Nonlinear optical crystals for use in consumer laser projection displays

Dieter Jundt, Crystal Technology, Inc.
Outline

Motivation for laser projection

Basic components used in LP
  - Light generation
  - Scanning/Modulation

Green laser challenges
  - SHG approaches
  - MgO:LN – preferred choice
    - Growth
    - Characterization
## Consumer display applications

**TV**
- Rear projection illumination  
  - High pressure lamps ~3000 hours
- Flat Panel: Plasma, LCD

**Overhead projection**
- Home theatre
- Business

**Heads-up display**
- Automotive

**Pico projector**
- use with laptop, I-pod, cellphone
- To be integrated into phones

1-3W per color

20-50 mW per color

50 mW per color
Why do we care?

Lasers have low étendue – basically point sources
- Simple optics – no focussing necessary
  - Simplified imaging, compact system, lightweight
- Scaling to larger sizes fairly easy

Energy efficiency
- Little heat – Plasma TV 600W → Lasers 200W
- Longer battery life for portable devices

Increased color gamut
- Better at rendering yellows and purple
Consumer display - TV

Arasor
IPO ASX (Australia)
(since delisted)

Channel 9
Australian TV
October 2006

Purchased Novalux 2008
Various players

- **TI – others**
  - Pull out after SONY exits rear projection in 2007

- **Mitsubishi – LaserVue**
  - On sale since Fall 2008
  - $7000 for 65”
  - Where is 83” LaserVue?

- **Arasor/Novalux**
  - Failed to get traction

- **Collinear**
  - Goal was RGB engine <$300
  - Failed to overcome technical hurdles
  - Dissolved 2007
Color Gamut

- **Lasers**
- **CRT**
- **LCD**

- **Red**
- **Green**
- **Blue**
Consumer display - Pico projector

Portable

- Small
- Easy to use
- Video capability
- Low power consumption
- Bright, but safe (<50mW)
- Low cost (<$200, better <$100)

www.microvision.com/pico_projectorDisplays/
Consumer display - Pico projector

Early prototype: Symbol
Current leader: Microvision
Microvision pico-projector

SHOW WX uses laser light sources which are always in focus. So, when you decide to move your movie from wall to ceiling or enlarge your 12” image to 37” or 100”, you never need to re-focus the projector. Even on a curved surface, the image from SHOW WX is ALWAYS in focus.
Laser display product roll-out

Microvision

March 5, 2009--Microvision, Inc. (NASDAQ:MVIS), a leader in innovative ultra-miniature projection display technology, reports:

“…while it (Microvision) received delivery of next generation green lasers for its customer trial units in September, the green laser suppliers have experienced longer than expected development and commercialization cycles for this critical component which forced the company to delay its accessory product launch plans to mid-2009.”

Mitsubishi

“temporarily suspended production of LaserVue televisions due to a problem with manufacturing equipment used to produce LaserVue TVs.” Mid February - End of March 2009
Laser sources

Red

- Diodes ideal
  - Cheap, mass produced, available
  - Many power levels, wavelengths

Green

- No laser diode
- Need SHG approach

Blue

- GaN diode pioneered by Nichia
  - First demonstration in UV, deep blue
  - Blu-ray ~405nm
  - Eye has problem focusing – not optimal
- 460nm needed
  - Early versions had power, lifetime problems
  - Now available
# Blue laser available

![Nichia Laser Image](image)

The photo might not exactly be the same as the original.

## Marketed Products

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Peak Wavelength [nm]</th>
<th>Optical Output Power [mW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDV4313</td>
<td>400-410</td>
<td>120</td>
</tr>
<tr>
<td>NDHB510APA</td>
<td>440-450</td>
<td>50</td>
</tr>
</tbody>
</table>

## Engineering Sample

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Peak Wavelength [nm]</th>
<th>Optical Output Power [mW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDB7112E</td>
<td>440-455</td>
<td>500</td>
</tr>
</tbody>
</table>

Display system components - DLP

Scanning/Modulation
- 1080p: 24frames/s; 2.1Mpixels
- Grey shades: 8-16 bits

2-dimensional MEMS
- DLP (Texas Instruments)
- Standard for rear projection TV
- Pixel imaged onto screen
- No need for source modulation
- Color multiplexing on same chip wasteful
- LCOS (liquid crystal on silicon) alternate approach
Display system components - scanning

Scanning

- Picture painting: horizontal: fast – vertical: slow
- Grey shades – need laser modulation
- MEMS fast axis (or both)
  - Silicon light machines (now Sony)
    - Ribbons electrostatic actuation
  - Microvision
    - 2-axis single mirror MEMS
  - Symbol prototype
    - Cascaded MEMS

Modulation

- Need laser modulation
- DPSSL no good – Nd:YVO lifetime too long
- Thermal effects need to be managed
Use barcode scanner technology to generate 2D
Green light always on: Nd:YAG – KTP - external Acousto-optic modulation

Contains electronics, lasers, scanners

KTP doubled diode laser is externally modulated
SHG approaches for green

SHG utilizes nonlinear optical properties of crystals

- Laser beam at $\lambda=1\mu m \rightarrow 500nm$ green

SHG notoriously inefficient

- Highest nonlinearity (lithium niobate): $d_{\text{eff}}\sim 20\text{pm/V}$
- KTP: 18; LBO: 1; BiBO: 2pm/V
- Efficiency $\sim d_{\text{eff}}^2 \cdot L^2 \cdot I_\omega$
  - Focus – diffraction limits Intensity
  - 1cm long crystal, 1W input: output <40mW

SOLUTION: Intensity enhancement

- Waveguide
- Resonating 1µm light in cavity
SHG and speckle

Speckle caused by interference on screen

- Undesirable in images
- initial idea: Use broad spectrum laser
  - Easy in red, blue diodes
  - Problem: SHG in crystals requires narrow spectrum
    - DBR lasers typically used (narrow)

- Solution
  - Multiple green beams
  - Intra-cavity SHG of multi-mode IR
  - Adding post-generation blur (motion, phase-wiggle)
  - Solution very system dependent
DPSS SHG in waveguide - Mitsubishi

LaserVue green concept

Diode array 808nm

Planar laser waveguide, stress-induced guiding in x

Intracavity SHG in MgO:PPLN

>10W green 42% 808→532nm

Multi-mode; independent beams → no speckle

SHG in waveguide – (Corning)

DBR (DFB): well established, single mode

SHG: in waveguide

Challenge: stable alignment
  - Expensive procedure
  - better than 0.4um
  - T sensitivity
  → Active using PZT

MgO:PPLN waveguide processing

Polarization of laser is horizontal → Need Z-axis horizontal

- MgO:LN (Y-cut)
- Field poling by comb-electrode
- LN or LT sub.
- bonding to substrate
- thickness reduction
- ridge formation & end polish
- Dry etching
- grind and polish
- flip upside down
Optically pumped semiconductor disk laser

IR emission is converted to green by intracavity SHG
Doping and DBR layers determine wavelengths

530 nm emission

1060 nm lasing

808 nm pump diode

intracavity MgO:PPLN

active layers

DBR mirror

Heat Sink

Courtesy of: PhAST 2008 | 06.05.2008 | OS IR LP | M.Kühnelt

Opto Semiconductors

OSRAM

Dieter Jundt, Crystal Technology, Inc.
OPS form factor

- Optically pumped semiconductor laser 1060 nm
- SHG in MgO:PPLN
- Packaged green laser
  12 x 6.5 x 3.5 mm³ < 0.3 cm³
OPS modulation speed

- direct amplitude modulation of pump laser
- biased to threshold for fastest response
- Driver limited rise/fall time of 10ns
Electrically pumped VCSEL

VCSEL – vertical cavity surface emitting laser

- Necsel™: Arasor (Novalux)
- Electrically pumped
- Extended cavity with MgO:PPLN
- Large mode size
  - Low diffraction output
  - Needs high resonating power
    - Low losses required
    - Volume bragg grating demanding
    - PPLN crystal size larger per mW

Power scaling: arrays
Reduces speckle
Lithium niobate (LN) crystals

Congruent LN – 1M 100mmØ wafers/year (50T of crystal) – SAW application

MgO:LN
Few 100kg/year
Optical applications
Czochralski Crystal growth

Growth from the melt
Automatic diameter control by adjusting heating power
Oriented seed defines growth axis
Growth rate ~ 1-5mm/hour

Thermal field engineering important to minimize strain to achieve optical quality
Czochralski Crystal growth
Wafer fab - Cylindrical shaping

Crystal shaping
- Diamond tools
- End cropping
- Outside-Diameter grinding

X-ray oriented flat grinding
Wafer fab – Slicing and edge rounding

- I.D. saw
  - X-ray oriented wafer face

- Wafer edge rounding
  - Resilience to cracking

Ø100.33 -> 100mm
Wafer fab - Lapping & polishing

- Removes saw marks
- Improves flatness

- CMP (colloidal silica)
- Single-side or double-side

Wafers being unloaded after lapping

Single-side polishing
Photorefractive Effect (PRE)

Photo-ionization from Fe$^{2+}$ (bulk photovoltaic effect)

Space-charge field

Electro-optic effect

Beam distortion

Original beam

PRE damage
Magnesium-doped LN

Resistant to PRE

- Reduce deep traps (Anti-sites Nb\textsubscript{Li})
- Increased conductivity $\rightarrow$ space-charge fields short out

3-component system - Li\textsubscript{2}O – Nb\textsubscript{2}O\textsubscript{5} – MgO

- More complex phase-diagram than CLN
  - No congruency point
    - Smaller crystals
    - Slower growth
    - Changing composition along growth axis
      - Varying properties from crystal to crystal

$\rightarrow$ need good characterization tools
MgO:LN growth – melt composition

26 crystals grown from different melts
Above threshold: No PRE effect
MgO:LN – PRE sensitivity

- OH peak good proxy for PRE
  - CLN – “unshifted peak”
  - Above threshold: shifted peak
    - No unshifted peak
    - No anti-site defects
    - No PRE effect

- Melt composition changes during growth
  - MgO decreases
  - Li$_2$O increases
  - unshifted $\rightarrow$ shifted
MgO:LN – characterization

Melt composition ↔ crystal composition → crystal properties

want know inverse relationship

Need method to accurately measure crystal composition

Chemical analytical methods not accurate enough

Optical methods

- Phase-matching temperature
  - ~110°C for birefringent SHG of 1064nm

- UV absorption edge
MgO:LN – phase-matching temperature

- $T_{pm}$ measurements along the crystal axis
- In region of interest: $T_{pm}$ increases
- Very sensitive measurement
  - Can see small variations in composition
  - for very high doping, $T_{pm}$ decreases (7.14 % MgO)
- Above threshold: High MgO $\rightarrow$ low $T_{pm}$
  - BUT
    - need second measurement to get info on both MgO and Li$_2$O
MgO:LN – UV Edge

- MgO = 5.1mol% all starting melts
- UV Edge shifts deeper as growth proceeds
- Extrapolation to 0 gives crystal property of known melt
- Very temperature sensitive
  - 0.15 nm/K
  - Need to stabilize or correct for drift
- Work still in progress
MgO:LN – variability

Birefringent PM
6K window

QPM in PPLN
3K window
Good enough
MgO:PPLN chips for green SHG

Patterned side (original +Z)

Opposite side (original –Z) 0.5mm thick

SHG intensity (relative units)

Temperature (°C)

6.96 µm  6.93 µm  6.90 µm

Standard lengths: 1, 3, 10mm
AR coatings available
Thank you for your attention

MgO Doped Lithium Niobate

MgO PPLN material has successfully been used to generate green and blue laser beams with good efficiency. Crystal Technology produces a range of such crystals where all the critical manufacturing steps are performed in house. Our growth method is well developed and geared to high volume production thus lowering manufacturing cost and allowing our crystals to be deployed into mass market application such as laser projection displays and other consumer applications. The purity of starting powders and the crystal growth parameters are tightly controlled to ensure consistent quality guaranteeing stable optical properties. Our research has resulted in crystal growth that is guaranteed to avoid photorefractive damage yielding devices with well controlled refractive index and birefringence.

The standard MgO:PPLN parts have 3 periodicities on a chip to allow the user to optimize operating temperature for the device. Both anti-reflection coated as well as uncoated chips are available in three lengths, 1mm, 3mm and 10mm to support both short and long pulsed sources at various power levels. Custom designs are also available.