APP NOTE # 1.3

DECEMBER 20

WAVELENGTH TUNING OF KOHERAS FIBER LASERS

A Koheras fiber laser is based on a distributed feedback (DFB) cavity design within a rare-earth doped optical fiber. The all-fiber design ensures stable single-frequency operation, plus the properties of its rare-earth dopants enables the low frequency noise characteristic of the lasers.

The laser cavity is fixed into a laser substrate that protects the laser from external disturbances and enables control of the laser wavelength.

Determined by the thermo-optic and elasto-optic coefficients of the optical fiber, the wavelength of the laser is controlled by the temperature and strain of the DFB cavity.

Tuning of laser wavelength

The laser wavelength can be modified by applying dimensional changes to the fiber laser and its substrate. Such changes can be obtained either by exploiting the thermal expansion characteristics of the laser components, or by incorporating a piezo actuator, where an applied electrical voltage mechanically affects the laser substrate dimension.

Controlling the temperature of a laser fixed in a laser substrate enables precise tuning of the wavelength. This is obtained through a combination of the thermo-optic effect and the elasto-optic effect caused by strain from the thermal expansion of the laser substrate and described by the following formula:

$$\frac{1}{\lambda}\frac{d\lambda}{dT} = \frac{1}{n}\frac{dn}{dT} + \alpha_s - p_e(\alpha_s - \alpha_f)$$

where T is the temperature, λ the laser wavelength and α_s the thermal expansion coefficient of the laser substrate. The optical fiber has the thermo-optic coefficient *(dn/dT)/n*, elasto-optic coefficient p_e and thermal expansion coefficient α_f. The formula shows that the tuning coefficient scales linearly with the wavelength of the laser.

Typical values for a silica optical fiber are p_e=0.22, α_f=5.5·10^{-7}/K and *(dn/dT)/n* =6.5·10^{-6}/K. For an aluminum laser substrate *as* =2.28·10^{-5}/K.

Wavelength tuning with millisecond response times is obtained by adding a piezo actuator to the laser substrate for fast strain control.

Wavelength tuning of Koheras lasers

Temperature tuning for Koheras BASIK and BASIK MIKRO modules is set using either the CONTROL GUI or the software development kit (SDK). This allows a user to specify the laser wavelength or the offset from the lasers reference wavelength (center wavelength).

The firmware of the laser module then translates the wavelength to a factory calibrated temperature for the laser substrate and changes the setpoint accordingly.

Wavelength modulation using piezo tuning on a Koheras BASIK module can be implemented using the CONTROL GUI or SDK. This is enabled using a built-in function generator and piezo amplifier. Alternatively, the piezo tuning can be controlled by connecting an external analog signal to the piezo amplifier.

Koheras BASIK MIKRO modules do not include a built-in function generator and piezo amplifier, but they offer a direct connection to the piezo actuator on the laser substrate.

Temperature tuning

Using a combination of a precision NTC temperature sensor and thermo-electric cooling elements (TECs), the temperature of the laser substrate can be controlled very precisely. This enables precise wavelength tuning over a large temperature interval as shown below in figure 1.

The resolution of the laser temperature setpoint is 10-3 °C, and the temperature stability is typically within 5·10-3 °C when operated over 1000 hours in a stable laboratory environment.

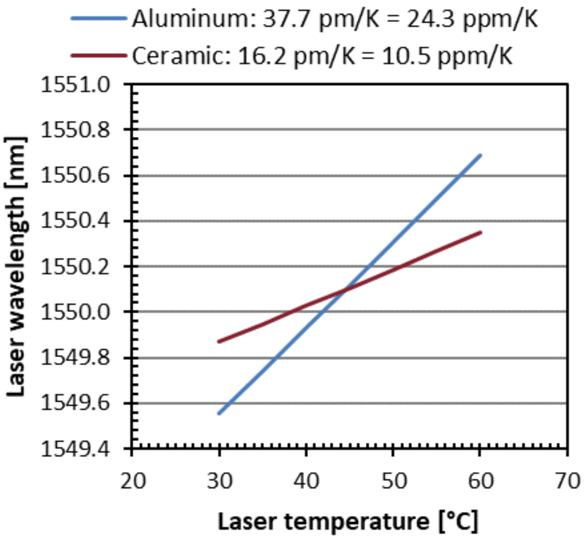


Figure 1: Thermal tuning of a 1550.12 nm laser in either an aluminum or ceramic laser substrate.

There is a small dependency between the module case temperature and the laser substrate temperature. This causes a wavelength drift that is typically <0.1 pm/°C for BASIK modules and <0.2 pm/°C for BASIK MIKRO modules.

The thermal tuning range is directly related to both the thermal expansion coefficient of the laser substrate and the heating/cooling capability of the TEC’s. Due to the TEC limits, the laser temperature range is also limited by the case temperature of the laser housing.

We specify the nominal laser wavelength at 45°C and limit the temperature range of the laser substrate to the interval from 30°C to 60°C. These settings ensure that the full tuning range can be obtained over a wide range of laser case temperatures.

For excessively low case temperatures, the heating capability of the TEC elements restricts the maximum substrate temperature to below 60°C.

Likewise, for excessively high case temperatures, the cooling capability of the TEC elements restricts the minimum substrate temperature to above 30°C. Typically, case temperatures should be kept between 15°C and 60°C to ensure full tuning capability.

Temperature tuning of the laser is obtained by changing the set point temperature of the laser substrate. The dynamic process of thermal tuning is illustrated in figure 2, where the set point is changed from 30°C to 40°C.

All though the dynamic tuning process to some degree depends on the case temperature, figure 2 nevertheless illustrates that smooth, continuous tuning of the laser substrate temperature is obtained.

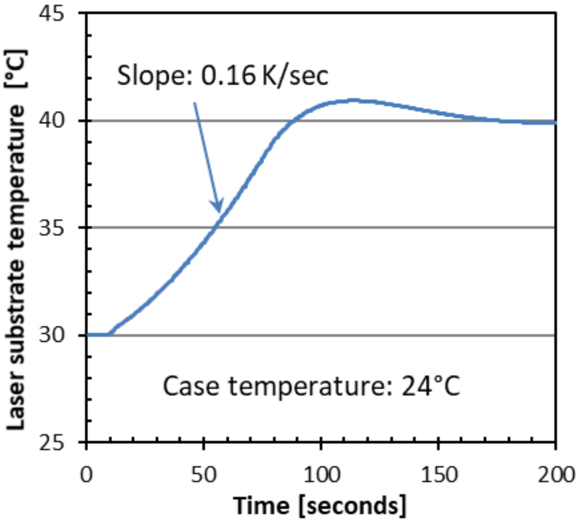


Figure 2: Thermal tuning dynamics of a 1550 nm BASIK E15 fiber laser in an aluminum laser substrate.

As figure 2 also shows, the module will, within a few minutes, stabilize at the desired temperature when thermal tuning is applied.

During wavelength stabilization, a temperature gradient is present over the substrate which may have a negative impact on the laser behavior. Hence, it is not recommended to use the laser before the wavelength (i.e. the temperature) is stable.

Piezo tuning

By using a laser substrate with a piezo electric actuator to apply tensional strain on the DFB laser cavity, it is possible to tune the laser wavelength with millisecond response times. Unlike semiconductor lasers, this makes it possible to obtain fast wavelength modulation without direct modulation of the output power.

A piezo actuator is a ceramic component that expands along the axis of an applied electrical field. From an electrical point of view, it acts in a manner similar to a capacitive load, and though the mechanical response is fast, it is not instantaneous.

To describe the temporal behavior of a piezo actuator we use the terms: Creep and hysteresis.

Creep is an effect experienced by all piezoelectric materials, where the material continues to expand for some time while charging from an applied electrical field. Similarly, the material does not return immediately to the initial strain level upon discharging. When a voltage is applied to a piezo, the wavelength change can be estimated by the following equation:

$$\Delta\lambda\ (t\ ) = \Delta\lambda\ _{t\ =0.1}[1 + y\ \ \log(t\ /0.1)]$$

where t is time in seconds, $\Delta\lambda(t)$ is the change in wavelength as a function of time, $\Delta\lambda t$=0.1 is the wavelength change after 0.1 seconds. γ is the creep factor, which is dependent on the material properties of the actuator.

The time dependence of creep is shown in figure 3. The piezo is first charged by changing the piezo voltage from 0 VDC to 100 VDC and then discharged by returning the piezo voltage to 0 VDC.

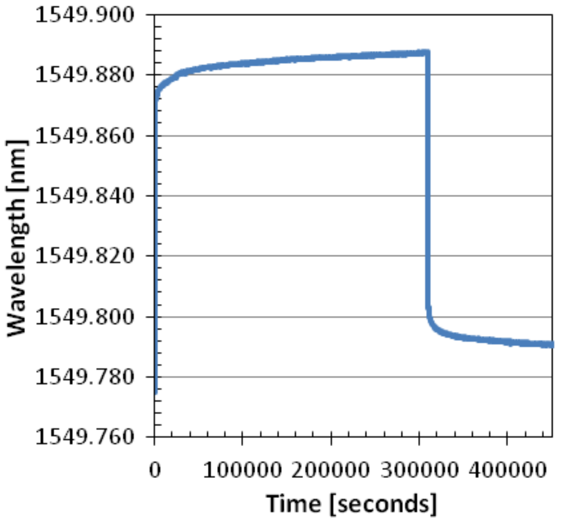
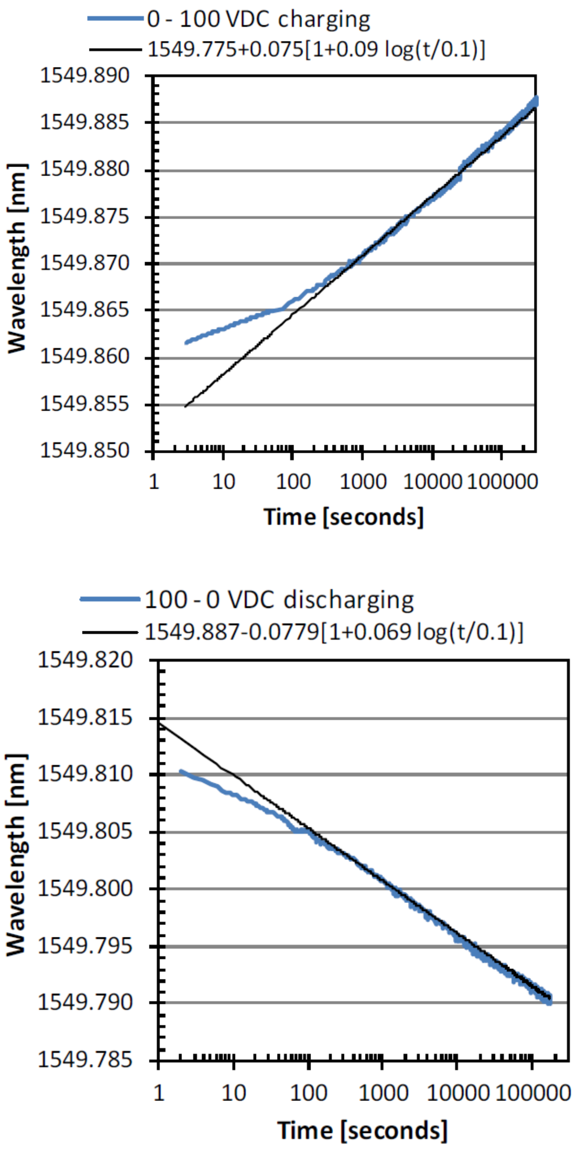


Figure 3: Time delay of wavelength tuning caused by piezo creep. The piezo voltage is changed from 0 to 100 VDC and then returned to 0 VDC after 30000 seconds. The wavelength is measured by a wavemeter during charging and subsequent discharging of the piezo.

The long-term effect can be estimated by using a logarithmic fit as shown in figure 4. The figure shows that the tuning rate is faster during charging of the piezo than during discharging.

If piezo creep is considered a problem, it can be minimized by primarily using thermal tuning and reserving the piezo tuning for minor corrections.



Figures 4 and 5: Hysteresis of piezo-tuned E15 fiber laser with slew rates from 0.1 V/s to 10 V/s.

The piezo tuning coefficient for the fiber laser is frequency dependent, due to the non-instantaneous time response of the piezo. The frequency response is approximately linear over a large frequency range, but mechanical resonances from the laser substrate influence the response at higher frequencies.

Figure 6 illustrates a typical piezo tuning frequency response. The measurement shows a piezo responsivity of around 0.45 ppm/V; and the first resonance of the laser substrate occurs at 35 kHz for aluminum and at 64 kHz for ceramic substrate.

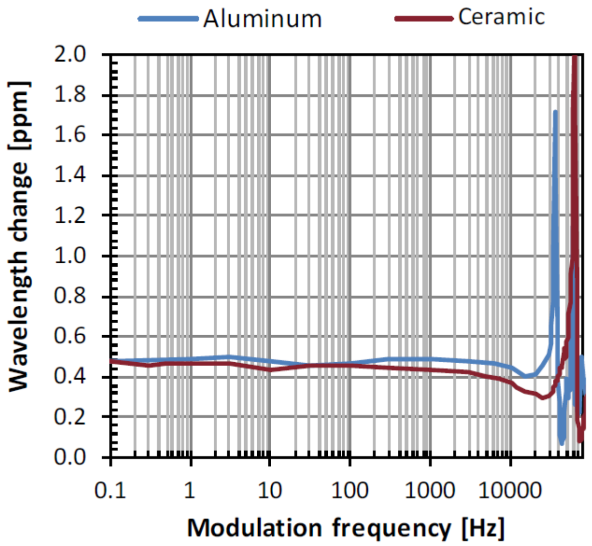


Figure 6: Frequency response of a piezo tuned BASIK MIKRO E15 fiber laser in either aluminum or ceramic laser substrate.

It is important to use a piezo signal with very low noise since any noise on the signal will induce noise on the laser wavelength.

Piezo tuning of a fiber laser involves only a small variation of fiber strain, for example, a 1 ppm strain on a 1550 nm fiber laser results in approximately 1.5 pm tuning of the wavelength. Still, a combination of a large modulation amplitude and frequency can make the laser output unstable. For this reason, the tuning speed should be kept below the maximum recommended slew rate of 13 ppm/ms (ex. 20 pm/ms @ 1550 nm).

Summary

The wavelength of Koheras fiber lasers can be controlled by either changing the temperature of the laser substrate or by applying tensile strain on the laser cavity with a piezo actuator.

Thermal tuning provides a precise and linear relation between the substrate temperature and laser wavelength.

The tuning mechanism is slow but provides a large tuning range with a tuning coefficient of approximately 24.3 ppm/K for aluminum substrates and 10.5 ppm/K for ceramic substrates.

Although, adding the piezo tuning option increases responsivity, its tuning range is limited when compared with thermal tuning which gives a wider range, albeit with a slower response time.

The piezo option gives a tuning coefficient of approximately 0.45 ppm/V which is reasonably linear until approaching the mechanical resonances for the laser substrate.

The first mechanical resonance occurs around 35 kHz for aluminum substrates and around 65 kHz for ceramic substrates.