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Photodiodes selection for the VIRGO detector, the first step

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Abstract

In the framework of the Gravitational Waves detector VIRGO, we are developing the photo detectors system. The diodes we will use must satisfy at the same time quite unusual criteria, among them a good quantum efficiency at a wavelength of 1.06 μm and a good linearity at MHz frequencies for an incident light power of 100 mW. We present here the test method and the first very promising results we obtained towards these directions with commercially available diodes in InGaAs.

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Introduction

The VIRGO experiment aims at the detection of Gravitational Waves. A large interferometer, with 3 km arm length is kept on its dark fringe. A Gravitational Wave is expected to produce a perturbation of the metric which will induce a change in the phase shift between the two arms, producing then a power change of the output signal. This change will be detected by photo detectors. The results presented here concern the choice of diodes capable to achieve this detection.

Aim

At the output of the VIRGO interferometer, we have to detect in vacuum and with high efficiency a light power of 1 watt at 10 MHz. This implies that the foreseen photo diodes located on the detection bench fulfil the following requirements :

- a high quantum efficiency at λ=1.06µm
- a good spatial uniformity of the response
- a good linearity in the response to light power of up to 100 mW in order to achieve the detection of 1 watt in total with a limited number of diodes
- a good high frequency response (the modulation frequency will be in the MHz range)

We have investigated the properties of commercially available detectors in order to explore up to where we could push their limits towards our purpose.

Quantum efficiency

The typical response of standard diodes(1), at a wavelength of 1.06µm, corresponds to 10% quantum efficiency for standard Silicon, to 40% for "special Silicon", to 78% for Germanium and to 85-90% for InGaAs. We have thus concentrated our test efforts first on 1mm and in a second step on 3mm diameter InGaAs diodes, see table 1 and 2. As a coarse measurement gave already a quantum efficiency of 90% (in the range of the commercial specifications), we decided to postpone a refined measurement on the final sample of diodes.

Uniformity of the response (1mm diameter diodes)

A laser beam of width 400µm at the base has been used to scan the whole surface of the photo diodes in steps of $40*40 \mu m^2$. All diodes present a smooth efficiency response compatible with the convolution of the beam shape with the diode surface.

Linearity in DC and high frequency (10MHz)

The experimental set up we used to perform linearity and high frequency response tests is sketched in fig. 1. A polarised laser beam (NdYAG, λ=1.064µm) is modulated in amplitude by the combined effect of Pokels cells and polarising beam splitters. A Si diode and a power meter continuously monitor the power delivered on the tested diode. In this scheme, the incoming DC power is adjusted either by changing the laser intensity or by applying a DC voltage on Pokels cell 1. The high frequency amplitude modulation is achieved by Pokels cell 2.

The DC response of the various 1mm diameter diodes, to a 300µm diameter beam spot localised at the centre of the detectors, is shown on fig. 2, for incident light power up to about 50 mW and for different values of the bias voltage. From these data we conclude that the response is very different from one manufacturer to another. This is very probably due to the different technologies used by the different constructors. We observe as well that the more the bias voltage applied on the photo diodes is increased, the more the linearity of the response is improved. This is particularly important for high incident power.We attribute this effect to the "effective" serial resistance of the photodiode.

It is noteworthy that even if the DC saturation is not observed, as shown on fig. 2, a strong saturation occurs at MHz frequencies, as illustrated on fig. 3. Here is shown the output amplitude of a EOS diode at 10MHz for 0. and 1.5 volts of bias voltage. The used modulation index corresponds to 1% amplitude modulation(2).

The saturation observed at high current is most likely due to an electron-hole recombination effect. In order to investigate a possibility to overcome it, we have modified the light density on the sensitive area of the detector. This is illustrated on fig. 4 where the DC response is plotted as a function of the incident light power of beams with a spot of 1mm and 300µm diameter incident on the EOS diode. Clearly, a saturation due to density effect is observed. This observation, also made on the other tested diodes, lead us to choose 3mm diameter diodes, which allow for larger beam spot size.

The gaussian shape of the beam we used to test the 3mm diodes(3) has a rms value of 0.5mm, which corresponds to a 0.3% power loss with a well centred beam.

In table 2 we summarise the results of our measurements concerning the capacitance, breakdown voltage and dark current of five different 3mm diameter diodes.

Considering the comparatively high dark current of the EGG and Laser Monitoring diodes, we have concentrated our further measurements on the Epitaxx, Hamamatsu and EOS diodes. The detailed measurements performed on the EOS 3mm diode are shown on fig. 5, both for the DC and 10MHz modulation up to an incident light power of 100mW. It is worth mentioning that with 100mW incident light power on a diode working at 10 volts bias, one dissipates about 1W, which may lead to an important temperature increase.During our measurements the diodes were equipped with an aluminium heat sink. We present the linearity response of the EOS, Epitaxx and Hamamatsu diodes on fig. 6. These three detectors present a satisfactory linearity. They will be investigated further because they are potentially good candidates for the VIRGO signal detection.

Conclusion

We have investigated the properties of InGaAs diodes of 1 and 3mm diameter that are now commercially available. We found:

- a very satisfactory uniformity of the response over the whole surface of the 1mm diameter investigated diodes,

- a saturation effect at high light intensity. Saturation is reduced by applying a bias voltage,

- a density effect which lead to the use of 3mm diameter diodes. This effect limits the frequency response due to the larger capacitance of the diode because of the non zero value of its "effective" resistance.

At least three today available diodes can detect with good linearity a 100mW light beam carrying a 10MHz signal. From these very promising results, we conclude that diodes available now on the market will very probably fulfil the VIRGO requirements: the tested diodes work even far away from their stated maximum rating values (sometimes a factor of 10).

Before the final choice, a detailed efficiency map and an accurate quantum efficiency measurement have to be done. Further tests will also be performed concerning:

- the noise
- the response with large index of modulation
- the behaviour in vacuum.

The reliability of these results will be checked on a statistically significant number of diodes. Their long term behaviour at high current (we have not yet tried more than 12 hours runs at 100mW incident power) will also be studied.

Figure caption:

Fig. 1 - Experimental set up used to perform linearity and high frequency response tests.

Fig. 2a and 2b - The DC response of the 1mm diameter diodes, to a beam focalised as a spot of 300μm diameter at the centre of the detectors, for incident light power up to about 50 mW and for different values of the bias voltage. The lines drawn on the graph correspond to a straight line fit.

Fig. 3 - Amplitude at 10MHz of the response of an EOS diode, normalised to the total incident power for 0. and 1.5 volts of bias voltage. The lines drawn on the graph are guide to the eyes.

Fig. 4 - DC response as a function of the incident light power for a beam with a spot of 1mm and 300μm diameter for the EOS diode (1mm diameter).

Fig. 5 - Detailed measurements performed on the 3mm diameter EOS diode, both for the DC response and the 10MHz response up to incident power of 100mW. The lines drawn on the graph are guide to the eyes, Id = diode current.

Fig. 6 - Linearity response in DC mode and at 10MHz of the EOS, Epitaxx and Hamamatsu diodes. The lines drawn on the graph correspond to a straight line fit.

References

1) Data from commercial data sheets of the following firms:

Si diodes -	CAL- Sensors Inc
Si enhanced diodes -	CENTRONIC Serie 4
Ge diodes -	Germanium Power Devices
InGaAs diodes -	Hamamatsu

2) A DC voltage corresponding to a 45° rotation of the E field was applied on Pokels cell 1 in order to avoid non linear effects during the high frequency tests.

3) VIRGO beam imaging system
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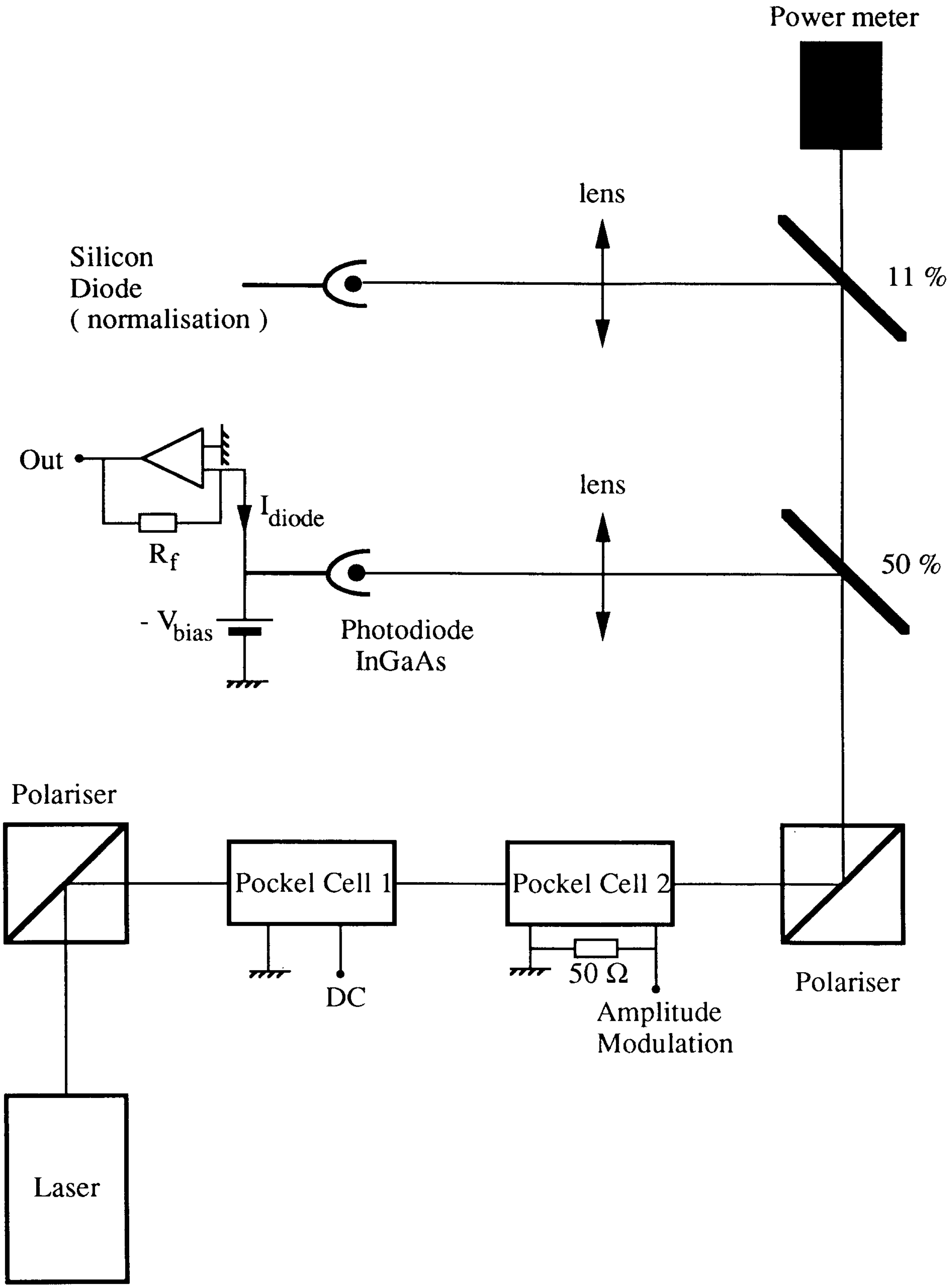
	Telcom Simple	Fermio -nics	E.G.G	Epitaxx	E.O.S	Laser Monito -ring	Hamama -tsu
Capacitance @ V_{bias}=10V	38 pF	25.3 pF	18.2 pF	-	-	26.5 pF	25 pF
Breakdown voltage @ 10 μA	75 V	not well defined	60 V	-	-	not well defined	70 V
Darkness current @ 10 V	2.5 nA	-	2 nA	-	-	150 μA	2 nA

Table 1: Photodiodes InGaAs 1mm of diameter

	E.G.G	Epitaxx	E.O.S	Laser Monitoring	Hamamatsu
Capacitance @ V_{bias}=10V	144 pF	330 pF	253 pF	125 pF	-
Breakdown voltage @ 10 μA	not well defined	30 V	85 V	not well defined	80 V
Darkness current @ 10 V	1 μA	11.5 nA	1 nA	150 μA	150nA

Table 2: Photodiodes InGaAs 3mm of diameter

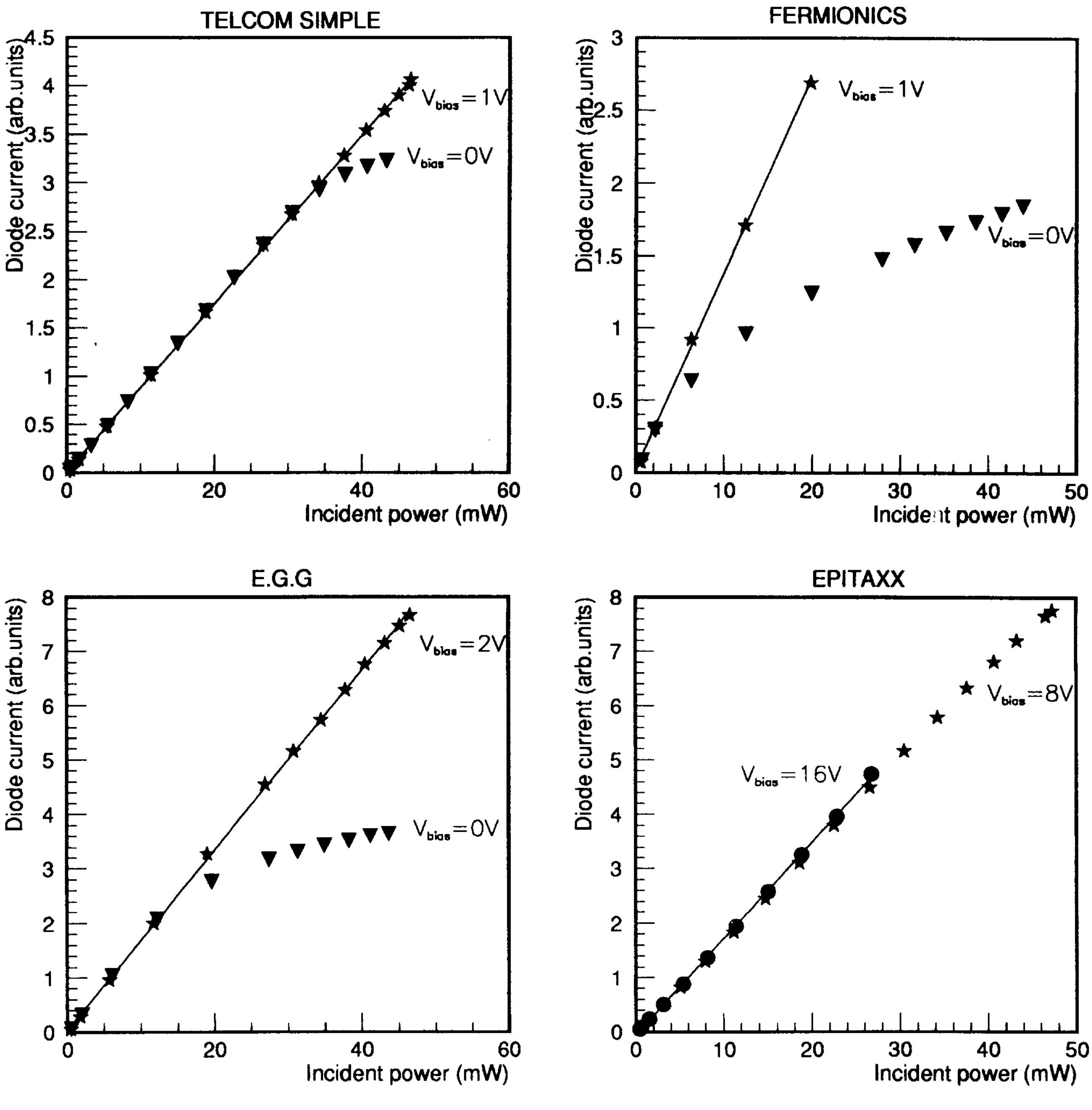
Experimental set-up



- Figure 1 -

PHOTODIODE RESPONSE VERSUS INCIDENT POWER FOR DIFFERENT InGaAs DIODES TYPES

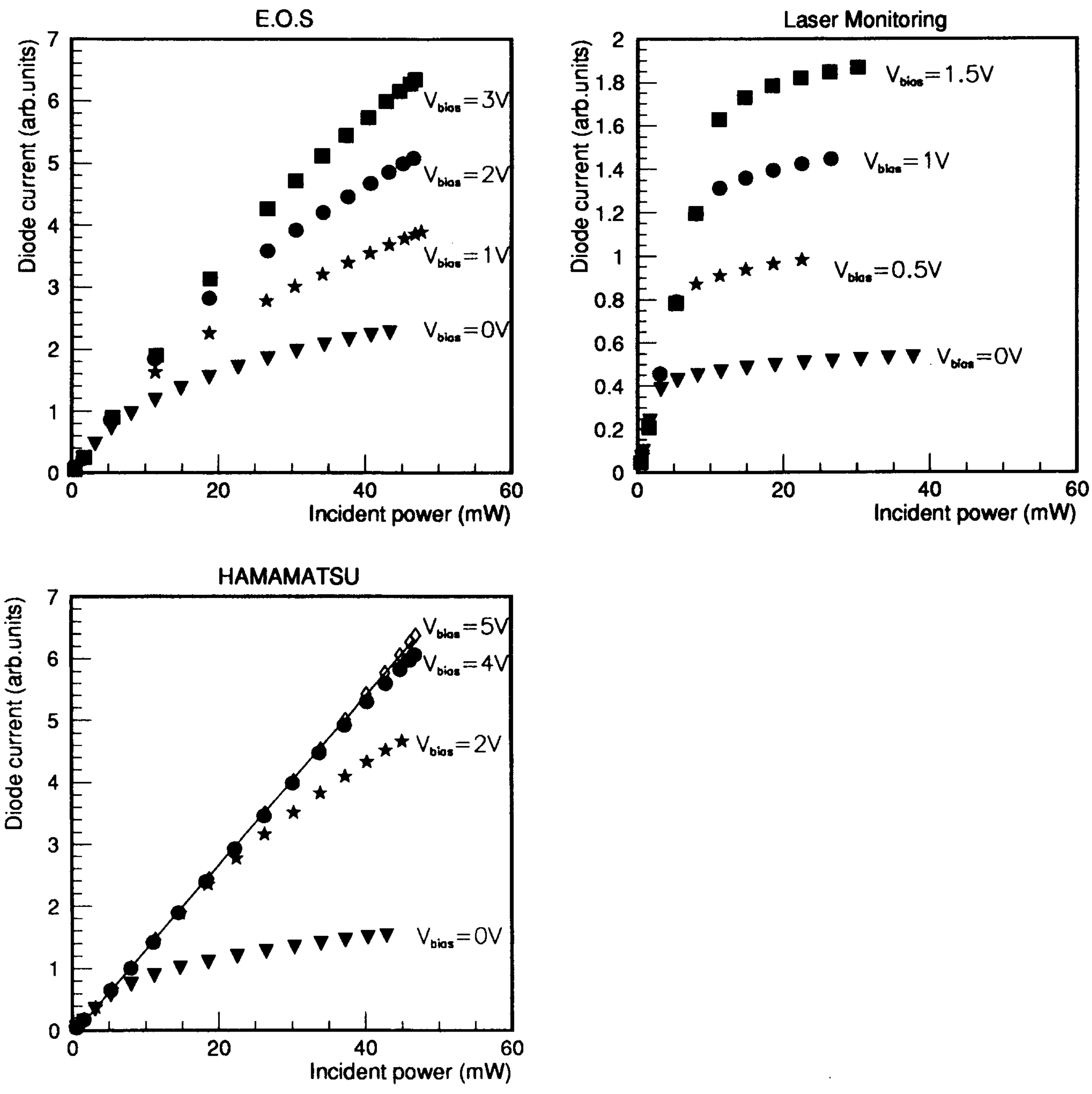
- 1mm diameter -



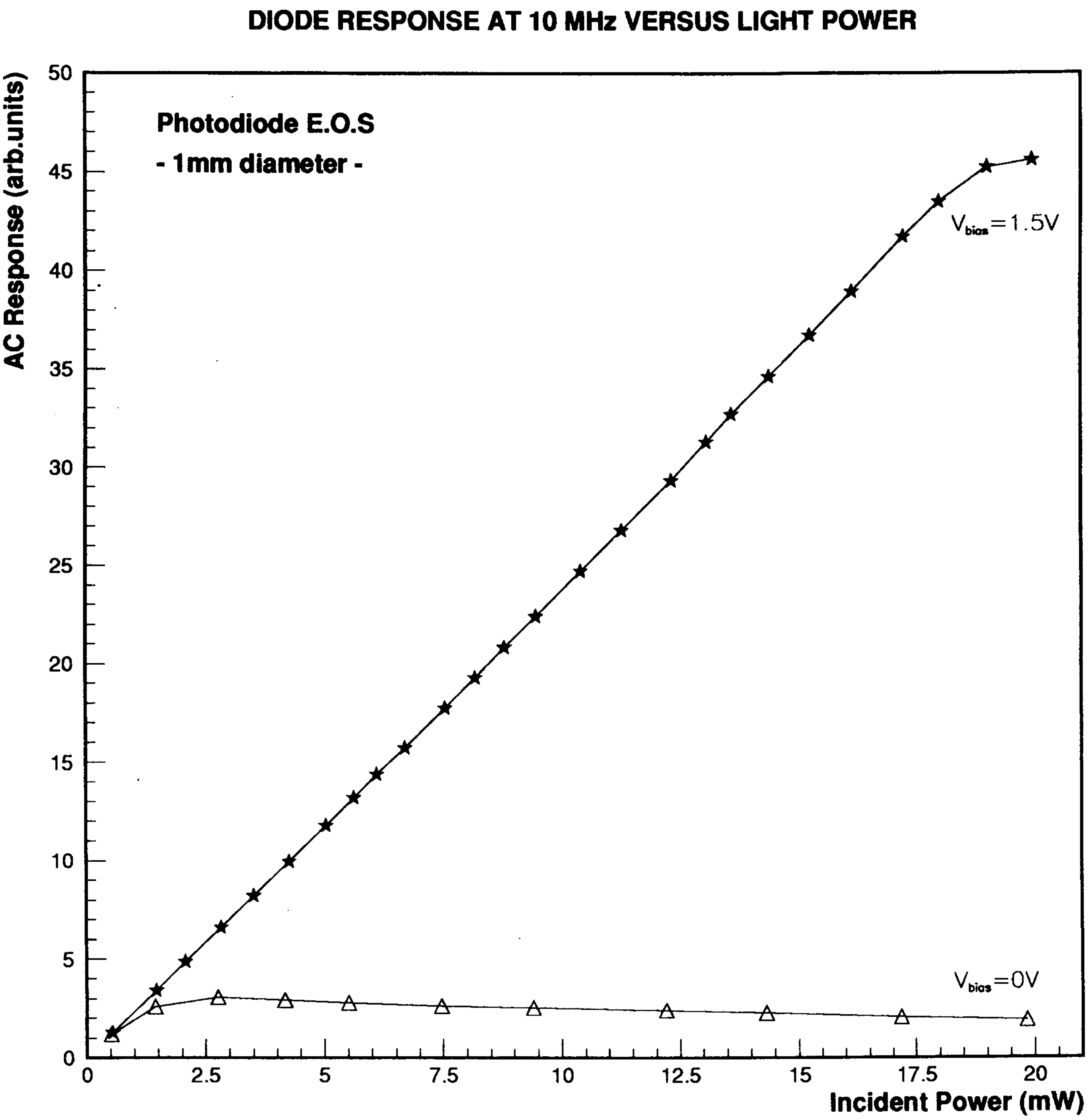
- Figure 2a -

PHOTODIODE RESPONSE VERSUS INCIDENT POWER FOR DIFFERENT InGaAs DIODES TYPES

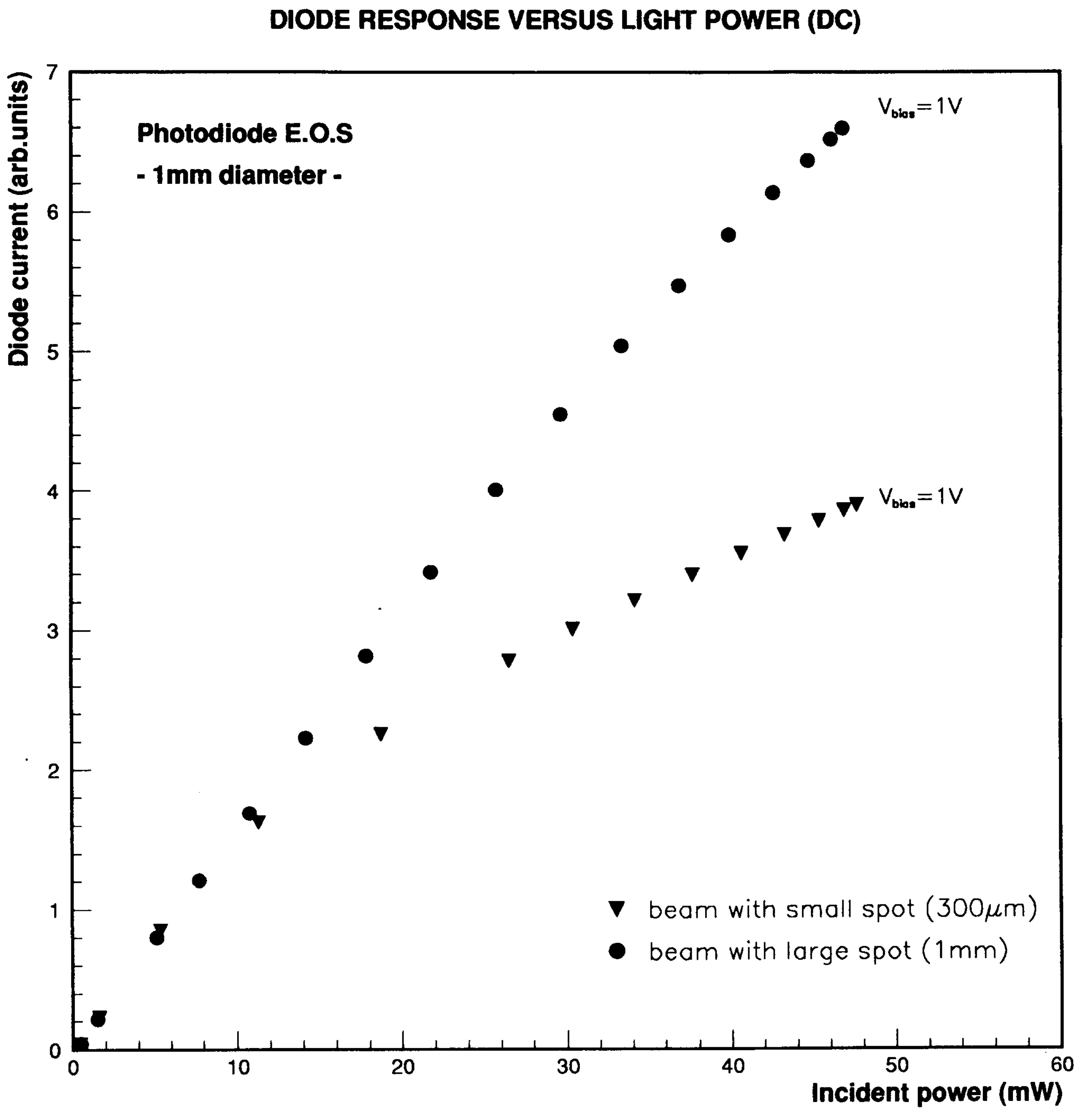
- 1mm diameter -



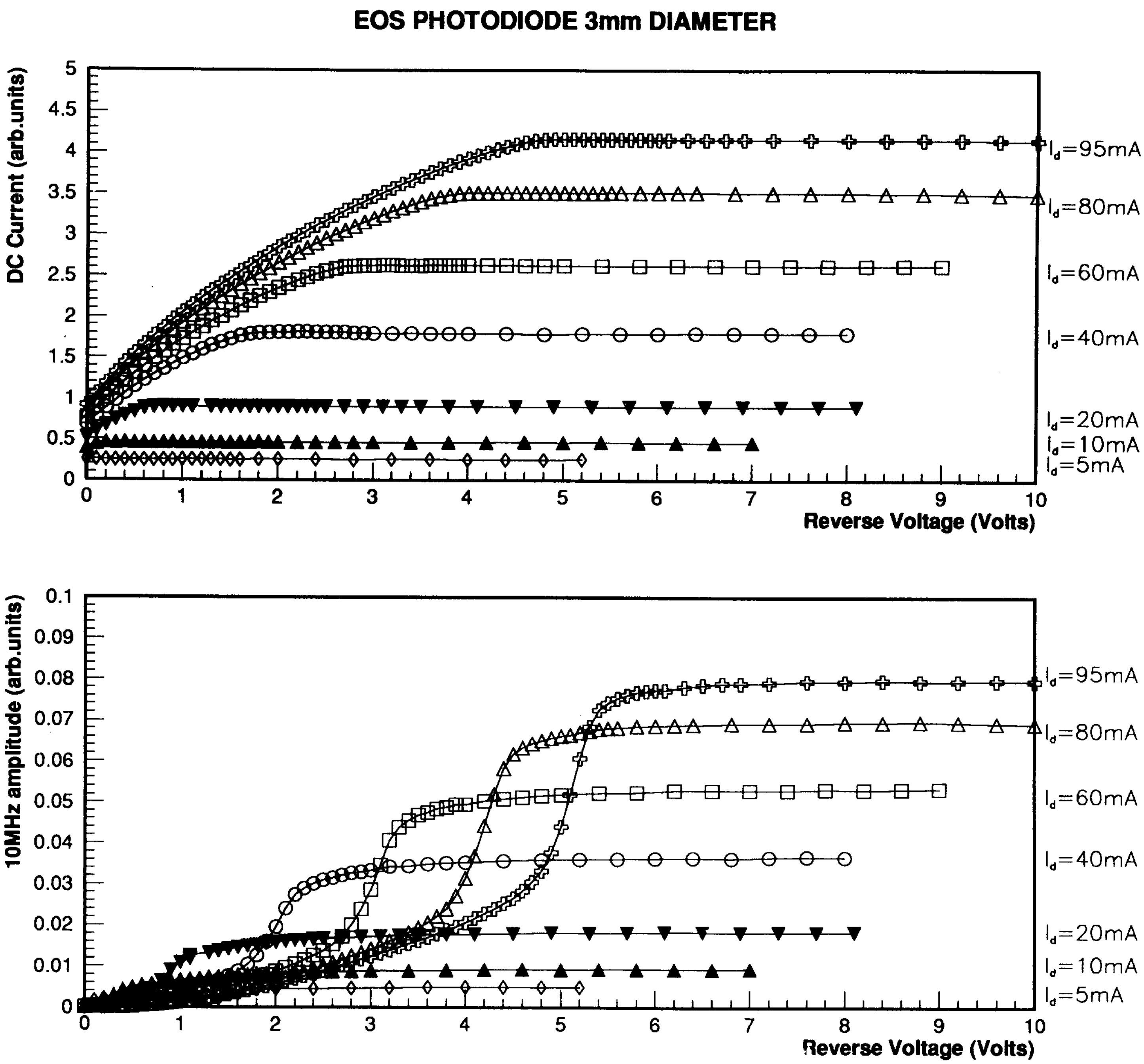
- Figure 2b -


DIODE RESPONSE AT 10 MHz VERSUS LIGHT POWER
Photodiode E.O.S
- 1mm diameter -
V_bias=1.5V
V_bias=0V
AC Response (arb.units)
Incident Power (mW)
0
5
10
15
20
25
30
35
40
45
50
0
2.5
5
7.5
10
12.5
15
17.5
20

- Figure 3 -

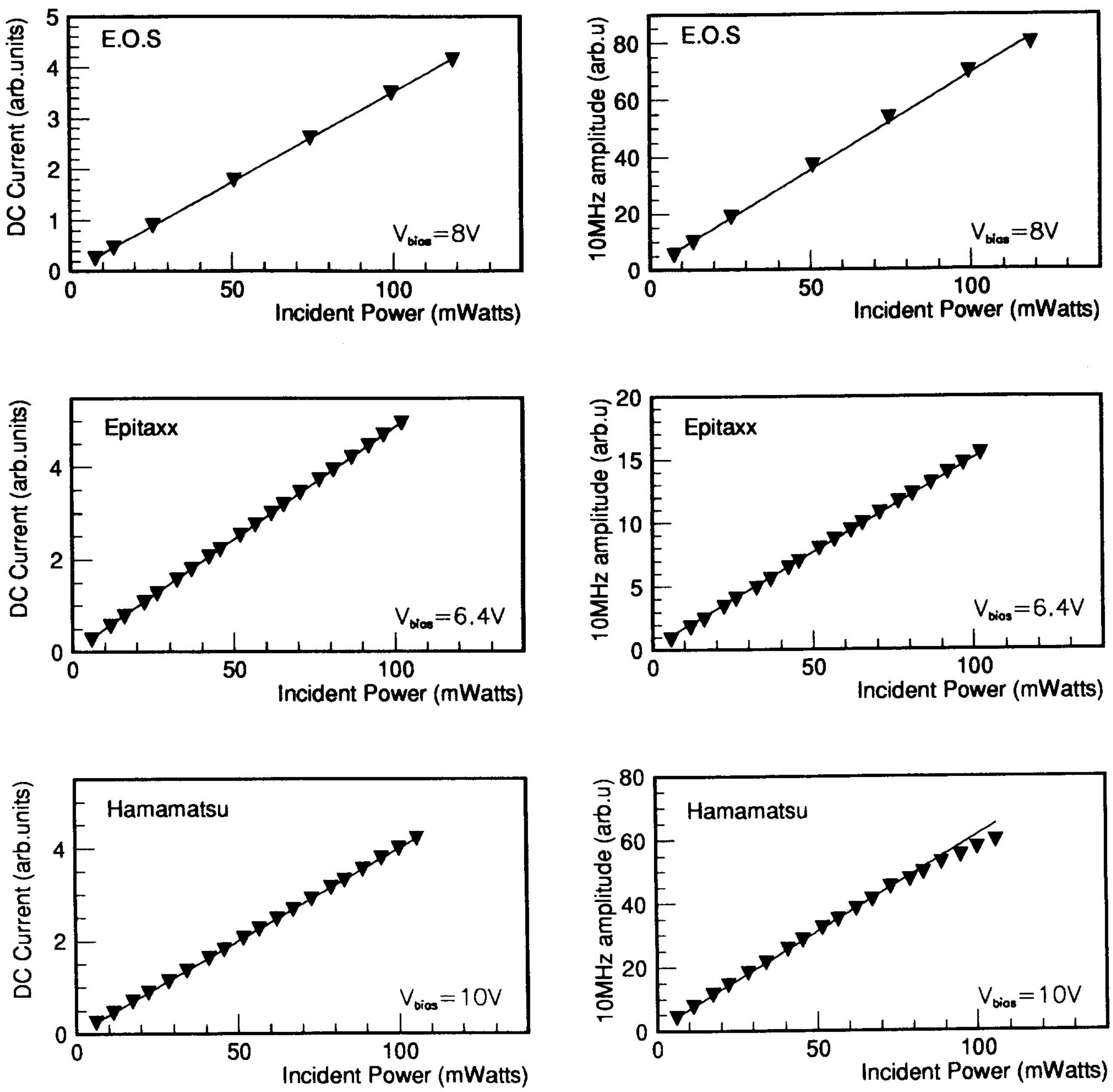

DIODE RESPONSE VERSUS LIGHT POWER (DC)
Photodiode E.O.S
- 1mm diameter -
Diode current (arb.units)
Incident power (mW)
V_bias = 1V
V_bias = 1V
beam with small spot (300μm)
beam with large spot (1mm)
0
1
2
3
4
5
6
7
0
10
20
30
40
50
60

- Figure 4 -


EOS PHOTODIODE 3mm DIAMETER
DC Current (arb.units)
Reverse Voltage (Volts)
I_d=95mA
I_d=80mA
I_d=60mA
I_d=40mA
I_d=20mA
I_d=10mA
I_d=5mA
10MHz amplitude (arb.units)
Reverse Voltage (Volts)
I_d=95mA
I_d=80mA
I_d=60mA
I_d=40mA
I_d=20mA
I_d=10mA
I_d=5mA

- Figure 5 -

LINEARITY OF InGaAs PHOTODIODES - 3mm DIAMETER



- Figure 6 -