

# A245 : Optical Frequency Doubling

*A lab report written by*

Group P20: Mrunmoy Jena and Ajay Shanmuga Sakthivasan

**Supervisor: Thilina Muthu-Arachchige**

Universität Bonn

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# Abstract

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# Introduction

# Experiment and Analysis of Results

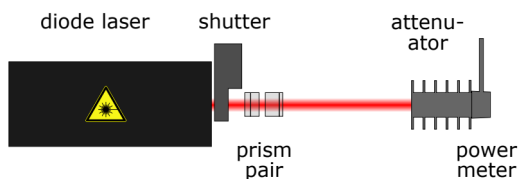
This section discusses the experimental setup and procedure, along with the calculation of the necessary quantities and their error analysis.

To begin with, a class 3B external cavity diode laser (TuiOptics, DL100) emitting light of wavelength 987 nm is used for the experiment. A shutter mounted onto the laser controls the beam and a pair of anamorphic prisms is used to modify the elliptical beam profile to a more circular shape. The laser, shutter and prism pairs were all fixed on a laser table beforehand. For each part of the experiment, other instruments and optical elements were added onto this setup.

## 2.1 Variation of fundamental laser output power with injection current

The first part of the experiment is aimed at familiarizing oneself with the dependence of the fundamental output power of the laser with the injection current and to extract various important parameters characterizing the laser such as the threshold current, differential slope efficiency and the differential quantum efficiency.

In order to perform this experiment, a power meter was mounted on table in such a manner that it remains at the same height as that of laser beam as well as aligned with the beam (i.e. the face of the power meter is perpendicular to the beam axis). This adjustment was first performed by using an IR (infrared) detection card in order to ensure that the entire beam went into the power meter. Then the power meter is switched on, and the wavelength to be measured by it is set to 987 nm. Subsequently, finer adjustment is performed by moving the power meter to a position where it gives the maximum power reading. The power meter is then screwed tight at this position.



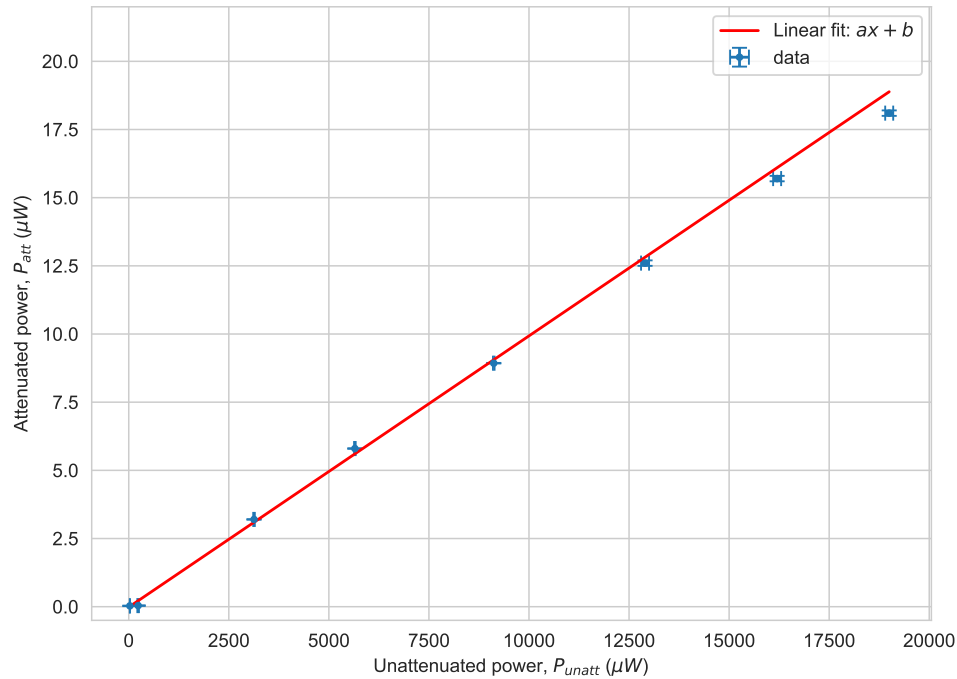
**Figure 2.1:** Set up to measure variation of laser output power with injection current [1]

The set up for this experiment (along with attenuator attached) is shown in Figure 2.1. With this setup in place, the injection current is increased from 0 to 280 mA in increments of 5 mA, and the corresponding values of output power are noted. Since the power meter sensor becomes non-linear for powers above 20 mW, it becomes necessary to use an attenuator. For our measurements, we took measurements both with and without attenuator in the unattenuated power range from  $28.2 \mu\text{W}$  to  $19000 \mu\text{W}$  (19 mW). Both the unattenuated and attenuated power values are necessary to be recorded over at least some data points in order to perform the calibration and extract a calibration factor from it. Beyond this range, the power is only measured with the attenuator attached onto the power meter, due to the aforementioned reason

of non-linearity of the sensor. The attenuator for the experiment is a ‘1000:1’ attenuator (meaning that ideally it would reduce the unattenuated power by a factor of 1000). The recorded data can be found in A.1. The values measured without attenuator are listed under the column ‘ $P_{unatt}$ ’ and the measured power values with attenuator are under the column ‘ $P_{att}$ ’. From now on, all errors stated in the tables should be assumed to be instrumental errors (least count of the measuring instrument), unless otherwise stated.

### Calibration of removable attenuator

In order to find the calibration factor, the data for the attenuated power vs. unattenuated power is plotted and a linear fit is applied to this dataset. To carry out the curve fitting procedure using the data points and some initial guess parameters, we used the function `curve_fit()` from the `scipy.optimize` module for *Python*. The data points (along with x-y error bars) and the linear fit modelled onto them is shown in Figure 2.2.



**Figure 2.2:** Calibration plot of attenuated output power vs unattenuated power

The linear fit chosen is of the form:

$$P_{att} = aP_{unatt} + b \quad (2.1)$$

The choice of the initial guess parameters is taken as  $a = 0.001$  (since as already mentioned before, attenuated power is around 1/1000 of the unattenuated power, due to use of ‘1000:1’ attenuator) and  $b = 0$  (y intercept expected to be a very small value, by visually extrapolating the data points). Indeed, after running the curve fitting procedure, we get fit parameters close to our initial guess:  $a = 0.000994 \pm$

$1.25 \times 10^{-6}$  and  $b = -0.016 \pm 0.006$ , giving:

$$P_{att} = (0.000994 \pm 1.25 \times 10^{-6})P_{unatt} + (-0.016 \pm 0.006)$$

Now we use the commonly applied reduced  $\chi^2$  test, to find the goodness of fit for this linear model:

$$\chi^2 = \sum_i \left[ \frac{y_i(x_i) - f_i(x_i; p)}{\sigma_i} \right]^2 \quad (2.2)$$

where  $y_i(x_i)$  are the recorded y values (attenuated power in this case),  $f_i(x_i; p)$  is are y values from the fitting function with  $p$  parameters (in this case the linear fit function with parameters  $a$  and  $b$ ).

Surprisingly, we get an extremely large reduced  $\chi^2$  value of 174.69.

# Bibliography

- [1] Universität Bonn, *A245 experiment description*.



# Appendix

**Table A.1:** Measured unattenuated and attenuated power of the fundamental beam vs the injection current

$I$ (mA)	$\Delta I$ (mA)	$P_{unatt}$ ( $\mu$ W)	$\Delta P_{unatt}$ ( $\mu$ W)	$P_{att}$ ( $\mu$ W)	$\Delta P_{att}$ ( $\mu$ W)
0	0.5	0	0.01	0	0
5	0.5	1.4	0.01	0	0
10	0.5	3	0.01	0	0
15	0.5	5.1	0.01	0	0
20	0.5	7.3	0.01	0	0
25	0.5	9.6	0.01	0	0
30	0.5	12.2	0.1	0	0
35	0.5	15.6	0.1	0	0
40	0.5	18.6	0.1	0	0
45	0.5	22.7	0.1	0	0
50	0.5	28.2	0.1	0.03	0.01
55	0.5	235	20	0.04	0.01
60	0.5	3130	20	3.2	0.01
65	0.5	5650	20	5.8	0.01
70	0.5	9120	20	8.93	0.01
75	0.5	12900	100	12.6	0.1
80	0.5	16200	100	15.7	0.1
85	0.5	19000	100	18.1	0.1
90	0.5	21730	104	21.6	0.1
95	0.5	25048	106	24.9	0.1
100	0.5	28064	107	27.9	0.1
105	0.5	30879	108	30.7	0.1
110	0.5	33995	109	33.8	0.1
115	0.5	36508	111	36.3	0.1
120	0.5	40630	113	40.4	0.1
125	0.5	43847	115	43.6	0.1
130	0.5	47064	117	46.8	0.1
135	0.5	49778	119	49.5	0.1
140	0.5	53095	121	52.8	0.1
145	0.5	56212	123	55.9	0.1
150	0.5	60132	126	59.8	0.1
155	0.5	63249	128	62.9	0.1
160	0.5	65058	130	64.7	0.1
165	0.5	68476	133	68.1	0.1
170	0.5	71190	135	70.8	0.1
175	0.5	74709	138	74.3	0.1
180	0.5	76820	140	76.4	0.1
185	0.5	80740	143	80.3	0.1
190	0.5	84661	147	84.2	0.1
195	0.5	86470	148	86	0.1
200	0.5	89888	152	89.4	0.1
205	0.5	93608	155	93.1	0.1
210	0.5	99137	160	98.6	0.1
215	0.5	98534	160	98	0.1
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Table A.1 – continued from previous page

$I$ (mA)	$\Delta I$ (mA)	$P_{unatt}$ ( $\mu\text{W}$ )	$\Delta P_{unatt}$ ( $\mu\text{W}$ )	$P_{att}$ ( $\mu\text{W}$ )	$\Delta P_{att}$ ( $\mu\text{W}$ )
220	0.5	100544	162	100	0.1
225	0.5	106576	520	106	0.5
230	0.5	109592	521	109	0.5
235	0.5	109592	521	109	0.5
240	0.5	114618	523	114	0.5
245	0.5	117634	524	117	0.5
250	0.5	120650	525	120	0.5
255	0.5	121655	526	121	0.5
260	0.5	125676	527	125	0.5
265	0.5	132713	530	132	0.5
270	0.5	134724	531	134	0.5
275	0.5	134724	531	134	0.5
280	0.5	141761	533	141	0.5