Radiation Damage of CVD Diamond Detector RD42 Note No. 16

The RD42 Collaboration

presented by

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Abstract

A simple phenomenological model of radiation damage on CVD diamond detector has been developed. The model postulates a) absorption of ionized charge with a local charge absorption length linearly proportional to the depth measured from the surface the CVD diamond and b) uniform creation of charge traps with a density proportional to the fluence independent of sample characteristics. The former is represented by a coefficient unique to each sample and the latter is represented by a factor universal to all CVD diamond irrespective of crystalline growth of each sample. Data on a variety of samples exposed to 300 MeV/c π^+-beam were well reproduced by such model.

1 Introduction

So-called "linear Model" has long been speculated by observing approximate proportionality of the charge collection distance of CVD diamond with the depth of the growth of polycrystalline structure. However a recent test using latest samples scraping the thickness from either side, 'substrate side' or 'growth side', in steps verified the validity of an explicit linear model.
In the meantime data on the radiation damage of CVD diamond has been systematically accumulated using $\gamma-$, π^+-, $p-$, and $n-$ beams in wide range of fluence. These two developments combined now prompt us to formulate a comprehensive description of the radiation effect.

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In the following we attempt to formulate a phenomenological description of radiation damage based on a simple principle and test it on a set of data of charge collection distance (CCD) of a number of CVD diamond samples repeatedly exposed to 300 MeV/c π^+ beam. The data set is plausible because 300 MeV/c π^+ is heavily damaging and also it includes the diamond samples of wide range of thickness and quality of crystalline growth in CVD process. In principle the same formula ought to be applicable to the radiation effect by other particles with different parameter values.

2 Formulation and fit to data

There was a set of data on CCD of nine samples taken before, and a set of new measurement on four latest high quality samples has been added recently. The data points are shown in Figs. 1 and 2 with large symbols connected by thick line segments.

It has been known for sometime that charge traps inherent to polycrystalline CVD diamond gives rise to almost linear increase of charge transmission along with the crystalline growth . An explicit model that assumes a local charge absorption length proportional to the depth has been recently developed.

In this "explicit linear model" the charge transmission is expressed by a local charge absorption factor

$$\exp\left(-\frac{|\Delta\,\zeta|}{\lambda^i(\zeta)}\right) \tag{1}$$

where

ζ : depth of the charge measured from original substrate surface,

with charge absorption length $\lambda^i(\zeta)$ of i-th sample given by

$$\lambda^i(\zeta) \;=\; c^i\,\zeta \tag{2}$$

where

c^i : a constant characteristic to i-th sample.

Since diamond is an insulator, the total induced charge, as an average over the surface and over many incident particles, can be calculated by simply integrating the locally induced charge as a function of ζ, z, and z'.

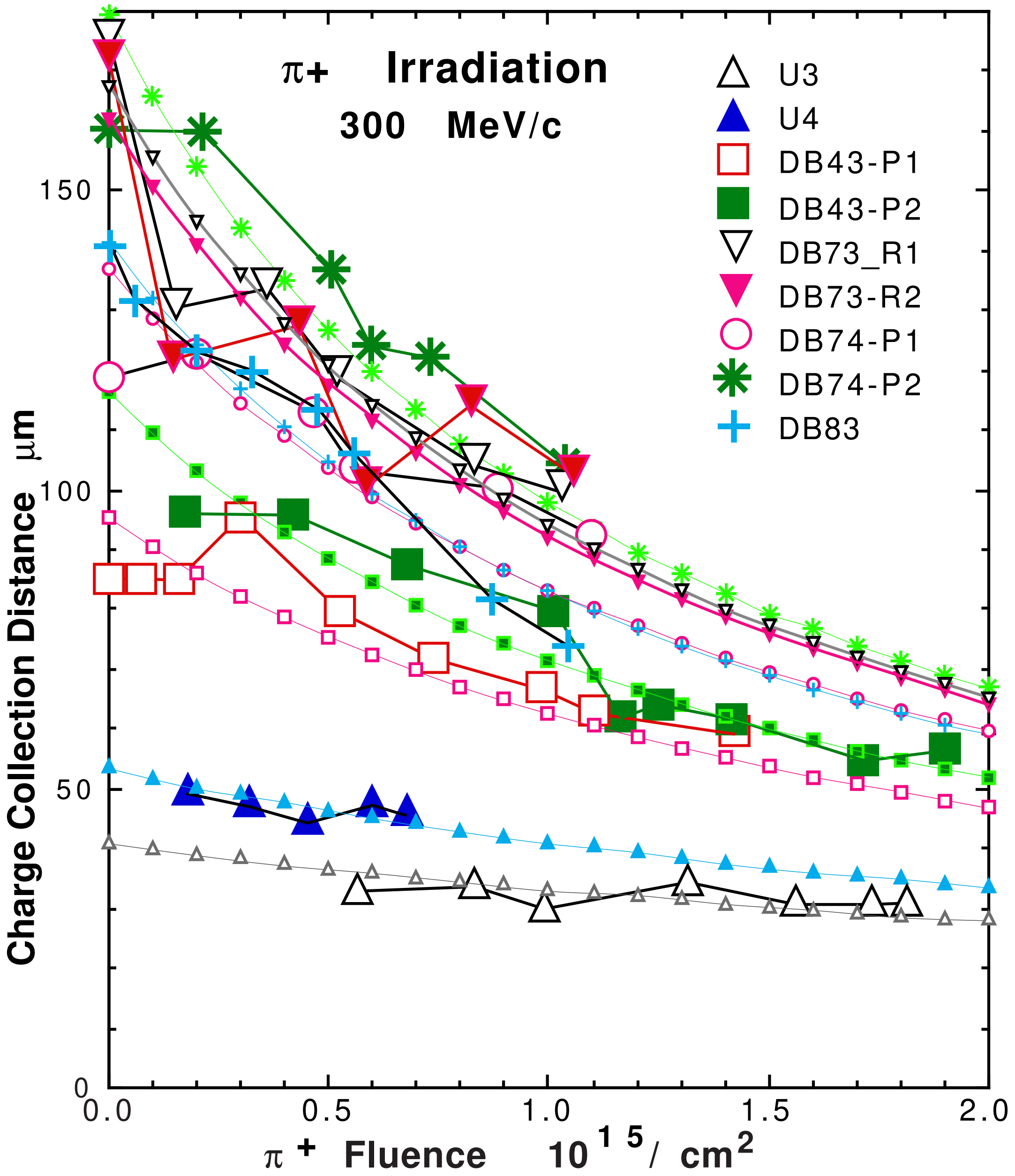

Fig. 1. Pion irradiation data measured before 1999 overlaid with fitted curves. For each sample, Measured (fitted) values of CCD are denoted by large (small) symbols connected by straight lines (a smooth curve).

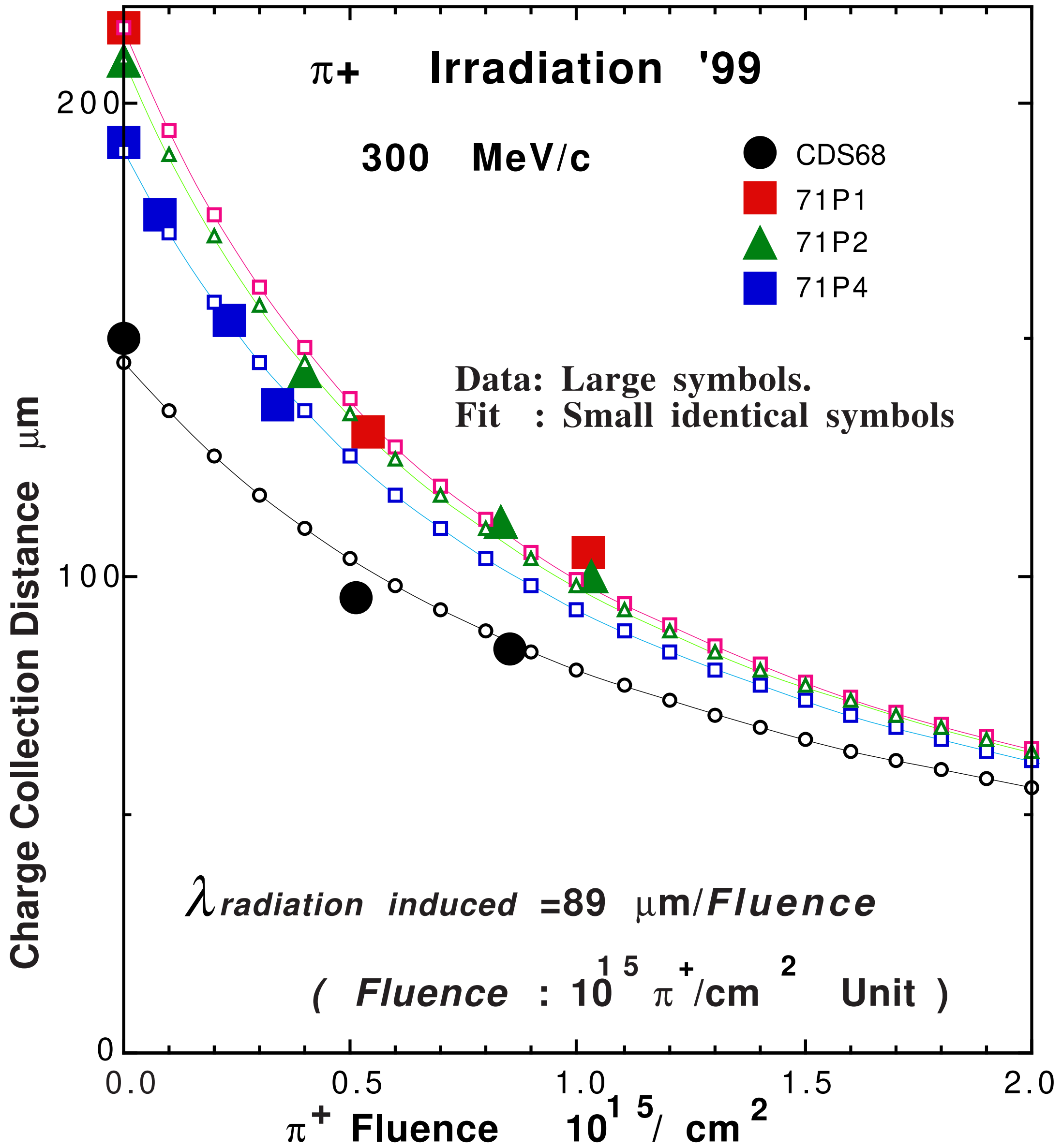

Fig. 2. Pion irradiation data measured in 1999. Notations are the same as Fig. 1

First, integration over ζ gives an absorption factor for a charge deposited at depth z' and travelling at depth$z$ as :

$$\left\{ \frac{T^i - z}{T^i - z'} \right\}^{c^i} \tag{3}$$

where

T^i : as-grown thickness of i-th sample before any lapping.

Then integration over z and z' also can be carried out analytically resulting in the charge induced on the electrodes as :

$$Q^i_{induced} \;=\; Q^i_{deposited}\, T^i\, f(c^i, r^i).$$

f is a function of r, a dimensionless ratio

$$\frac{T^i_s}{T^i} \tag{4}$$

where

T^i_s : Thickness scraped off from substrate side out of T^i.

given by an explicit formula

$$f(c, r) \;=\; \frac{1}{2}\frac{1}{1-k^2}\frac{1}{1-r}\left[1 + r^2 - k(1-r^2) - 2r^{1+k}\right]. \tag{5}$$

using k, the inverse of c, for convenience:

$$k \;=\; \frac{1}{c}. \tag{6}$$

In the above suffix i was omitted for simplicity.

Therefore the constant c^i can be determined from the measured total induced charge sample by sample. Such model seems to reproduce the measured dependence of the CCD on T^i and the final thickness after removing some thickness from one or both sides of the sample well. Especially the change in CCD of two newly fabricated samples which were scraped in steps, one from substrate side and another from growth side, was well reproduced by this model.

When diamond samples were exposed to high energy radiation, it is natural to assume that that irradiation creates charge traps uniformly which introduces an exponential factor with a single charge absorption length λ_{rad}, constant in the depth and common to all samples:

$$\exp\left(-\frac{|z-z'|}{\lambda_{rad}}\right). \tag{7}$$

The radiation induced absorption length λ_{rad} must be inversely proportional to the pion fluence. We define f_{conv} as a factor that covert $Fluence^{-1}$ into λ_{rad}:

$$\lambda_{rad} = \left(\frac{f_{conv}}{Fluence}\right). \tag{8}$$

The total induced charge can be calculated in the same manner as before. Due to a simple exponential form of the radition induced charge absorption with a constant absorption length, the combined absorption factor is trivially the product of the two factors, (3) and (7). Now the integration over z and z' needs to be carried out numerically. To find out the value of λ_{rad}, we vary f_{conv} and seek for minimum of σ^2_{CCD} summed over all the data points.

The best fit to the old data of nine samples yielded 139 $\mu m \times 10^{15}\pi/cm^2$ and the fit to the latest four samples resulted in 89 in the same unit as the value of f_{conv}. CCD calculated as a function of the fluence using these values is overlaid on the data points in Figs. 1 and 2. The fit is shown by smooth curves conneting small symbols identical to the large symbols of each sample. It is seen that the calculated curves reproduce the general trend well. Although there is a difference between two values, the old data set apparently has a larger systematic uncertainty reflected in the fluctuation of data points. Individual fit shows that the two samples, DB74-P1 and DB74-P2, which are exhibiting significant fluctuation, are dragging the overall fit of f_{conv} towards greater value deviating from the value obtained from the new data set. The fit to the new data set is better possiblly due to better control of the measurement conditions.

3 Conclusions

A simple assumption that the effect of radiation is to create uniformly distributed charge traps, on top of the charge absorption linearly proportional to the depth inherent to CVD diamond, reproduces the trend of signal decrease of

CVD diamond well. The fit to the 300 MeV/c π^+ irradiation data of a number of samples of widely spread quality and thickness yields the radiation induced charge absoprption length of $\sim$ 100 μm for a fluence of $10^{15}\pi^+/cm^2$. Since the observed CCD is the result of the convolution of two charge absorption mechanisms, one pre-existed and another radiation induced λ_{rad}, the effect of the latter is more pronounced for the samples of high CCD in the relative magnitude. The significance of such radiation induced charge absorption length can be understood by comparing with the avarage charge absorption length of un-irradiated sample. If the CCD of un-irradiated sample is of the order of 200 μm, the avarage charge absorption length is $\sim$ 100 μm assuming two charge carriers, electrons and holes, in diamond. A similar analysis on neutron irradation data is in progress.