of pattern is 10 μm

Experiment: Input and output coupling was accomplished with rutile prisms. An 8 cm focal length cylindrical lens at the input focused the beam in the plane of the waveguide. With 1 mW of CW power at 1.06 μm measured at the output of the waveguide, we observed the generation of 0.5 nW of 532 nm radiation. Both the fundamental and harmonic waves had the proper polarization for operation using d21. The conversion efficiency of the device was about 5% per W cm2.

We modelled the waveguide as a step-index guide with a refractive index increase of 0.003. Estimating the depth of the waveguide to be in the range 4-7 μm, we calculated theoretical conversion efficiencies ranging from 7 to 10% per W cm2, in reasonable agreement with the experimental value. From these values we calculate that the observed second harmonic power is roughly 1500 times larger than what one would see if the interaction were not phase-matched.

We are pursuing techniques to improve the conversion efficiency of the device. Two orders of magnitude can be gained by increasing the grating size from 1 mm to 1 cm. A first-order grating offers a nine-fold increase in efficiency over that provided by the current third-order grating, and a further substantial improvement can be obtained with a channel rather than a planar waveguide. Scaling the observed conversion efficiency of 5% per W cm2 with these improvements implies that mW levels of second harmonic could be generated from tens of mW of input fundamental power. While we are currently working with 1.06 μm fundamental radiation, the application of this QPM technique to the doubling of diode lasers offers an attractive method for generating coherent blue light.

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REFERENCES


EXTREMELY NARROW LINEWIDTH (~1 MHz) AND HIGH-POWER DFB LASERS GROWN BY MOVPE

Indexing terms: Semiconductor lasers, Epitaxy

A suitable structure of narrow linewidth DFB laser is studied experimentally. By thinning the active layer to around 0.007 μm, controlling αL to 1 G, and improving the geometri
cal uniformity of active region, the linewidth less than 1 MHz is achieved at an output power of around 20 mW in 1.55 μm DFB lasers with 1.2 mm long cavity length.

Introduction: In coherent optical transmission systems, a narrow spectral linewidth DFB laser diode is indispensable. In particular, a narrow spectral linewidth oscillation at high

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