Methods to determine fluence threshold for CVD diamonds

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29.8.2011

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Abstract

In this work I present how X-ray damages CVD diamond. Our main goal is to determine the fluence damage threshold. For that we need to determine the energy threshold and effective beam area. In order to determine these quantities we need to measure the damage area. I will present the primary method used by XFEL optics group to measure the size of this damage area. This method uses a graphical program called gimp and is strongly operator dependent. In order to make the whole procedure faster and easier, we have programmed an automated matlab program that measures the damage area of the surface. Results gained from this program are then compared with results from hand measurements.

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Introduction

The European X-ray free electron laser (XFEL), which is currentlyunder construction, will be one of the most advanced research facilities in the world. The x-ray FEL will deliver 27 000 ultrashort coherent X-ray pulses per second with a peak brilliance10^9 higher compared to synchrotron light X-ray sources. It is obvious that this 4^{th} generation light source of such a unique characteristics requires technological equipment with very specific properties.This laser system will be very demanding on optical elements of the beam line.

European XFEL optics groupis in charge of the beam-line design and the development of the beam transportation system. It is crucial for our group to know how the x-ray beam affects mirrors and other optical elements of the beam line.

The interaction of such FEL light pulses with solids is still not completely understood. The lack of knowledge in this field leads to serious limitations in designing beam line optics. Firstly we must understand the laser-matter interactions.

The FEL pulse carries a large amount of energy which can lead to damage from phase transition toablation of the optical elements of the beamline. Our main goal is to determine the fluence threshold of damage. In order to determine this we need energy damage threshold and effective beam area.These two basic properties can be determined by the damage to energy dependencies. While energy of the pulse is measured during the experiment, the damage area must be measured from surface pictures measured by optical microscopy. In order to do these measurements we use a graphical program gimp, in which we could easily select the damage area. But this technique strongly depends on the user and is not very uniform. Therefore our task was to create a program that will automate these measurements and reduce the user dependence.

Method

Nowadays the most commonly used materials for optical elements of beamlines are carbon based materials. Among them, diamonds have very good optical properties such as low absorption coefficient and can be used as crystal monochromator.

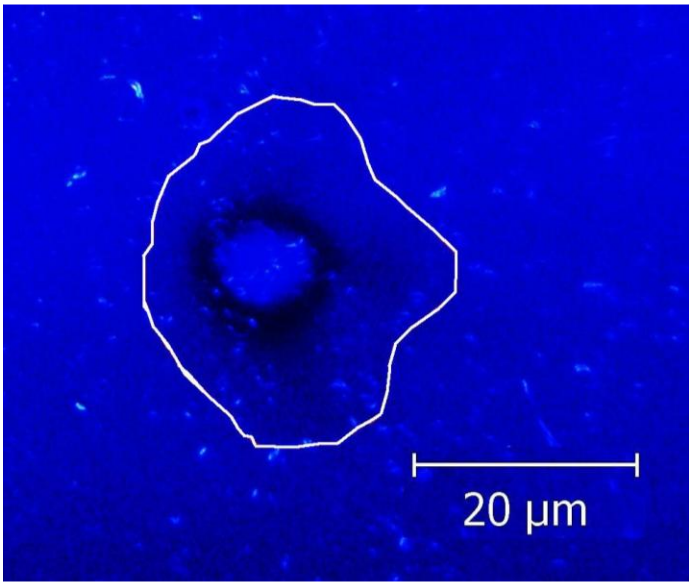

Fig 1.Damage of CVD diamond. The white line defines the outer contour used to measure the damage threshold.

In order to determine the fluence damage threshold single crystal diamond was exposed to single FEL pulses with different energies. The experiment was performed at Spring-8 Compact SASE Source (SCSS) facility in Japan at 51 and 60 nm wavelength. The beam causes damage to the surface of the diamond due to energy it carries. Of course, the larger the energy of the beam, the larger is the damage done to the CVD diamond. The samples were investigated using an optical microscope. Each picture of the damage area was takenby a CCD camerafixed on the optical microscope (Fig 1.). There are two clearly visible damage areas. The external one (faint) corresponds to the lowest damage threshold while the inner surface corresponds to large damage. But investigations of these damage processes are beyond the scope of this paper.

One of the basic properties of the material is the threshold damageenergy which is the energy of zero ablation. For each shot the area of outer contour of the damage was measured and correlated with measured laser energy. To measure the damage area we used the graphic program called gimp. In this program we selected by hand the outer contour of the damage area and measured the number of pixels enclosed by this contour. Then using a simple mathematical formula we converted the damage area from pixels to μm². The dependence of the surface to the damage area is shown in Fig 2. for 60nm and 51nm CVD diamond.

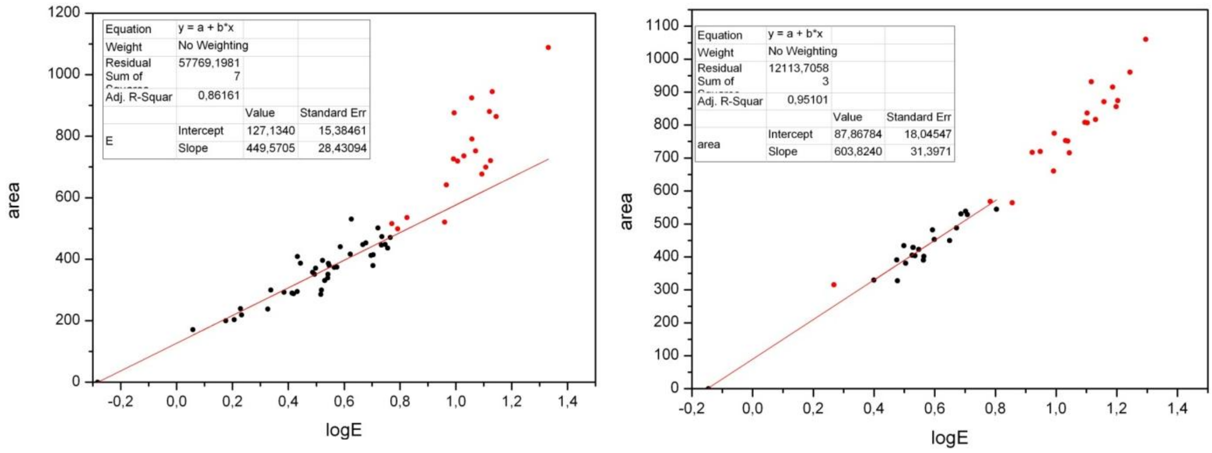

Fig 2. 60nm(left) and 51nm(right) CVD diamond, damage area versus log(E) of the laser pulse. Measurements made with gimp

Another important characteristic is the effective area of the non-Gaussian beam. Effective area of the beam is utilized to characterize the real beam spot area. In order to calculate its valuewe have to normalize energies with threshold energy. Then we can plot the dependence of normalized energy to surface of the damage which is shown in Fig 3. The effective area is calculated as numeric integral of this dependence.

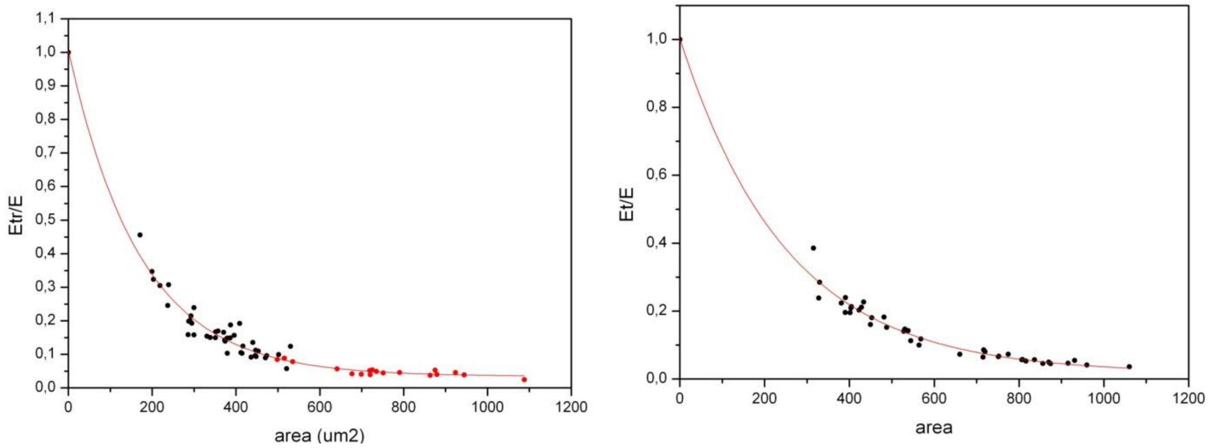

Fig 3.Dependence of normalized energy on surface of 60nm(left) and 51nm(right). Measurements made with gimp

While the technique of measuring damage area is simple, it depends on the scientist's "eyes". Therefore we have developed a program in matlab that is capable of finding the outer contour of the damage area and then calculating the number of pixels enclosed by this contour. Before the contour is drawn the program performs several additional graphical changes to the original picture. First the picture is cropped, turned to negative and gray scale. Then it applies a filter and enhances contrast in order to reduce background. After that the picture iscontoured. The users' interface is therefore reduced only to choose the correct contour around the damage area, rest is automated. After choosing the right contour the program calculates the amount of pixels enclosed by this contour. The results and the name of file are then saved to a user-specified location and file. The flow diagram of the program is split in two parts (see in appendix).

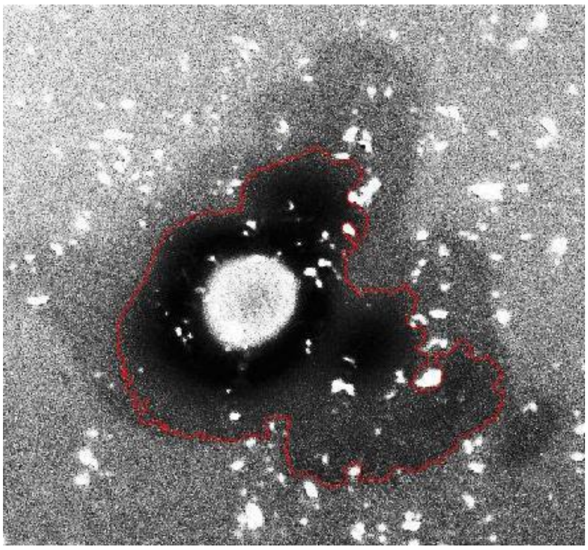

Fig4.Contour selection

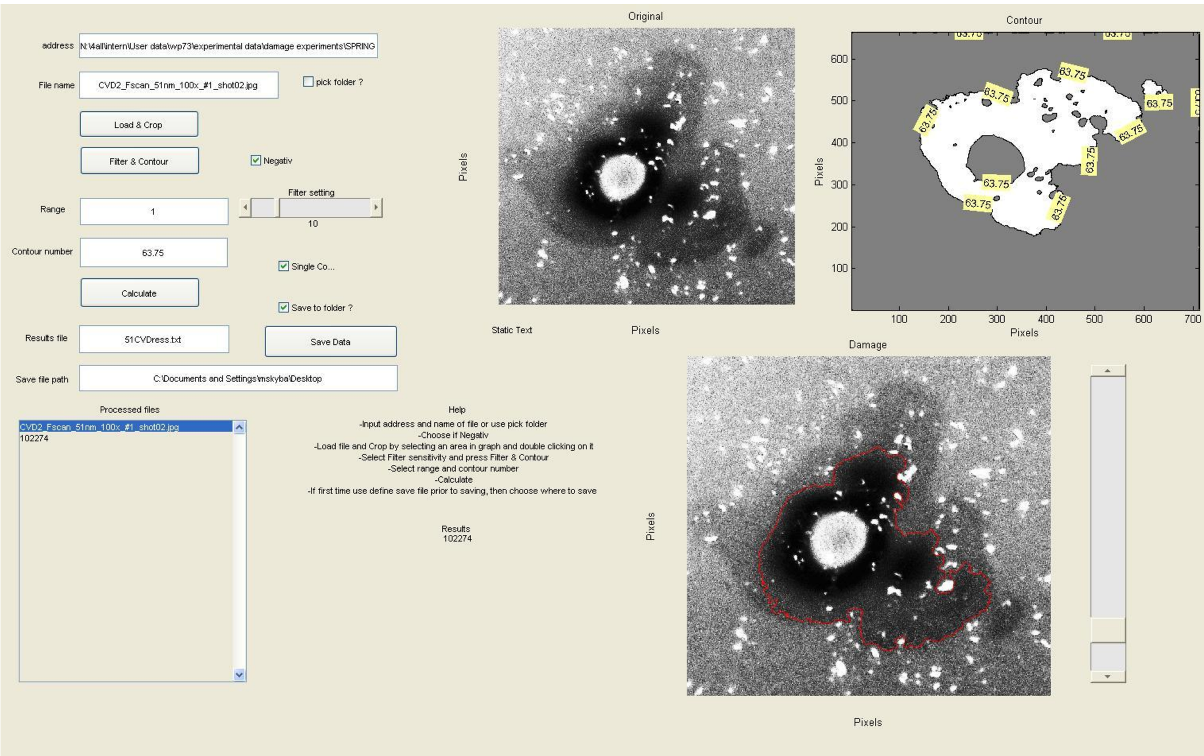

Fig5.Program layout

Results

First measurements of damage area were made by hand on the 60nm and 51nm CVD diamond.

For 60nm CVD diamond the threshold energy was determined as intersection point with X-axis of linear fit of the dependence of damage area on logE (Fig 2.). The threshold energy is E_{TR}=0.52μJ.

Then we plotted the dependence of E_{TR}/E (normalized energy) on damage area. This dependence was fitted by exponential decay function and was integrated (Fig 3.). The integral value corresponds directly to effective area of the beam A_H=204.33μm^2.

For the 51nm CVD diamond (tight focus), the threshold energy was E_{TR}=0.72μJ and effective area A_H=263.28μm^2, see fig 2. and fig 3.

After hand measurements we measured damage areas for 60nm and 51nm CVD diamond using the matlab program. The dependence of the damage area versus log(E) is shown in Fig 6. This way the threshold energy is E_{TR}=0.83μJ.

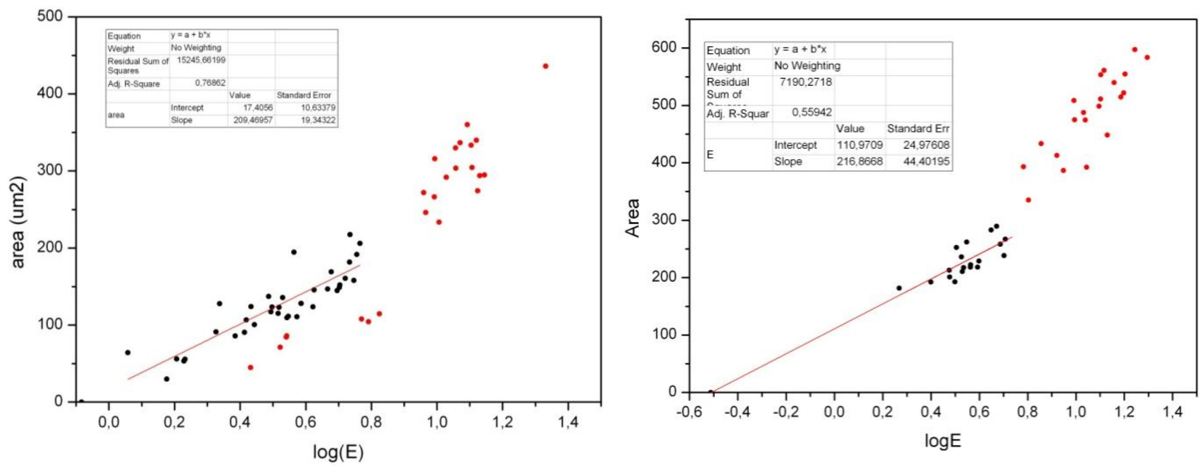

Fig 6.

Dependence of damage area on log(E) for 60nm(left) and 51nm(right) CVD diamond. Program measurement.

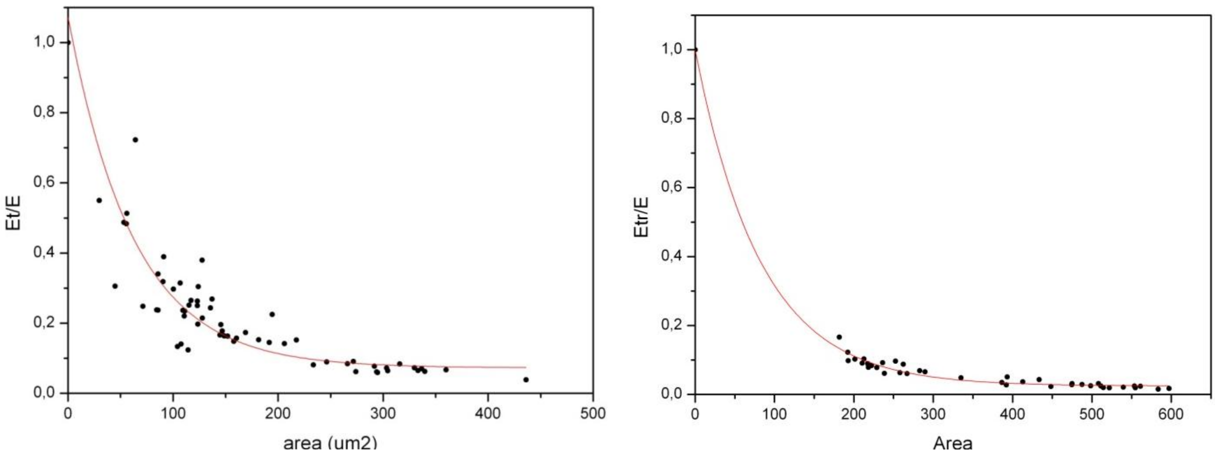

Fig 7.

Dependence of normalized energy on damage area for 60nm(left) and 51nm(right) CVD diamond. Program measurement

Effective area is A_H=94.2µm^2.

Results for 51nm CVD diamond. The threshold energy is E_{TR}=0.31µJ(fig6).

Effective area is A_H=95.44µm^2(fig 7).

If we compare first (gimp) measurements with program based measurements we see that there is a large difference between threshold energies and effective areas. Figure8shows the difference between estimated damage sizes measured by gimp (red) and measured by program (black) in pixels.

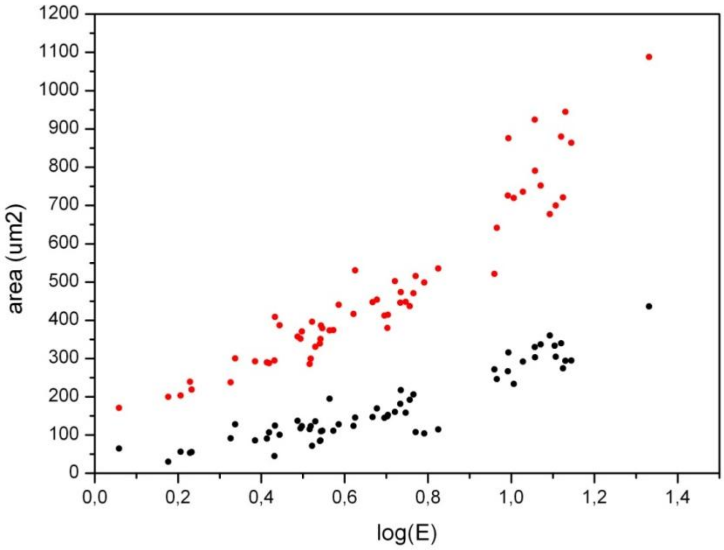

Fig 8.Comparison of measured damage areas between gimp measurement (red) and program measurement (black) in pixels.

This large difference in measured area is caused by the contour selection of the program. The program chooses smaller areas and due to large background neglects faint parts of damage areas mistaking them for background.

wavelength	method	Etr [μJ]	Aeff[μm^2]	Fluence[J/cm^2]
60nm	Gimp	0.52	204.326	0.25
	Program	0.83	94.197	0.88
51nm	Gimp	0.72	263.28	0.27
	Program	0.31	95.44	0.32

Tab 1. Results for 60nm and 51nm CVD diamond using gimp measurements and program measurements

Conclusion

Calculations of damage threshold energy and especially effective areaof beam strongly depend on the damage area measurements. Although gimp measurements seem to be less accurate and are slow, they tend to lead to better results in effective area of beam in case of very faint damage. On the other hand program is fast and very accurate. It works perfectly for high contrast damage and is currently being used in the group.But for the low contrast damage, the damage areas are smaller due to large background that covers areas with very faint damage. In the example case presented here, CVD diamond irradiated by VUV radiation, the damage was very faint and therefore we have large differences between the program and gimp measured results. We did the first steps in automation of our method but in order to make our program work more accurately for low level contrast pictures we need to find a way to subtract disentangle background and faint damage area.

Further references

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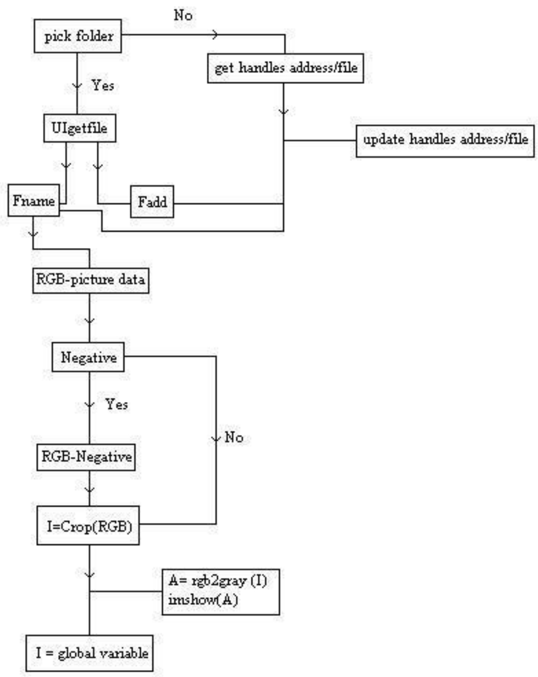
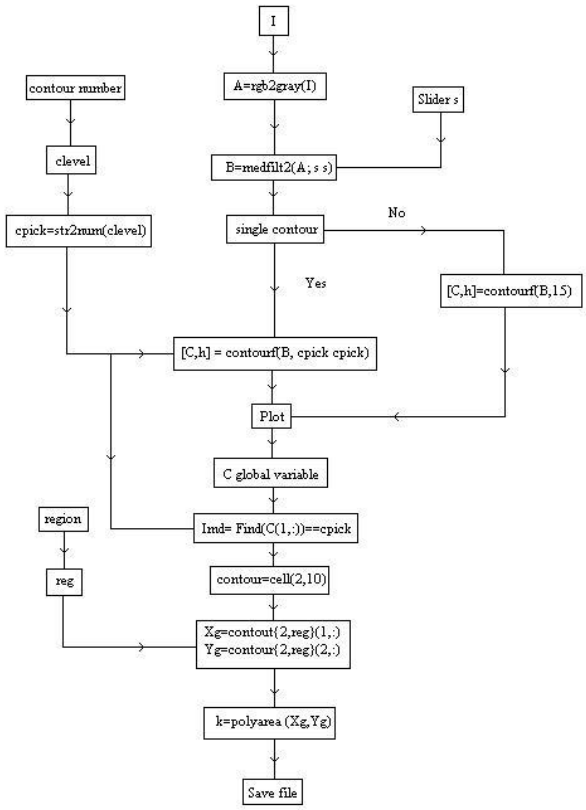
Appendix



First part of flow diagram



Second part of flow diagram.