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Mobile full-color projection

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In search of the missing color

Just as mobile phones have steadily grown in performance and functionality while shrinking in size, their displays have undergone a similarly impressive development over the past decade. Throughout their evolution from monochrome displays to colour touch-screens covering the entire surface of a portable communication and entertainment device, display technologies have helped to define the user experience. Not only do they make it easier to use mobile phones, they are the prerequisite for added functions such as cameras, e-mail, navigation or the attractive display of web pages.

Now miniature laser projection technology is poised to open a new dimension in portable information display. Its advantages for compact mobile devices are compelling: the collimated light with its infinite depth of focus enables ultra-sharp images that are always in focus regardless of any surface irregularities or projection distance. The laser projector has no need for a focusing lens, allowing it to be integrated into thin portable devices.

Green light the technological challenge

Still, technological barriers stood in the way of designing miniaturized projectors capable of projecting the three primary colors of red, green and blue that are needed for the full-color display of images. While compact semiconductor laser sources are available for red and blue light, there are none that are yet capable of emitting green light.

Blue and red lasers are based on indium gallium nitride (InGaN) and indium gallium aluminum phosphide (InGaAlP), respectively. While work is ongoing in research labs to create green emitting diode lasers, the technology is far from achieving the required power or lifetime. Today, green lasers work with infrared laser light that is converted into green laser light. The conversion is done by a so-called nonlinear crystal. Yet, just such a laser product is what OSRAM Opto Semiconductors is currently developing. The search for the best nonlinear crystal able to produce a laser beam of the missing color green led to periodically poled lithium niobate (PPLN) technology.

In the laboratory and in highly specialized applications, PPLN crystals, as produced by Crystal Technology, Inc. (CTI), a subsidiary of EPCOS based in Palo Alto, California, have shown that they are able to convert high power infrared laser beams to other wavelengths. CTI as the world's leading supplier of lithium niobate wafers that are used for SAW filters in mobile phones, TV receivers and set-top boxes has developed highly efficient crystal growth processes to support those markets amounting to some 1.5 million wafers each year. Starting with the high quality lithium niobate, the researchers at CTI have also developed PPLN crystals used for difference frequency generation in high-resolution mid IR spectroscopy. The regular lithium niobate material however is not suitable for the production of green laser light.

MgO: PPLN chips generate green laser light

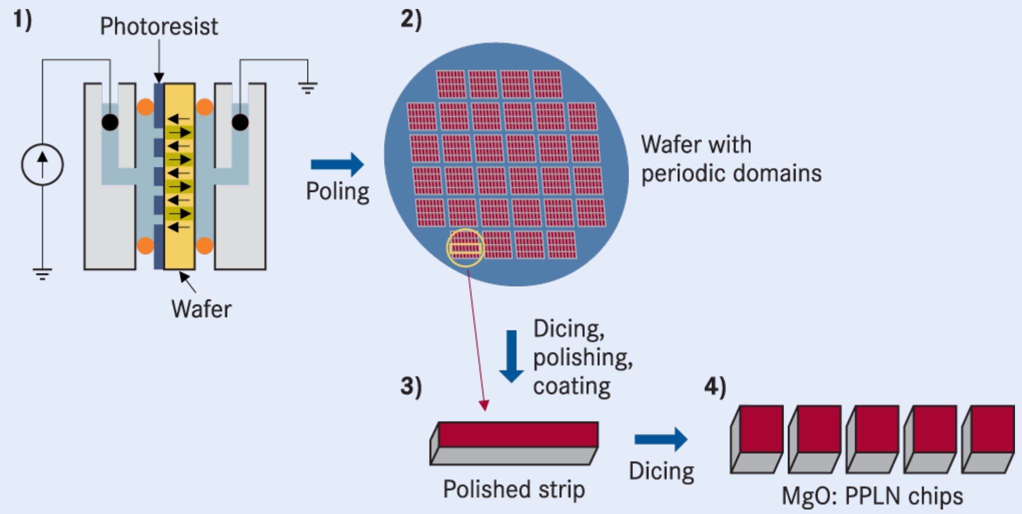
In order to generate green laser light conventional lithium niobate material is first doped with magnesium-oxide (MgO), which makes the material capable of handling high light intensities. CTI engineers employed a process that is known as periodic poling, which inverts the crystal polarization in alternating crystal domains of approximately 3.5 µm throughout the wafer thickness of 0.5 mm. Lithography is used to define the microstructure in the crystals. In one of several possible periodic poling methods, the resist acts as an insulator while a liquid electrolyte contacts the wafer surface at the places where the resist is removed. A strong electrical field is applied across the wafer thickness which creates domain reversals in the places of contact.

Once the field poling is completed the wafer is diced into strips that can be polished on two sides for the laser beam to pass through undistorted. The strips are anti-reflection coated to reduce light loss, and finally diced into individual chips (Fig. 1). After that they can be assembled into the laser module.

The result is a periodically poled lithium niobate crystal chip that is able to convert the near infrared wavelength of a single-mode laser at 1060 nm to a green laser at 530 nm. This doubling the frequency of the fundamental beam of laser light is also known as second harmonic generation (SHG), a process in which two photons of the incident wave combine to produce a photon having twice the energy or half the wavelength.

CTI masters the challenge of handling, processing and polishing the miniature parts that ultimately measure approximately 1 x 0.5 x 1 mm³. The performance of the chip depends not only on good domain pattern fidelity, but also on a good polish with no scratches or digs. “We are currently the only manufacturer worldwide that is able to offer the PPLN chips in quantities suitable for high-volume green laser applications,” explains Jon Fowler, head of CTI.

FIGURE 1: THE MAKING OF PPLN



After growing the magnesium oxide doped lithium niobate crystal, the wafers are periodically poled using a photolithographic process and high voltage application. The wafers are then diced and processed to obtain the finished MgO:PPLN chips.

Maximizing the efficiency of SHG

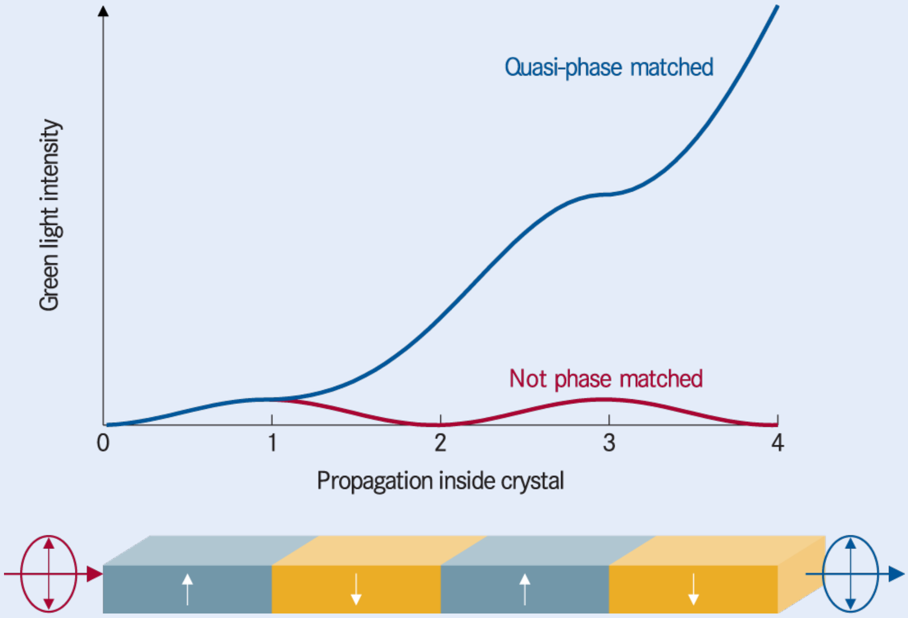
One of the challenges for CTI was to achieve the required efficiency. “SHG is notoriously inefficient. That’s why it is so important to choose the best crystal materials with the best nonlinearity,” notes Dieter Jundt, head of research and development at CTI. For a 10 mm long crystal 1 W of infrared input typically only yields about 40 mW. “That corresponds to a conversion efficiency of 4 percent,” says Jundt. “It is thus necessary to significantly enhance the light intensity in the crystal beyond what focusing can do.” One possible solution is to put the crystal into the laser cavity so that the intensity is increased by multiple bounces inside the cavity. With proper optical coatings and alignment, the enhancement of the basic infrared laser wave can result in several hundred times the laser diode intensity. This method also permits the use of bulk crystals and simplifies the alignment procedure after assembly. “Our unique cavity design provides excellent efficiency with highly stable and consistent output pulses. Our micro-assembly processes lead to an extremely small package,” notes Dr. Thomas Hoefer, director of laser projection at OSRAM Opto Semiconductors.

High efficiency with quasi-phase matching

Another challenge in reaching the best possible efficiency is to optimize the chip for the correct laser wavelength. “We employ a technique known as quasi-phase matching, in which high conversion efficiencies are obtained in a crystal by periodically varying the sign of the nonlinearity,” explains Jundt (Fig. 2). The precision and the aspect ratio of the periods determine the precision of the quasi-phase matching and thus the efficiency of the chip.

Here the two interacting waves, which propagate at different speeds, are essentially resynched at each domain reversal. “While this sounds challenging, semiconductor lithography with its high precision allows us to tailor the period to just what is required for the infrared semiconductor laser.”

FIGURE 2: QUASI-PHASE MATCHING

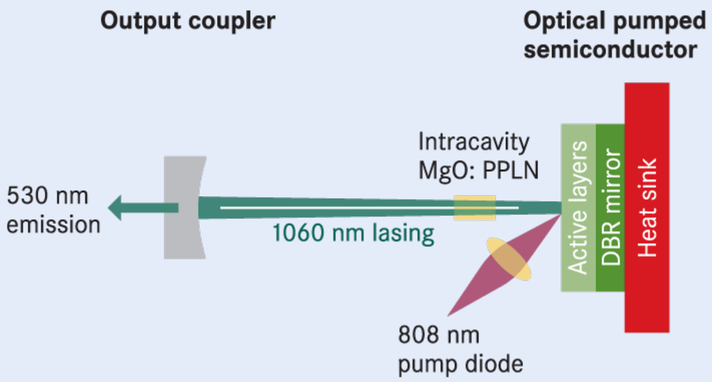


In quasi-phase matching, the incoming infrared laser beam is polarized such as to maximize the nonlinear response. In a uniform material where the velocities are not phase matched, the generated green light waxes and wanes in amplitude along the crystal direction because the various green contributions are out of phase. By periodically switching the domain orientation, all the contributions add up coherently resulting in efficient SHG.

Design of the green laser module

OSRAM's green laser module employs an 808 nm GaAlAs laser diode (pump diode). Together with an end mirror as output coupler, an optically pumped semiconductor disk laser (OPS) designed for an emission of 1060 nm forms the laser cavity. At the heart of the cavity setup is a miniature MgO:PPLN chip which converts the beam to the desired 530 nm output (Fig. 3). In order to reach maximum power output, the crystal must be kept at a certain temperature. For this purpose the chip is bonded to a thin-film resistance heater.

FIGURE 3: DESIGN OF LASER MODULE



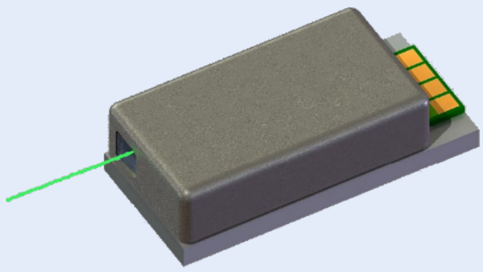
The MgO:PPLN chip is a key component in the cavity setup, converting the 1060 nm laser light emitted by the OPS to a wavelength of 530 nm. The 1060 nm laser light circulates as a standing wave within the cavity between the distributed Bragg reflector (DBR) and the output coupler, which allows only green laser light with a wavelength of 530 nm to exit the cavity.

With this technology a stable, efficient, and compact green laser (530 nm) is achieved with a nominal optical power output of 50 mW. It is suitable for applications that require superior beam quality, excellent stability, and high modulation speeds. The small package dimensions with a volume of less than 0.4 cm³ make it the laser light source of choice for miniature projectors in mobile devices (Fig. 4).

The laser exhibits a wide operating temperature from 10 to 60 °C without the need for active cooling. Direct power output modulation from zero to nominal output power can be performed by varying the amplitude of the electrical input with a bandwidth of at least 40 MHz for the pulse-width modulation.

"With our frequency-doubled optically pumped semiconductor green laser, we have developed an easy-to-integrate solution that is scalable with regard to output power and fits all requirements of the target application," points out Dr. Thomas Hoefer

FIGURE 4: LASER MODULE



The elegant module design with few parts enables a self-contained and compact green laser with a volume of less than 0.4 cm³.

CTI as partner for cutting-edge solutions

Based on its many years of experience with growth and electric field poling of lithium niobate crystals, CTI meets the requirements for a commercially viable MgO:PPLN component. These include the ability and competence to:

- source all the necessary raw materials reliably and in the quantities needed for volume production,
- grow lithium niobate crystals on a large scale,
- engineer the crystal composition to achieve good optical quality and consistency,
- periodically pole wafers on a commercial scale,
- handle and polish large volumes of miniature components precisely, and
- produce Mg:PPLN chips with high yields.

"CTI has been very supportive during the laser prototyping phase, and convinced us that they can successfully produce MgO:PPLN in the volumes we would need," summarizes Dr. Thomas Hoefer. Today, CTI offers two series of MgO:PPLN chips for green and blue lasers, both with and without dielectric anti-reflection (DAR) coating (Table).

With the successful demonstration of green lasers using MgO:PPLN crystals the door is open to new kinds of applications such as miniature projectors in mobile phones, notebook computers or other compact mobile devices as well as in head-up displays in vehicles, micro-displays in headsets, or intelligent displays in retail stores.

TABLE: PORTFOLIO OF MAGNESIUM DOPED PERIODICALLY POLED LITHIUM NIOBATE

Domain periods [µm]	Dimensions [mm³]	Order number
6.9 - 6.96 for 1064 nm doubling, no dielectric anti-reflection (DAR) coating, (DAR), d_{eff} > 14 pm/V	3 x 0.5 x 1 3 x 0.5 x 3 3 x 0.5 x 10	97-03040-01 97-03040-02 97-03040-03
6.9 - 6.96 for 1064 nm doubling, DAR, R < 0,25% at 1064 nm, R < 0.5% at 532 nm, d_{eff} > 14 pm/V	3 x 0.5 x 1 3 x 0.5 x 3 3 x 0.5 x 10	97-03038-01 97-03038-02 97-03038-03
5.22 - 5.27 for 976 nm doubling, no DAR coating, d_{eff} > 14 pm/V	3 x 0.5 x 1 3 x 0.5 x 3 3 x 05 x 10	97-03043-01 97-03043-02 97-03043-03
5.22 - 5.27 for 976 nm doubling, DAR, R < 0.25% at 976 nm, R < 0.5% at 488 nm, d_{eff} > 14 pm/V	3 x 0.5 x 1 3 x 0.5 x 3 3 x 0.5 x 10	97-03042-01 97-03042-02 97-03042-03