

SELF MIXING EFFECT IN SINGLE MODE DIODE LASERS

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ABSTRACT

Optical feedback has very profound effect on diode lasers and has been used extensively in extended cavity diode lasers (ECDL). However, direct feedback of the retroreflected wave from a mirror or target give rise to self-mixing effect. Study of self-mixing effect in single mode diode lasers under different feedback conditions from stationary as well as modulated target exhibited mainly two types of effects. First effect was threshold lowering but in lesser extent than observed in ECDL but non-single mode operation at large current ranges. Second effect was no threshold lowering, but substantial increase in monitor photodiode (MPD) output, however, at higher injection currents MPD output exhibited sine wave, followed by ramp type periodic structures. In addition, Self-mixing interference fringes was also observed. The behaviour of such an external cavity giving rise to self-mixing effect was compared with that of the developed Littrow ECDL.

INTRODUCTION

Feeding back a part or full of emitted diode laser output back to the diode cavity has very profound effect. Frequency selective coherent optical feedback has been used extensively for improving coherent properties of diode laser in extended cavity diode laser (ECDL) and for tuning ECDL frequency to particular atomic or molecular transition. Extended cavity diode lasers (ECDL) have been very useful as tunable laser source for particular atomic or molecular transition and they have been an essential tool for manipulation of atoms in numerous experiments involving laser cooling and trapping of atoms, frequency / wavelength standards and spectroscopy. On the other hand, direct feedback of the retroreflected wave from a mirror or target into the diode laser cavity give rise to self mixing interference effect which has been applied to laser based measurement systems such as absolute distance measurement [1, 2,3], vibration measurement [4], laser Doppler velocitometry, self mixing type phase locked laser diode interferometer [5], laser ranging, blood flow measurement etc. Most of these studies were pursued with multimode diode lasers. Since single mode index guided diode lasers have been successfully used by us for developing frequency stabilized ECDL systems [6], it was thought prudent to investigate the self mixing effect in these single mode diode lasers under different feedback conditions from stationary as well as modulated target.

EXPERIMENTS

The self-mixing effect was studied for optical feedback from a mirror mounted on a PZT, along the laser beam axis. The mirror could be modulated by applying any waveform to the PZT from the function generator. A single mode index guided diode laser (SDL 5402 H1, TO3 package) at 846 nm was used. The laser diode package contained a monitor photodiode (MPD) whose output was observed on an oscilloscope. The output was also observed on an optical spectrum analyzer comprising a scanning confocal Fabry Perot cavity. The output power was measured with laser powermeter.

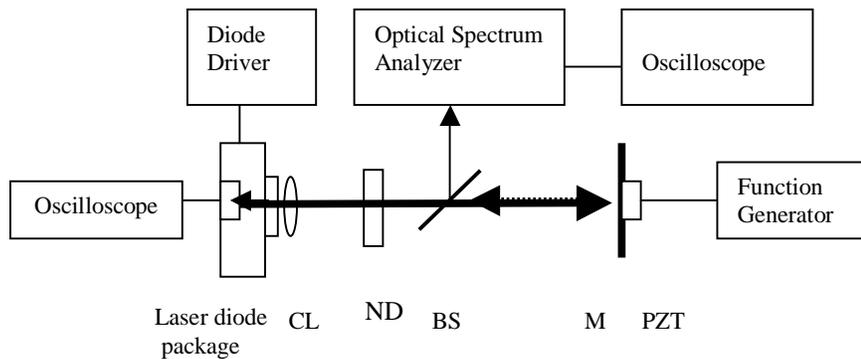


Fig.1 Experimental arrangement for observing self-mixing effect. Laser diode package contains laser diode in front and monitor photodiode in the rear. CL is collimating lens, ND IS neutral density filter, BS is beam splitter, M is mirror.

RESULTS

Two types of effects were mainly observed by varying the feedback conditions, depending upon the angle of tilt of the mirror both for fixed as well as modulated target. Self-mixing interference was also observed.

1. Threshold lowering

In the first case, threshold current of the diode laser decreased from 27 mA to 23 mA and narrowing of single mode was observed in the Optical Spectrum Analyzer (OSA), as in the case of ECDL. The injection current of the diode laser was increased and after a certain limits (30 mA), OSA output showed triangular type structure till higher current (86 mA), but as soon as feedback was removed, single mode appeared at the OSA output. The behaviour is shown in Fig. 2a & 2b. This indicated disturbance of coherence in the laser diode. However when a half wave plate was inserted between laser diode and mirror, except for short current range (30 –40 mA) sharp single mode was observed. MPD output showed a dc signal without any structure in the oscilloscope.

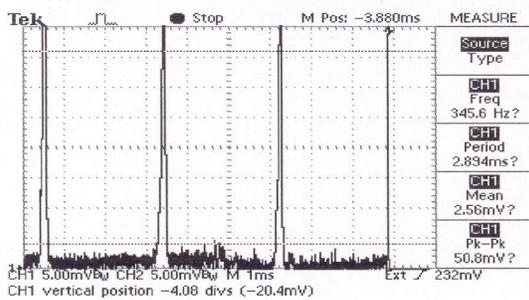


Fig. 2a Single mode structure observed with feedback at 24 mA of injection current.

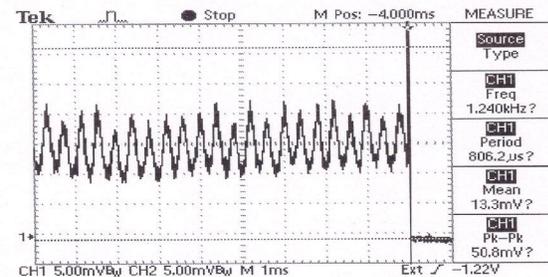


Fig. 2b Ramp type structure observed in OSA output at 61 mA injection current.

2. Monitor Photodiode output increase

In such feedback conditions, threshold current of diode laser was not lowered but substantial increase in the monitor photodiode output was observed with increase in injection current. From 27 mA to 50 mA single mode (broader than case 1) was observed in OSA. MPD output observed in the oscilloscope showed a dc signal till 50 mA. At 50 mA MPD output showed sinewave followed by ramp type periodic structure as shown in Fig.3, with increase in injection current. When the mirror was modulated with a sinewave of 100 Hz, the frequency of MPD output waveform was about 580 kHz (at 50 mA) decreasing continuously with increase in injection current to 229 kHz (at 80 mA). Repetition of the same pattern was observed when sinewave modulation frequency was changed. Onset of sinewave modulation of MPD output shift to higher injection current when temperature of laser diode was decreased in the same feedback conditions. Such waveforms could be used for measurement of distance and velocity of target [1].

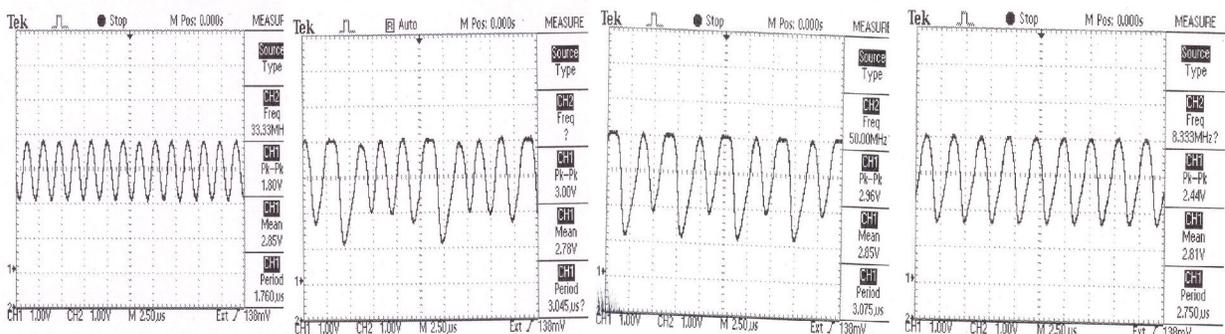


Fig. 3. MPD output showing variation from sinewave to ramp type structure of laser diode power variation, from left to right, injection current 51 mA, 55 mA, 57 mA, 59 mA .

Self-mixing interference

By very careful alignment of the mirror, self-mixing interference fringes were obtained (Fig.4). The diode laser output was then analyzed by a scanning Fabry Perot interferometer; the output of which showed an interferometric type structure corroborating the MPD output (Fig.5). Such self-mixing or induced modulation similar to interferometric fringes is believed to happen for very weak feedback [7]. The behaviour of such an external cavity giving rise to self mixing effect was compared with that of the developed ECDL with a grating in the Littrow configuration. When a ramp or sinusoidal signal was applied to the PZT attached to the grating, the MPD output followed the periodicity of the applied signal and no self-mixing signal was observed (Fig.6).

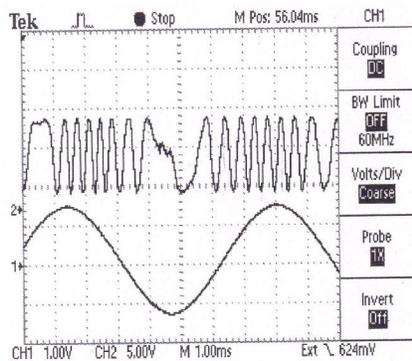


Fig.4 Self-mixing interference fringes observed in the MPD output. Sinewave modulation signal is shown in the lower curve.

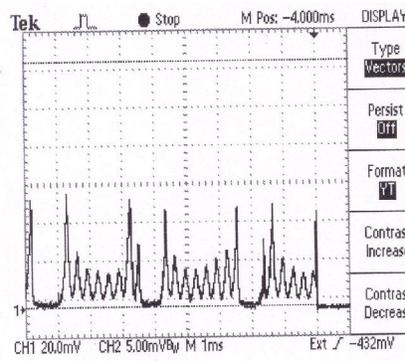


Fig.5 OSA output corresponding to self-mix fringe of Fig 4.

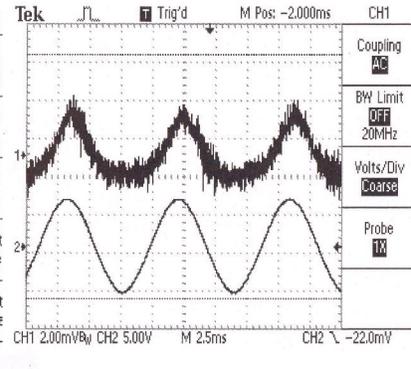


Fig. 6 Amplitude modulation of ECDL output as observed in the output. Lower curve shows the sinewave modulating the grating.

Comparison of the feedback regimes

The different behaviour of the laser diode output under self mixing feedback conditions were compared by measuring the laser output power and MPD output (dc value) under no feedback conditions, threshold lowering feedback conditions and MPD output increase feedback conditions. The results are shown in Fig.7 a-d. Fig. 7a shows that whereas laser power increased in threshold lowering feedback but power decreased in the MPD output increase feedback even lower than the no feedback case. Fig 7b shows how strikingly the MPD output increased in that feedback conditions but it is not reflected in the laser power output. This regime was further investigated by measuring the MPD output and laser output power simultaneously in MPD output increase feedback conditions in Figs 7 c & d. In case of direct feedback from mirror, MPD output started showing structures as shown in Fig 3 beyond 50 mA injection current. However, putting a halfwave plate at the feedback path had the striking effect that structures disappear and only dc signal was observed in the MPD output and single mode structure in the OSA output. Also insertion of a half waveplate had the effect of decreasing the MPD output and increasing the laser power output indicating more power going into the lasing mode.

CONCLUSIONS

Induced modulation in the diode laser cavity under different feedback conditions from a remote mirror exhibited self mixing effects which could be differentiated based on the laser diode output characteristics. Whereas, self-mixing interferometric fringes were observed in very weak feedback conditions, moderate feedback gave rise to threshold lowering and single mode oscillations indicating coherent feedback conditions. However, at higher feedback levels MPD output exhibited an amplitude modulation showing sinewave or distorted ramp type structure. The slope of such periodic structures and their frequency can provide information about the absolute distance of the remote target, its velocity etc. The study also indicated the complexity of the induced modulation not only on the feedback level but also on the phase and polarization of the feedback wave. When such external remote mirror cavity was

compared with the developed ECDL in Littrow configuration, no such self mixing effect was observed and MPD output changed showing the synchronous single mode scanning with the sinewave modulation of the grating.

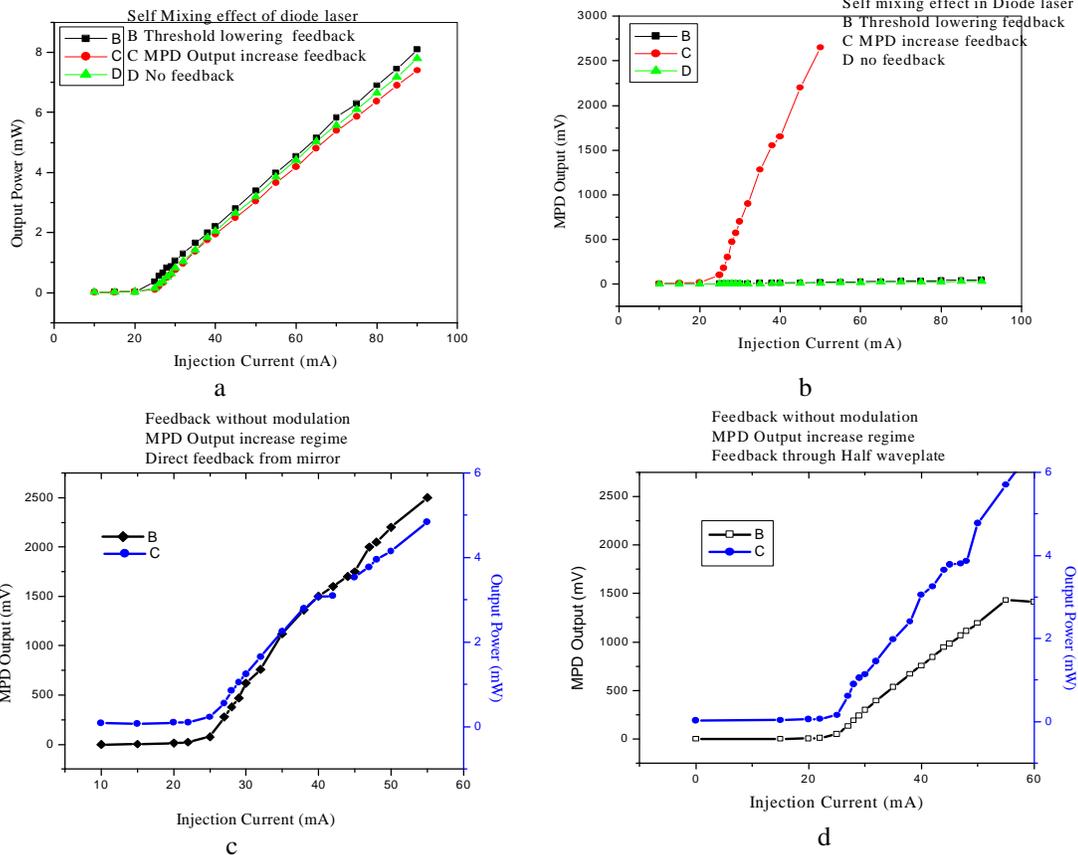


Fig.7 (a) Difference in laser output power for no feedback, threshold lowering feedback and MPD output increase feedback regime, (b) difference in MPD output for all three cases and the striking fact is that substantial MPD output increase is not reflected in the laser power output. Difference between MPD output and laser output power in the MPD output increase case is shown in (c) for direct feedback from mirror, (d) feedback through a halfwave plate,

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