Fiber-Integrated Second Harmonic Generation Modules for Visible and Near-Visible Picosecond Pulse Generation

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Acknowledgments

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Overview of Presentation

- Motivation
- PPLN capabilities
- 780 nm fiber to fiber frequency doubling unit
- Four Wave Mixing (FWM) in crystal fiber
- 560 nm frequency doubling unit
- Future Outlook
- Summary
Motivation - G&H Optical Technology

3 UK Facilities:
- Ilminster (AO & Precision Optics)
- Torquay (FO)
- Glenrothes (PO)

5 US Facilities:
- Cleveland (EO, NLO, Crystal Growth)
- Palo Alto (AO & NLO)
- Boston (FO)
- Moorpark (Precision Optics)
- Orlando (Light Measurement & Imaging Systems)
Motivation - Commercialization of NLO Material

G&H KDP Crystals

G&H Lithium Niobate Crystals

FIBER LASERS
PPLN Capabilities

- Lithium niobate crystal growth
  - High temperature growth
  - Growth stations designed in-house
  - Highly automated & high yield

- Lithium niobate wafer production
  - Wafers polished from congruent LN (CLN)
  - Lapping & polishing

- Periodically poled material
  - Crystals of CLN, MgO:LN can be lithographically patterned and processed to induce desired domain inversions

- Sophisticated NLO model (developed by Bob Eckardt)
PPLN Optical Material

- Efficient conversion of laser wavelengths - wide range of configurations
  - Flexibility – great for laboratory

- P PLL is arguably the most highly developed optical nonlinear material offering capability of high volume, low cost manufacturing

- PPLN has long history but poor commercial success

- Small available aperture often cited as greatest drawback
  - Practical difficulties
  - Power level constraints

OSRAM green laser
780 nm PPLN Frequency Doubling Unit

- Several applications require this wavelength with specific characteristics making PPLN a suitable option at this wavelength

- Depletion source for STED microscopy
  - Relatively low peak power pulses of several hundred picoseconds required
  - Beam quality extremely important

- Cooling rubidium atoms
  - CW light at the Watt level

- Choice of laser sources limited
  - Ti:Sapphire lasers complex and expensive
  - Not suitable for direct diode

- Fiber lasers and amplifiers are robust and cost effective, but do not lase directly and efficiently in the visible (or near visible)

Develop robust fiber coupled SHG module that can simply be spliced onto fiber laser source
Fiber Coupled SHG Module Platform

- Single pass frequency conversion in PPLN
- TEC control to maintain PPLN crystal temperature and baseplate for stability
- Configurable for fiber-to-fiber and fiber-to-free space
- Choice of fiber output position
- Options to place additional components e.g. filters, PDs
Fiber to Fiber 780nm SHG Module

- Small footprint (120 X 40 X 26.5 mm)
- Leveraging robust fiber alignment technology
- Simple to integrate with commercial fiber amplifiers and lasers

- PPLN crystal 35mm long
- Poling period 19.48 µm
- Phase matching temperature ~70°C
- Input fiber – Nufern PM1550-XP
- Output fiber – Nufern PM780-HP
1560 nm Pulsed Laser Source

- 1560 nm master oscillator power fiber amplifier
  - 15.6 W average output power
  - 430 ps pulse width
  - 50 MHz repetition rate
  - <0.01 nm linewidth (measurement resolution limited)

- 780 nm required for STED microscopy of defects in diamond
780nm SHG Module Output

- Fiber coupled 780 nm output after SHG module
  - 3.5 W average output power
  - 150 W peak power
  - 410 ps pulse duration
  - 50 MHz repetition rate
  - <0.1 nm linewidth
- SHG conversion efficiency of 22%
- Polarization extinction ratio >15 dB
- SHG FWHM temperature bandwidth ~1.7°C
Four Wave Mixing in Crystal Fibre

- Full fiber system
- Up to 100 mW, 662 nm, 668 nm
- Pulse duration, ~200 ps

- System designed as STED illumination source
1120nm Pulsed Laser for 560 nm SHG

- 560 nm required for STED microscopy of green fluorescent protein (GFP)
  - 1120 nm Raman fiber amplifier
  - 1.8 W average output power
  - 197 ps pulse width
  - 47.5 MHz repetition rate
  - 0.29 nm linewidth (OSA resolution limited)
- SHG module
  - PPLN crystal 15 mm long
  - Poling period 8.06 µm
  - Phase matching temperature ~75°
  - Input fiber – Nufern PM980-XP
- Configured for a free space output with a beam waist ~1 mm
560 nm SHG Module Output

- 560 nm SHG output
  - 450 mW average output power
  - 150 ps pulse duration
  - 47.5 MHz repetition rate
  - 0.1 nm linewidth

- SHG conversion efficiency of 25%

- Linewidth reduction due to phase matching bandwidth of PPLN crystal

- Beam quality of output $M^2 < 1.1$
Future Work

- Continue to develop platform – 30 units built so far
- Run product through validation program
- Develop 780 nm source for atomic cooling

DFB  
EDFA  
Fibre-Q  
FC-PPLN  
PM Coupler Module  
Collimators
Conclusion

- A robust fiber coupled frequency doubling module platform has been developed.

- This module has been built and tested with two picosecond pulsed fiber amplifier systems to produce sources suitable for bio-photonic imaging.

- A 780nm pulsed source with a PM fiber output suitable for use as a depletion beam in STED microscopy of defects in diamond.
  - Additionally used to generate wavelengths of 662nm & 668nm through FWM.

- A 560nm pulsed source with a free space output suitable for use as a depletion beam in STED microscopy of fluorescent green protein.

- Platform has also been used for CW SHG to generate 780 nm.
Thank You

- Further information on 780nm source – come to G&H booth