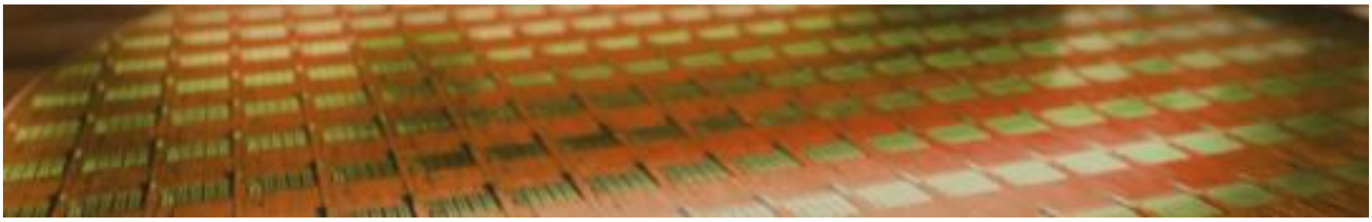

DEMONSTRATION OF AN ULTRA-LOW NOISE, HIGH-POWER LASER SYSTEM AT 532 NM WITH 80 W OPTICAL POWER

We present an advanced ultra-low noise, high-power laser demonstrator delivering 80 W of optical output at 532 nm. The system achieves RIN noise levels below 0.02 % rms in the frequency range of 10 Hz to 10 MHz, owing to its precision-engineered components and proprietary noise suppression technologies. The system comprises a DL pro seed laser with extremely low frequency-noise density (FND), a high-performance fiber amplifier providing up to 130 W output power at 1064 nm, and a resonant frequency-doubling stage for efficient conversion to 532 nm. Applications of this technology include the pumping of titanium-sapphire lasers and advanced semiconductor inspection systems, where stability and noise suppression as well as high power levels are paramount.

INTRODUCTION

The demand for high-power, low-noise laser systems at 532 nm continues to grow, driven by applications in advanced research and industry. Titanium-sapphire laser pumping and cutting-edge semiconductor inspection systems require precise and stable light sources. Currently available systems (DPSS or fiber-amplified lasers) often struggle to achieve the necessary balance between high performance and low noise. With acceptable noise levels, they can only reach power levels in the 20-30 W range, and at higher power levels, the required noise performance cannot be achieved.

This white paper details the design and performance of a 532 nm laser system optimized for such applications, leveraging innovative technologies to achieve an unprecedented combination of high power and low-noise performance.

SYSTEM ARCHITECTURE

The ultra-low noise, high-power 532 nm technology demonstrator comprises three main stages:

- **Seed Laser:**
  A narrow-linewidth external-cavity diode laser in Littrow configuration (DL pro) operating at 1064 nm serves as the seed source. This laser is characterized by its exceptionally low frequency noise density (FND), a crucial factor for achieving low overall system noise.

- **Fiber Amplifier:**
  A high-power fiber amplifier boosts the seed laser output up to 130 W at 1064 nm. The amplifier is designed to minimize the introduction of additional noise, preserving the excellent noise characteristics of the seed laser.

- **Resonant Frequency Doubling Stage:**
  A resonant-cavity frequency doubler converts the 1064 nm radiation to 532 nm with high conversion efficiency. This stage has been refined over many years and is a key component in TOPTICA's established DL/TA -SHG pro and DL/TA -FHG pro products.

While all three stages on their own have proven their reliability in TOPTICA's product portfolio, the combination of the three demonstrates their high performance and great benefits for users with high power requirements who cannot do without very low-noise operation at the same time.

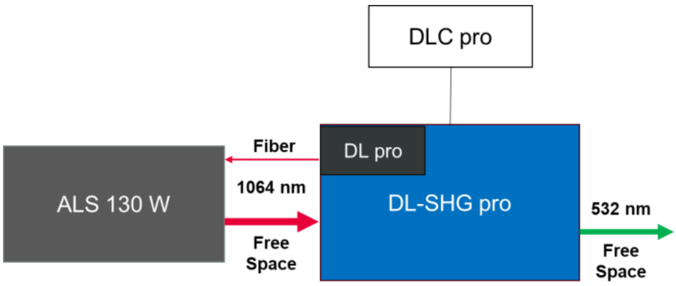

Fig. 1: Simplified schematic of the technical demonstrator setup

Seed laser and the doubling stage form the integrated DL-SHG pro system, which is controlled by TOPTICA's digital laser controller DLC pro. The DLC pro also regulates the fiber amplifier via an external control line. Fig. 1 shows a schematic of the technical demonstrator setup consisting of the DL-SHG pro (Seed Laser DL pro + Resonant Doubling Cavity SHG pro), Fiber Amplifier, and DLC pro controller. Both the fiber amplifier and the DL-SHG pro laser head are water-cooled using a close-loop chiller.

KEY COMPONENTS AND DESIGN CONSIDERATIONS

Seed Laser: DL pro

Ultra-low frequency noise operation is paramount to ensure lowest possible amplitude noise after the final frequency-doubling stage.
Two narrow-linewidth semiconductor laser systems were tested and compared to identify the best available option as seed laser for the technical demonstrator setup. As a result, the DL pro clearly outperforms the alternatively tested seed laser option, (a commercially available, narrow-linewidth laser module), both in terms of intrinsic linewidth and with a significantly lower RIN.

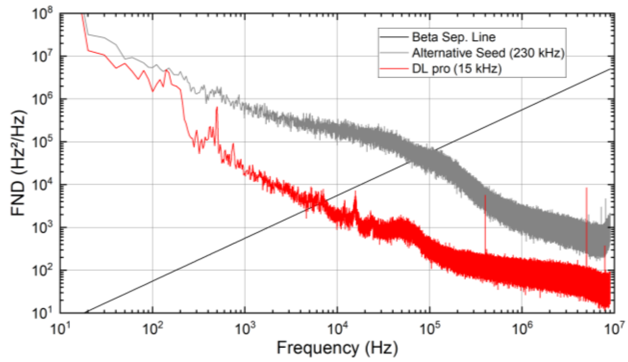

Fig. 2: Frequency-noise density of DL pro system and alternatively tested seed laser

The intrinsic linewidth was derived from the frequency noise density measurement (Fig. 2) via the beta separation-line method to 15 kHz for the DL pro and 230 kHz for the alternative seed laser. A comparison of the RIN measurement (Fig. 3) resulted in a 0.0024 % vs. 0.01 % rms (10 Hz -10 MHz) advantage for the DL pro.

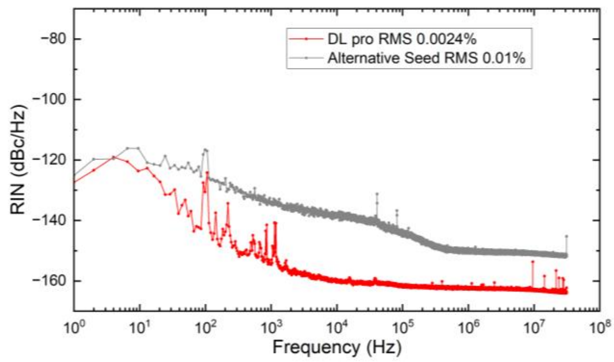

Fig. 3: Comparison of RIN for the two evaluated seed lasers

Based on these results, the DL pro was selected to be the seed laser at the core of our demonstrator system, providing a stable and reliable foundation for subsequent amplification and frequency doubling stages. It was set to operate at 1064 nm with a power output of about 80 mW. The master laser output passes a double-stage optical isolator (60 dB) and is subsequently coupled into a SM-PM fiber. The fiber connection allows for convenient transfer of the seed laser light to the fiber amplifier.

Fiber Amplifier: ALS-1064-130

TOPTICA's fiber amplifier ALS-1064-130 boosts the 1064 nm signal emitted from the seed laser to an output power of up to 130 W. The two-stage amplification scheme incorporates advanced design strategies to minimize noise amplification, ensuring that the high-quality signal from the seed laser is preserved. Proprietary noise-suppression technologies further reduce amplified spontaneous emission (ASE) and other noise contributions, maintaining the integrity of the signal for frequency doubling. Fig. 4 and the derived RMS data demonstrate the excellent noise performance of the fiber amplifier.

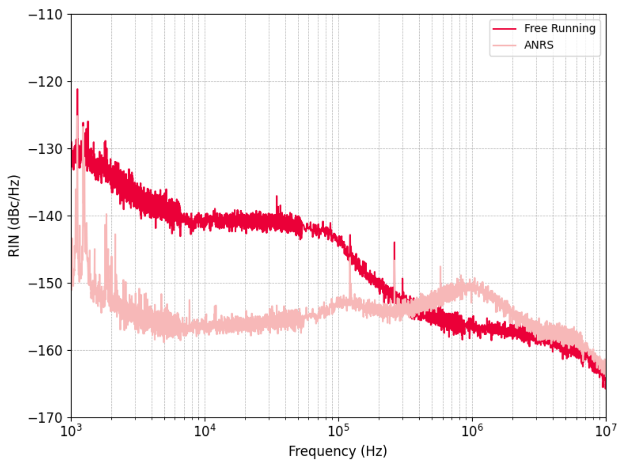

Fig. 4: Relative intensity noise of the ALS-1064-130 amplifier integrated into the technical demonstrator

Operating Power:	120 W
RMS Value - Free Running (100 Hz to 10 MHz):	0.006 %
RMS Value – ANRS (100 Hz to 10 MHz):	0.005 %

Resonant Frequency-Doubling Stage: DL-SHG pro

The final stage is a resonant doubling cavity, which converts the amplified 1064 nm signal to 532 nm via second-harmonic generation (SHG). This design is based on our proven DL/TA/ -SHG pro and DL/TA - FHG pro systems. Over years of continuous refinement, this technology has achieved remarkable efficiency and stability. The doubling stage operates with high conversion efficiency, ensuring minimal power loss and consistent performance.

PERFORMANCE METRICS OF HIGH-POWER HARMONIC OUTPUT

The main objective of our project is to demonstrate extremely low noise performance at power levels > 50 W. A first measurement campaign with the technical demonstrator setup described produced an optical output power of 80 W @ 532 nm and an integrated RIN of 0.013 % rms (10 Hz to 10 MHz) (Fig. 5).

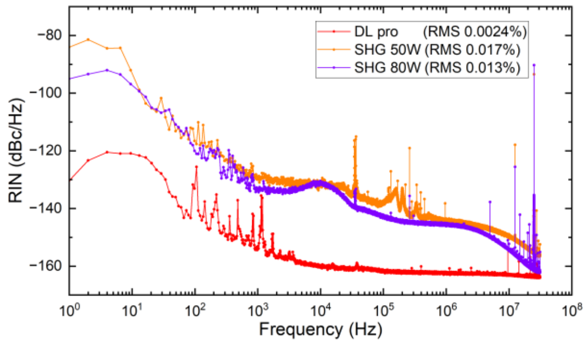

Fig. 5: RIN at 532 nm and fundamental 1064 nm

With the feature of our Active Noise Reduction System (ANRS, Fig. 4), the RIN can be drastically reduced into the kilohertz range. This is the basis for excellent system performance after the frequency doubling stage. Even the servo bump at 1 MHz for the amplifier is suppressed in the RIN spectrum of the SHG signal. We even expect potential for further noise reduction by carefully balancing the noise budget of the different stages.

The setup demonstrates a remarkable passive power stability as show in Fig. 6. A 16-hour test was performed in a stabilized ambient environment. The conditions were held to 22 ± 1°C and 40 ± 10% RH. Without active power stabilization, the output of the laser remained well above 80 W and had a standard deviation of 2 %. Based on our experience, we expect the power drift to be limited to < 0.5 % with active power stabilization.

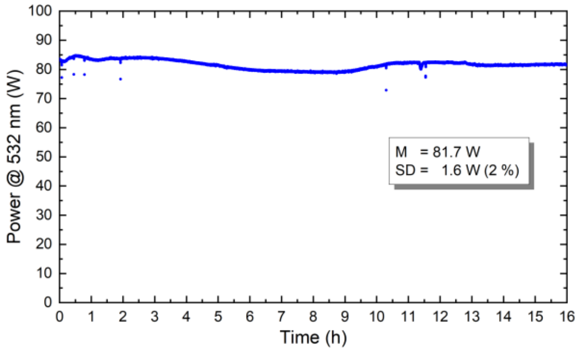

Fig. 6: Passive power stability of demonstrator setup i.e., no active power stabilization applied

Furthermore, the wavelength stability was measured over the 16-hour test period. Very stable behavior was observed (Fig. 7). The drift was well below 1 pm.

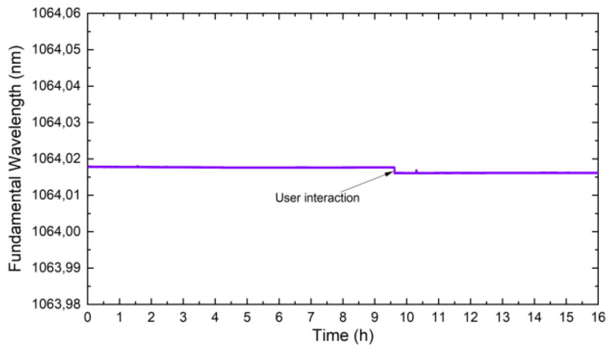

Fig. 7: Seed laser wavelength stability

CONCLUSION

The presented ultra-low noise, high-power laser system at 532 nm will set a new standard for stability and performance. By combining a narrow-linewidth seed laser, a noise-optimized fiber amplifier, and a resonant doubling cavity, the system achieves an output power of 80 W while maintaining an outstandingly low RIN figure of < 0.02 % rms.

Future development will focus on further validating the long-term performance of the system, expanding its applicability to pumping titanium-sapphire lasers and high-end, next-generation semiconductor inspection systems. While the demonstrated results affirm the high-power potential of this technology concept, long system lifetime and compact footprint must also be considered as key requirements for future OEM integration.