Fiber coupled low coherence laser sources

Series 51nano

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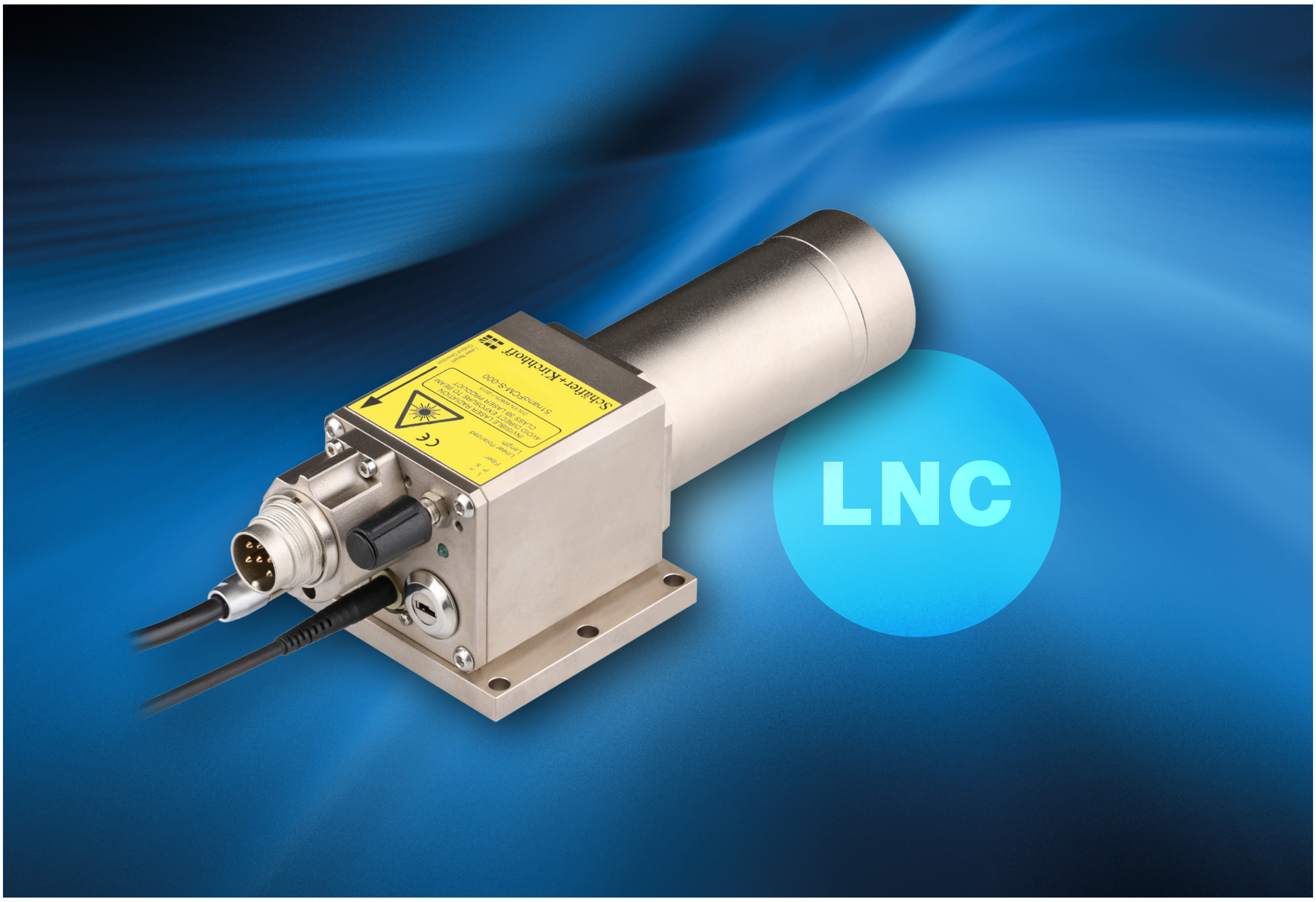

Fig. 1:
Laser beam source series 51nano.

The fiber coupled laser source series 51nano is a low coherence laser source coupled to a singlemode or singlemode polarization-maintaning fiber cable. Special features inlude low coherence as well as low power noise and as a result often unwanted intereferences can be oppressed.

It is often used as a laser for high precision position measurement or as a pilot laser during alignment tasks. Other applications include Atomic Force Microscopy (AFM) or back-reflection particle measurement.

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Conventional singlemode laser diodes are semiconductor lasers and usually have one favored longitudinal mode. However, the semiconductor laser material exhibits a temperature dependency, altering the gain profile and refractive index, so that other longitudinal modes are amplified stochastically. This mode hopping causes the output wavelength to jump rapidly by a few nm [1]. For non-stabilized singlemode diodes the output power can change erratically by as much as 3%. These disturbances are intensified when laser light is back-reflected into the laser diode, either through direct reflection or simply through back-scattering.

Back-reflection can be prevented effectively by coupling the laser beam source using an optical fiber in which the fiber end-face has been polished at an oblique angle. Since some form of back-coupling into the laser diode e.g. due to back-scattering in the fiber, however, cannot be avoided completely, fiber-coupled laser diode beam sources often exhibit an increased power noise.

The undesirable features of power noise and mode hopping are eliminated in the 51nano series by modulating the current of the laser diodes at a high frequency. This RF-modulation excites numerous longitudinal modes of emission while simultaneously lowering signal noise significantly to <0.1 % RMS. This induced broadening of the spectrum, in a controlled and stable way, has the added advantage of considerably reducing the coherence length of the laser beam which, in turn, reduces laser speckle contrast and suppresses the generation of interference patterns. For measurement tasks, where back-coupled light is inherent to the method, a Faraday isolator (series 51nanoFI), serving as an optical diode, protects the laser diode, guaranteeing a stable mode of operation.

Comparison with Standard Laser Diode Beam Sources

The notable benefits of RF-modulated laser diode beam sources become visible when comparing them with the features of a standard fiber-coupled laser diode beam source. Fig. 3 depicts noise, spectrum and laser speckle as well as interference behavior when using a laser of type 51nano, Fig. 2 when using a standard laser diode beam source.

In order to improve comparability, the same 51nano is used as a standard source only with RF-modulation switched-off. In this configuration a 51nano does not differ much from any other standard fiber-coupled laser diode beam source.

In Fig. 2a and 3a two noise measurements (threshold of 1MHz, period of 60 minutes) are contrasted with each other. Peak values in noise exceed >1 % for a standard laser diode while the RF-modulation of the 51nano reduces noise to <0.1 %, a value close to the detection limit.

Without RF-modulation, the laser jumps stochastically between several emitting modes (Fig. 2b), different colors). Upon RF-modulation, numerous modes are excited within the gain profile of the resonator (Fig. 3b), producing a broad spectrum with about 1.5 nm FWHM (full width at half maximum).

Fig. 2c and 3c show the corresponding laser speckle behavior, a frequent problem in optical metrology. Speckle arise from multiple interference, e.g. diffuse reflection of laser radiation on optically rough surfaces (> $\lambda/4$). For fully coherent laser sources the laser speckle contrast is 1 with areas of zero intensity within a laser spot. Due to the emission from multiple laser modes the coherence length of type 51nano lasers is reduced to <300 µm and the speckle contrast is lowered (compare Fig. 2C with Fig. 3C).

Another effect of a reduced coherence length can be observed in Fig. 2d and 3d. The recording of a collimated laser beam by a CCD area scan camera reveals a disturbing interference pattern when using a standard laser diode (Fig. 2d), caused by internal reflection within the protective glass window of the detector. The coherence length of the 51nano is reduced to a value less than the thickness of the glass and no interference arises (Fig. 3).

Evaluation of a 51nanoFI using a simulation of Atomic Force Microscopy (fiber-optic Fabry-Perot Interferometer)

One possible of application of the laser diode beam source 51nano is atomic force microscopy (AFM).

This measurement method is based on scanning the surface of a sample with the tip of a cantilever, which is brought close to the sample surface. A piezo-element either moves the tip over the sample or the sample is moved under the tip. Atomic forces (such as Van der Waals or electrostatic forces) between the tip and the sample cause a deflection of the *a)* *b)* *c)* *d)*

a) Power noise from a laser source coupled to a fiber. The fiber generates an external cavity with the laser diode, resulting in stochastic power jumps.

b) Mode hopping: temporal jumps between modes. The short-term coherence of individual modes is > 1 m, but effective coherence length is smaller.

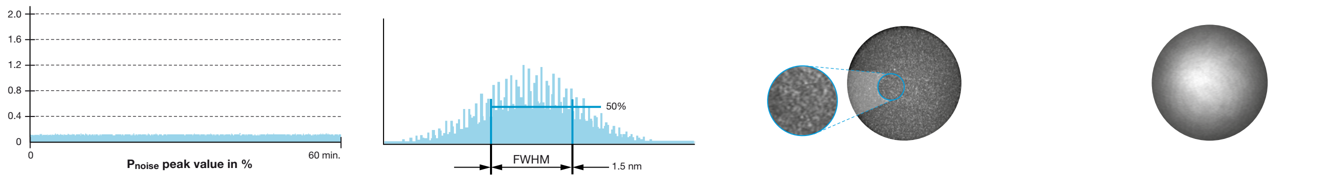
c) The laser spot produced by a standard laser diode beam produces a speckle pattern, increasing the statistical uncertainty in position determinations.

d) The collimated laser beam is recorded directly using a CCD sensor. Reflections at the protection window generate an interference pattern.

Fig. 2:

Characteristics of a standard fiber-coupled laser diode beam source. High noise, mode hopping, laser speckle and unwanted interference can constrain the optical resolution.

a) *b)* *c)* *d)*



a) The RF modulation results in a constant mean laser power. Power noise < 0.1% RMS (<1MHz).

b) Broadened spectrum (~1.5 nm FWHM) with reduced coherence length (~0.3mm) as a result of using RF-modulation.

c) Low speckle contrast due to reduced coherence length: uniform illumination of a position sensitive diodes for AFM and improved edge detection during position measurements.

d) Gaussian intensity distribution of the collimated laser beam at a CCD sensor. No interference patterns, despite the CCD sensor protection window.

Fig. 3:

Advantages of the laser diode beam source 51nano with lower noise a), spectral broadening b), reduced laser speckle c) and less interference d).

cantilever. By evaluating this interaction, conclusions can be drawn about the surface structure, surface composition and the physical properties.

Most AFMs are based on two different working principles: laser deflection measurement or fiber-optic Fabry-Perot interferometry. With a laser deflection measurement typical resolutions of 10 to 1 nm are reached, with Fabry-Perot interferometry, the limit is about 10 times lower, i.e. down to about 1 Å. A fiber-optic system has the added advantage that only the fiber itself needs to be placed in direct proximity to the sample, not the detection of the signal. This is particularly useful when the experiments are conducted in a vacuum chamber.

The optical scheme of a fiber-optic Fabry-Perot Interferometer in an atomic force microscope is depicted in Fig. 4. The laser light emitted by the diode is guided through a fiber-optical beam splitter and then onto the cantilever tip. The light emanating from the fiber is partially back-reflected at the fiber end-face (approx. 4%) and is also reflected by the oscillating cantilever. These two waves interfere and the interference signal is passed through the beam splitter to the detector. The signal reaching back to the laser source is blocked using an integrated Faraday isolator.

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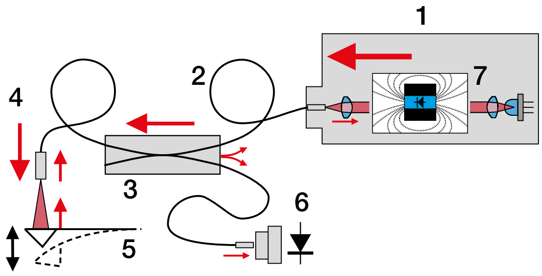

1) Laser beam source 51nanoFI
2) Singlemode fiber
3) Fiber-optical beam splitter
4) FC-PC fiber connector
5) Cantilever
6) Detector
7) Faraday isolator

Fig. 4:

The optical scheme of a fiber-optic Fabry-Perot Interferometer in an atomic force microscope (AFM). Laser light is passed through a fiber-optical beam splitter and reaches the cantilever.

The interference between the reflection at the fiber end-face and the moving cantilever is recorded by the detector. Signal quality is improved by using a 51nanoFI.

The phase difference between the interfering waves serves as a measure of the cantilever deflection. Unfortunately, the desired interference signal between the fiber end-face and cantilever is confused by interference from reflections at all fiber ends and between the detector and the fiber end-face.

A feasibility study of the use of the laser diode beam source 51nanoFI was successfully performed as a simulation in cooperation with Prof. Dr. H.-J. Eifert, MND, FH Gießen-Friedberg [2].A 51nanoFI beam source that can be switched between two different states, non-stabilized (without RF-modulation) or stabilized (with RF-modulation) was used as a fiber-coupled laser source. The radiation was split using a 50/50 fiber-optical beam splitter. One portion is directed to a spectrometer to analyze the spectral power density of the source. The other part is guided to a mirror under piezo-control that oscillates sinusoidally with a frequency of 1.5 kHz (which simulates a cantilever tip). Fresnel reflection causes a small part of the radiation to be reflected at the fiber end-face, which interferes with the light that is reflected by the oscillating mirror. The interference signal is then split again at the fiber-optical beam splitter. A specifically developed transimpedance converter (threshold frequency 6 MHz) then transforms the photo signal into an oscilloscopic voltage signal.

For mirror movements within the frequency range 100 Hz to 1.5 kHz, the stabilized beam produced by the 51nanoFI laser diode exhibits a highly stable interferometer signal with low noise (Fig. 5a). Without RF-modulation, mode hopping and undesirable interference result in signal noise that varies stochastically (Figure 5b and 5c). Productive interferometer measurements are only feasible when using a stabilized laser diode together with an integrated Faraday isolator. The small coherence length ensures that only the desired interference signal, between the fiber end-face and the cantilever, actually contributes to the signal and the signal quality is enhanced.

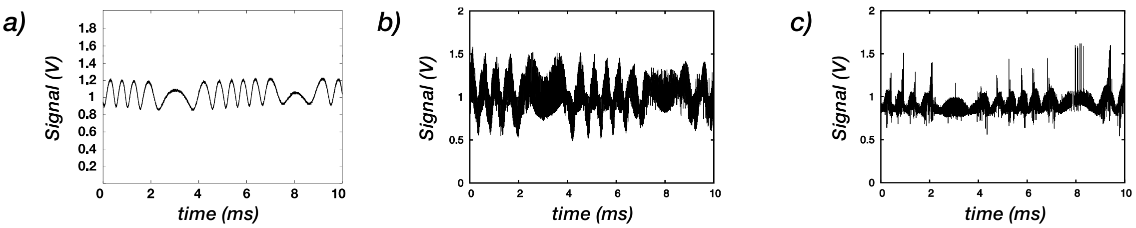

Fig. 5:

Interferometric signal using a 51nanoFI a) compared with the unstable interferometric signal using the laser source without RF-modulation b) and c).

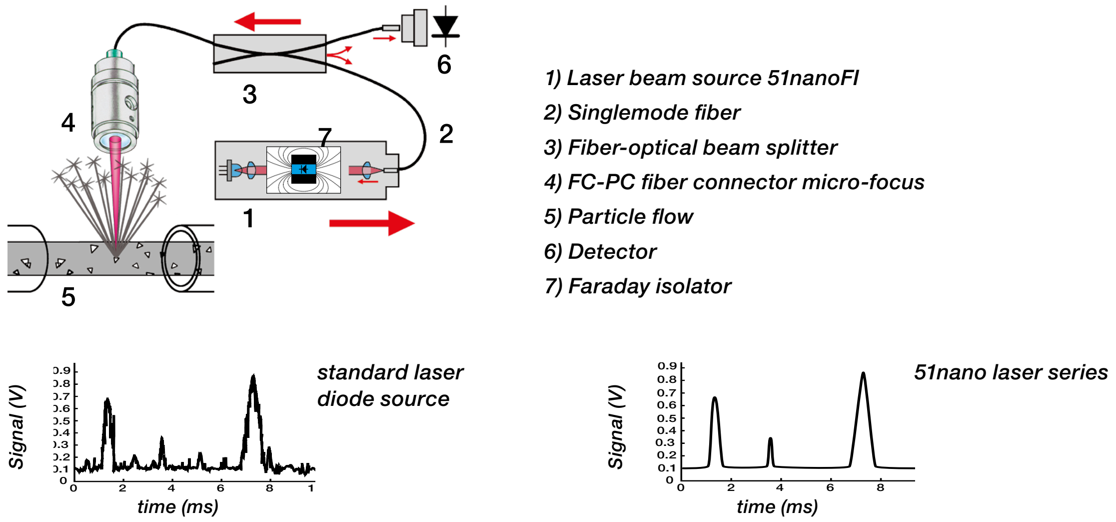

Fig. 6:

Optical scheme for back-reflection particle measurement. Particles scatter light back into the fiber. The precision of the measurement is enhanced by using a beam source with low power noise.

Application Example: Laser Deflection Measurement in AFM

In order to measure the deflection of the cantilever, a laser spot is placed on the back of the cantilever tip under a certain angle. Its reflection is then detected by a position sensitive diode. The position of this spot has to be detected very precisely, since it is the basis for the evaluation of the AFM measurement. Interference (e.g. from reflections at the protective window of the detector) or laser speckle on the detector constrain the resolution of this signal. Using a RF-modulated beam source, the interference at surfaces with optical path differences longer than the coherence length of the source is suppressed and the speckle contrast is reduced, thus enhancing signal quality.

Application Example:
Back-Reflection Particle Measurement

The 51nano series can also be used for particle measurement by back-reflection. The radiation of the laser source is guided via a singlemode fiber and a fiber-optical beam splitter onto the particle flow (Fig. 6).
Particles passing through the focused beam cause the light to scatter, and some light is back-reflected into the emitting fiber. Precise measurements require low speckle contrast and a constant laser power without noise. By using a 51nano, the coherence length is reduced, and the power averaged, resulting in a detected signal with much less noise.

References

[1] K. Petermann, Laser Diode Modulation and Noise, Kluwer Academic Publishers, Dordrecht, Boston, London 1991

[2] M. Schulz, Aufbau eines Messsystems zur Evaluierung einer Laser Beam Source für die Rasterkraftmikroskopie, Diplomarbeit, Fachbereich Mathematik, Naturwissenschaften und Datenverarbeitung der FH Gießen-Friedberg, 2009 (Betreuer Prof. Dr. H.-J. Eifert)