SINUSOIDAL FREQUENCY MODULATION FOR CONCURRENTLY ACHIEVING IODINE-FREQUENCY-STABILIZED LASER DIODE AND HIGH-PRECISION DISPLACEMENT-MEASURING INTERFEROMETER
（正弦波周波数変調によるヨウ素周波数安定化レーザダイオードと変位計測の同時達成）

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Laser diodes (LDs) have many features that make them suitable sources for optical metrology such as high efficiency, compactness and a long lifetime compared to gas lasers. Additionally, LDs enable direct frequency modulation by modulating the injection current and tuning over a wide frequency range without mode hopping. However, the frequency stability of normal LDs, typically of GHz order per minute, must be improved before they are applied for high-precision measurements. Locking to suitable resonant frequencies supplied by cavities or atom/molecular transitions can achieve excellent stability for LDs. This thesis proposes a combined method to achieve both frequency stabilization for LDs and a high-accuracy displacement-measuring interferometer using the sinusoidal frequency modulation technique. The focus of this thesis is first to stabilize the frequency of LDs to some defined transitions of molecular iodine (I_2) based on the frequency modulation spectroscopy (FMS) method. Secondly, a high-accuracy, long-measurement-range displacement measuring-interferometer is constructed using the I_2- frequency-stabilized LDs. The thesis is organized into 5 chapters:

Chapter 1: Introduction. The research background of frequency stabilization techniques for laser diodes (LDs) and high-precision displacement-measuring interferometers is presented. The advantages and disadvantages of existing laser frequency stabilization and displacement measurement methods are briefly analyzed. On the basis of this analysis, the objective of this research is introduced which is to use the frequency modulation (FM) of LDs to improve both the frequency stability of LDs and the accuracy of displacement-measuring interferometer.

Chapter 2: Frequency stabilization of laser diode to I_2 Doppler-broadened absorption. In this chapter, the frequency stabilization for a normal LD is investigated. The LD has a linewidth and relative frequency stability of approximately 150 MHz and 10^{-5} order, respectively. The frequency instability of the laser is a limitation in its ability to apply to high-precision measurements. To overcome this limitation, the LD frequency is stabilized to an I_2 Doppler-broadened absorption line near 633 nm. A sinusoidal frequency modulation of 3 MHz is applied to the LD and the first derivative signal of the I_2

Doppler-broadened absorption is detected to lock its frequency to the center of the absorption line. A comparison of the frequency change between free-run and stabilized operations indicates that our locking system can improve the frequency stability of the LD to 10^{-7} order.

Chapter 3: Frequency stabilization of external cavity laser diode to I_2 Doppler-free absorption. This chapter reports the frequency stabilization of an external cavity laser diode (ECLD) to an I_2 Doppler-free absorption (hyperfine component) near 633 nm. A high modulation frequency of 300 kHz was applied to the LD via sinusoidal modulation of the injection current. The hyperfine spectrum of the 6-3, P(33) transition of $^{127}I_2$ (633 nm) was detected using the third-harmonic lock-in technique. The frequency of the ECLD was locked to the b_{21} hyperfine line of the 6-3, P(33) transition of $^{127}I_2$ using a simple PID controller. Beat frequency measurement between the locked ECLD and a reference laser, an I_2-frequency-stabilized He-Ne laser, indicated that a frequency stability of 10^{-11} order could be achieved.

Chapter 4: Displacement-measuring interferometer based on I_2-frequency-stabilized laser diodes. In this chapter, a displacement-measuring interferometer based on the I_2-frequency- stabilized laser is reported. The interferometer is developed on the basis of both the stabilized LDs that were investigated above: I_2 frequency-stabilized LD to the Doppler-broadened absorption and the I_2 frequency-stabilized ECLD to the Doppler-free absorption. The theoretical basis and the advantageous features of the interferometer are first analyzed in detail. Stabilizing the frequency to an identified Doppler-broadened absorption/Doppler-free absorption of I_2 can avoid the ambiguity or fluctuation of the carrier frequency, and hence the accuracy of the displacement measurement can be improved even when a wide range or a long measuring time is required. Moreover, the phase shift induced by the displacement of the target mirror in the interferometer can be accurately extracted from the interference signal using the lock-in detection technique. Using the interferometer, the measurement range is extended to 10 m by selecting suitable pairs of consecutive harmonics.

Chapter 5: Summary. A review of my research work, existing problems and future works are discussed.