Reliable Versatile Low Noise Laser
Empowering Sensing Technologies

Lew Stolpner

Redfern Integrated Optics Inc. Santa Clara, CA 95054, USA
Outline

- Laser source requirements for Coherent Doppler Sensing and other metrology applications
- Planar External Cavity PLANEX technology
- PLANEX laser key performance
- Stability and Reliability
- RIO laser product portfolio
- RIO subsystem integration capabilities
Optical Sensing and Metrology

Applications

Sensing Technologies

Lasers
- Low Noise
- Narrow Linewidth

Brillouin
- DTSS
- BOTDA/R

C-OTDR

Photonic Doppler
- Velocimetry/Vibrometry

Coherent Rayleigh

Interferometric

Military/Security
- Perimeter intrusion detection
- Navy acoustic detection

Oil & Gas
- Seismic Reservoir Monitoring
- Down well and SAGD
- Pipeline Intrusion and Leakage Detection

Avionics/Space
- LIDAR
- RFOG

Wind Metrology
- Wind energy
- Air traffic control

Structural Monitoring
- Static strain detection
- Dynamic strain/vibration detection

Military/Industrial/R&D

Lasers

Military/Security

PDV workshop June 2014
Lasers for Sensing: Key Requirements

- Challenges for optical sensing market laser business
  - Market size is relatively small
  - Requirements vary significantly for various sensing technologies
  - Critical to make versatile laser source suitable for multiple applications

- Performance
  - 1550 nm wavelength range to utilize availability of Telco solutions
  - Low Phase/ Frequency Noise, Narrow linewidth, low RIN

- Features
  - Small size, suitable for large multi-laser system integration
  - Frequency modulation and wavelength tunability

- Field deployable
  - Stability in harsh environmental conditions
  - Reliability qualification to industry standards (Telcordia, MIL, Space)
## Lasers for Coherent Optical Detection Technology

**Methods of Coherent Optical Heterodyne Detection**

- Photonic Doppler Velocimetry (PDV)
- Coherent Laser Vibrometry
- Coherent Doppler CW LIDAR
- Optical Frequency Synthesis
- Optical Phase Lock Loop, OPLL
- R&D Heterodyne Metrology

**Requirements for Single-Frequency Narrow-Linewidth Lasers**

- Wavelength and power stability, over time
- Wavelength and power stability, on/off
- High frequency stability, $\mu$sec/msec
- High polarization stability
- Low coherent excess noise
- Low $M^2$ factor for high coherent efficiency
- Low RIN and High RIN stability

- Market size for PDV lasers is relatively small and growing slowly
- Only versatile COTS lasers can service PDV applications without costly custom development
Planar External Cavity Laser Technology
PLANEX™

- PLC with Bragg grating on silicon wafers
- Gain: optimized InP MQW chip
- Packaging: 14-pin butterfly package, proven processes and materials
PLANEX™ Performance: RIN – shot noise limited up to 5 GHz

- High frequencies of relaxation oscillations
  - Electron – Photon resonance
  - Photon-photon resonance (cavity round-trip)
- RIN
  - < −140 dB/Hz at frequency > 2 kHz.
  - Shot noise limited up to 5 GHz
PLANEX™ Performance: Laser Phase Noise

Phase Noise Comparison

- RIO PLANEX
- FL-O
- FL-K

Phase Noise (urad/sqrt(Hz)-m)
Frequency (Hz)
Both measurement and spectral integration match well down to -40 dB level on Linewidth (LW) spectrum. (LW ~ 2.7 kHz @ -20 dB)

When only white noise level is integrated, SI provides pure Lorentzian LW ~ 1.2 kHz.
PLANEX™ Performance: Excess Noise – Linewidth interpretation

- Numerical value of Lorentzian linewidth does not provide all key information, critical for many applications.

- Central portion of spectrum leads to very narrow LW estimate (~ 850 Hz), but spectrum has very wide and elevated tail of the spectrum.

- Excess noise is very high: >10 dB (at f > 5 MHz) corresponding to pure LW >30 kHz.

- Excess noise for ORION laser with Lorentzian linewidth of 1.6 kHz is < 0.2 dB.
PLANEX™ Wavelength Stability and Tunability

PLANEX wavelength setting and tuning

- Sensitivity to cavity temperature \( \sim 12.5 \text{ pm/}^\circ\text{C} \) (1.5 GHz/\(^\circ\text{C})
- Sensitivity to bias current 0.2 - 0.3 pm/mA (25-40 MHz/mA)
- Small cavity with fast stabilizations time
- Phase continuous temperature tuning range ± 30 pm (± 4GHz)
- Fast wavelength tuning via bias current up to 4 pm (500 MHz)

Comparing with DFB Semiconductor Lasers

- 5-10x better wavelength stability vs. cavity temperature and current
- Allows precise wavelength setting
- Immune to the instability of electronics

Comparing with Fiber Lasers

- No mechanical stretch on the cavity
- No piezo tuning: no hysteresis and resonances
- Allows fast wavelength stabilization and excellent on/off repeatability
**PLANEX™ Frequency Stability**

<table>
<thead>
<tr>
<th>Measurement Time</th>
<th>Frequency stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 msec</td>
<td>150 kHz p-p</td>
</tr>
<tr>
<td>30 sec</td>
<td>1.5 MHz p-p</td>
</tr>
<tr>
<td>1 hour</td>
<td>4 MHz p-p</td>
</tr>
<tr>
<td>12 hours</td>
<td>20 MHz p-p</td>
</tr>
</tbody>
</table>
PLANEX™ Performance: Freq. Stability – Allan Deviation

- Free-running.
- Case temperature stabilized: <0.2°C over 3 h
PLANEX™ Performance:
Wavelength turn off/on repeatability

- Virtually no warm-up time required (< 1 min. for ORION module)
- Excellent wavelength and power repeatability over repeated power ON/OFF

<table>
<thead>
<tr>
<th>Wavelength Repeatability *</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Δ ~ 1 pm</strong></td>
</tr>
<tr>
<td>(limited by wavemeter diff. accuracy: +/- 3pm)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Power Repeatability *</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Δ ~ 0.01 dB</strong></td>
</tr>
<tr>
<td>(limited by wavemeter diff. accuracy: +/- 0.2 dB)</td>
</tr>
</tbody>
</table>

* Measured 1 min. after power ON for each trial.
PLANEX™ Performance: Long-term wavelength and power stability

- ORION laser is stabilized in thermal chamber
- ORION case reaches near const. case temp. after 30 min. of power-up

- Pk-Pk wavelength change over 3 days: 0.6 pm
  (NOTE: measured with Agilent 86122A WM, WL differential accuracy: +/- 0.4 pm)

- Pk-Pk output power change over 3 days: 0.19 mW
  (NOTE: measured with Agilent 86122A WM, P calibration accuracy: +/- 0.5 dB)
PLANEX™/ORION

Wavelength Tuning and Direct FM

- Tuning TEC Temperature and Bias Current
  - Slow thermal tuning up to +/- 30 pm (+/- 4 GHz)
  - Fast direct frequency modulation efficiency
    - CW: 100 MHz/V ORION, ~ 50 MHz/mA PLANEX
    - 10 kHz: 50 MHz/V ORION, ~ 25 MHz/mA PLANEX
    - DM BW > 200 MHz

![Diagram of ORION DM Modulation]

![Graph showing WL tuning, Delta Phase Noise, and FM sensitivity vs Frequency]
Direct Modulation/Pulsing of PLANEX™ laser

- PLANEX laser modulation bandwidth > 1 GHz
- 25 Ohms impedance input
- Unique direct modulation/pulsing while maintaining narrow linewidth performance
- Minimal pulse shape distortion

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulse Width</td>
<td>&gt; 5 nsec</td>
</tr>
<tr>
<td>Pulse Repetition Frequency</td>
<td>up to 10 MHz</td>
</tr>
<tr>
<td>Extinction Ratio</td>
<td>25-32 dB</td>
</tr>
<tr>
<td>Linewidth</td>
<td>&lt; 15 kHz at pulse plateau</td>
</tr>
<tr>
<td>Pulse shape distortion</td>
<td>Minimum or none</td>
</tr>
<tr>
<td>RMS Jitter</td>
<td>150 ps max</td>
</tr>
</tbody>
</table>
Frequency noise spectrum of the PLANEX laser with (blue) and without (red) frequency stabilization.

Within the control bandwidth of ~60 Hz, the noise was suppressed by a factor up to ~1000.

PLANEX™: Exceptional Reliability

- Telcordia qualified
- Space qualified
  - Defined by NASA as “Game changing laser” for unique combination of high performance and outstanding reliability for space applications
  - Selected by ESA and NASA for several space programs: PROBA-3, GRACE FO, LISA and successfully completed Phase 1 of qualification testing
- Reliability testing for space qualification
  - Environmental stress far exceeding Telcordia and MIL requirements
  - Tested production PLANEX units without special builds/selection/screening
  - Minimal changes after 1000 operating temperature cycles in vacuum and over 500 severe non-operational temperature cycles
RIO Product Offering

- **Wavelength**
  - 1550nm ITU DWDM, 1064nm or custom wavelength
- **4 Grades of linewidth (1550nm only)**
- **PMF & SMF options**

**PLANEX™ and ORION™**
- > 10 mW
- > 20 mW

**RIO Grande**
- >0.2 W
- >1.0 W
- > 2.0 W

- **RIO COLORADO**
  - Wide tunable

**Optical Phase Locked Loop (OPLL)**

<table>
<thead>
<tr>
<th>Linewidth , kHz</th>
<th>Grade 1</th>
<th>Grade 3</th>
<th>Grade 4</th>
<th>Grade 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;15</td>
<td>&lt;5</td>
<td>&lt;2</td>
<td>&lt;1</td>
<td></td>
</tr>
</tbody>
</table>
## ORION Laser Modules

### Features

- Low noise current source and TEC controller
- Input for direct modulation and wavelength tuning
- OEM Module with SPI, RS-232 and RS-485 interface options, GUI
- Benchtop OEM Source with USB interface options, GUI

<table>
<thead>
<tr>
<th>Specification</th>
<th>Specification Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage Temp, °C</td>
<td>-40 to +85</td>
</tr>
<tr>
<td>Size, mm</td>
<td>100x56x13</td>
</tr>
<tr>
<td>Operational Temp Range, °C</td>
<td>0-70</td>
</tr>
<tr>
<td>Power supply</td>
<td>5 V</td>
</tr>
<tr>
<td>Power Dissipation,</td>
<td>&lt; 6 W</td>
</tr>
<tr>
<td>@ 35 C case temperature</td>
<td>&lt;3 W</td>
</tr>
<tr>
<td>@ 50 C case temperature</td>
<td>&lt;4 W</td>
</tr>
</tbody>
</table>
RIO GRANDE: Amplified High Power Modules

- Nominal power 0.2 W up to 2 W
- Power set range 10-100%
- Low phase noise
- Ultra low RIN
- Narrow linewidth
- High OSNR
RIO COLORADO Widely Tunable Laser

- **Performance Highlights**
  - Low frequency noise
  - Low RIN
  - Available for C or L spectral bands
  - Cost effective solution
  - Convenience: GUI, integration

- **High Wavelength Stability (HWS) Mode**
  - Narrow linewidth <100 kHz
  - Optical Power Adjustment from 5 to 25 mW
  - Continuous Wavelength Sweep: 24 GHz peak-peak or +/- 12 GHz max
  - Amplitude Modulation to 1MHz, M up to 10%

- **Ultra-Narrow Linewidth (UNL) Mode**
  - Ultra narrow linewidth ~ 25 kHz
  - Fixed wavelength and optical power
  - Frequency Modulation is available

---

![Performance Highlights Graph](image-url)
Multi-Wavelength/Multi Functional Subsystem Integration

- Building Blocks: RIO OEM modules
  - PLANEX: high performance laser core
  - ORION: PLANEX + low noise driver and controller
  - GRANDE MOPA: ORION + optimized amplifier

- Integration options
  - Scale up multichannel (DWDM) sources 19” rack mountable
  - Custom designed and build
  - Added functionality, enhanced performance and features - OPLL
OPLL - Dual Laser Source

- OPLL for distributed sensing and coherent metrology applications:
  - Distributed Brillouin Fiber Optic Sensing (BOTDA/BOTDR)
  - Heterodyne/Coherent Metrology
## OPLL Key Performance Specs and Features

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>CW power</td>
<td>&gt; 5 mW</td>
<td>average, two PM optical outputs</td>
</tr>
<tr>
<td>Laser frequency noise</td>
<td>$10^3$ Hz/$\sqrt{\text{Hz}}$ @ 100 Hz</td>
<td>under locking conditions:</td>
</tr>
<tr>
<td>Linewidth</td>
<td>&lt;10 kHz</td>
<td></td>
</tr>
<tr>
<td>Linewidth</td>
<td>&lt;10 kHz</td>
<td></td>
</tr>
<tr>
<td>Phase noise</td>
<td>-65 dB/Hz</td>
<td>at 100 kHz offset</td>
</tr>
<tr>
<td>Frequency offset</td>
<td>From 0 to 14 GHz</td>
<td>step tuning</td>
</tr>
<tr>
<td>Tuning resolution</td>
<td>10 kHz</td>
<td></td>
</tr>
<tr>
<td>Continuous sweep tuning</td>
<td>over 1 GHz</td>
<td>resolution 10 kHz @ 50 $\mu$sec speed</td>
</tr>
<tr>
<td>Locked step response time</td>
<td>5 $\mu$sec</td>
<td>at 10 MHz step</td>
</tr>
</tbody>
</table>

![Frequency Noise of locked Pump and Probe Lasers at Frequency Offset 11 GHz](image1)
![OPLL Pump/Probe Lorentzian Linewidth 7.5 kHz](image2)
![Graphical data visualization](image3)
Summary

- RIO PLANEX laser technology and products:
  - semiconductor single frequency coherent versatile lasers

- Unique combination of:
  - High performance
  - Wide set of features
  - Unsurpassed stability and reliability
  - Small form factor and sophisticated control/GUI, user friendly and low maintenance

- Portfolio of integrated products and custom solutions

- Widely accepted for multiple optical coherent Doppler sensing and other metrology applications

- Widely accepted as an optimal laser source for PDV

We are open for product improvement and sub-system integration:
  - please provide us with your wish list.
Thank you.