Nuclear Instrument and Methods in Physics Research A 765 (2014) 12-16

Technology developments and first measurements of Low Gain Avalanche Detectors (LGAD) for high energy physics applications

JC104
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2019-4-19

Introduction

- A new concept of silicon radiation detector with intrinsic multiplication of the charge, called Low Gain Avalanche Detector (LGAD).
- Difference between APD (Avalanche Photo Diode) and LGAD:
  - low gain requested to detect high energy particles
  - the possibility to have fine segmentation pitches
  - thinner devices with the same output signal
- Simulation: effect on geometry of electrodes, structure, doping
- Measurement:
  - I-V, C-V of sensor for wafer uniformity
  - charge collection measurement irradiation/non-irradiation
  - effect of temperature and anneal

LGAD

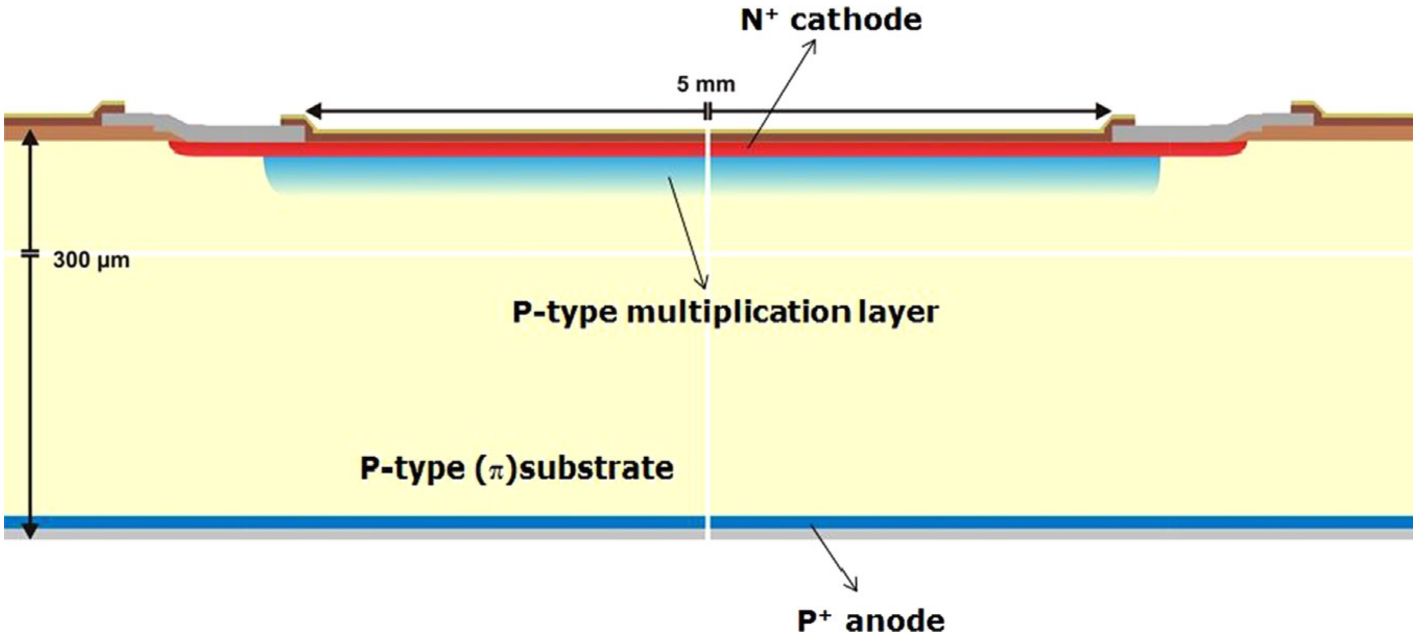


Fig. 1. Schematic cross-section of the LGAD pad design. A p-type layer is diffused below the n þ electrode to form the n+ /p/p- junction where the multiplication takes place.

Simulation of the effect on Boron Implant Dose

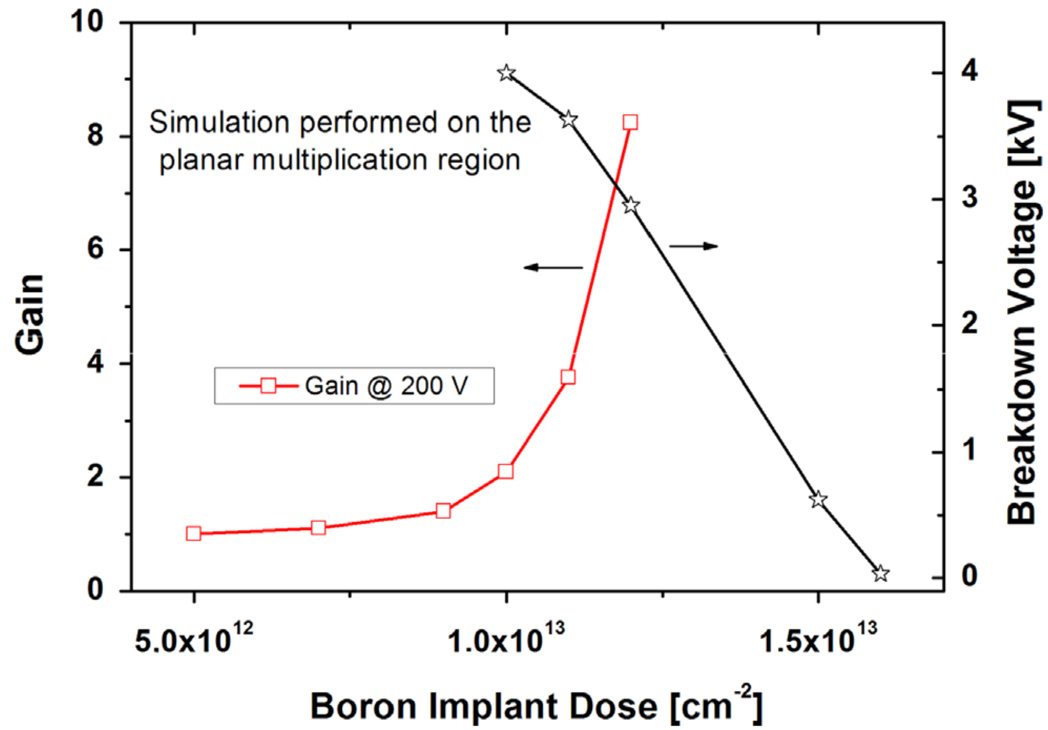


Fig. 2. Simulated dependence of gain and breakdown voltage as a function of the boron dose implanted to form the p well.

Simulation: structure of JTE and field plate

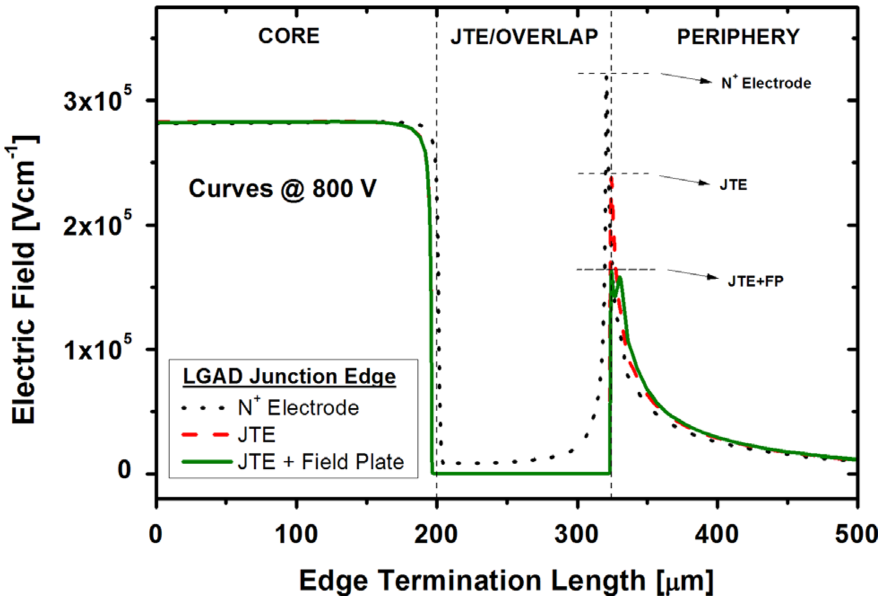


Fig. 3. Simulated electric field distribution at the multiplication junction edge for different termination designs: n+ electrode extension, JTE, and JTE with field plate.

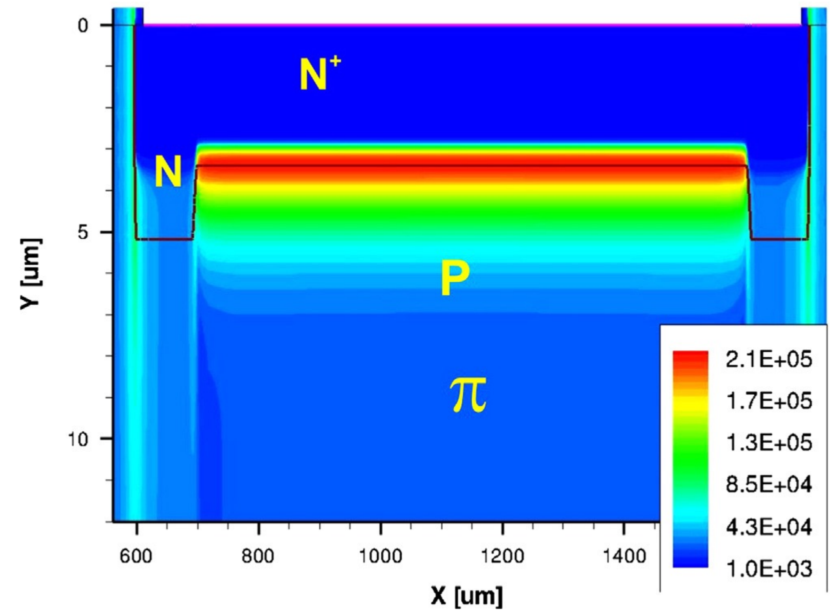
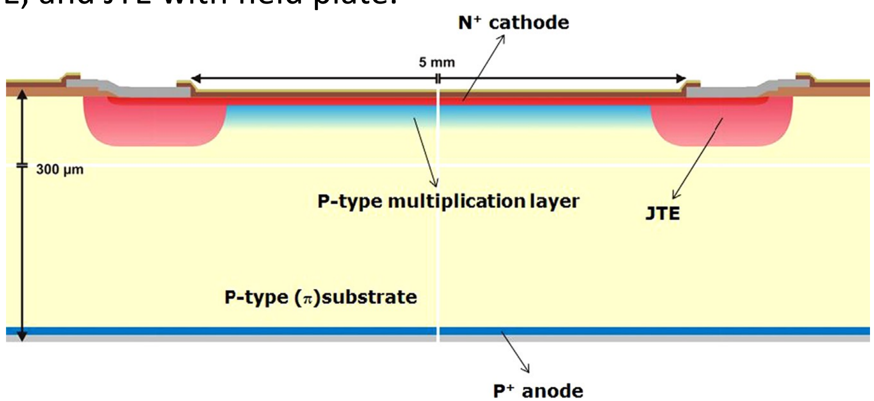


Fig. 5. Simulated electric field distribution throughout the multiplication junction of a LGAD ended with a JTE.



Measurement

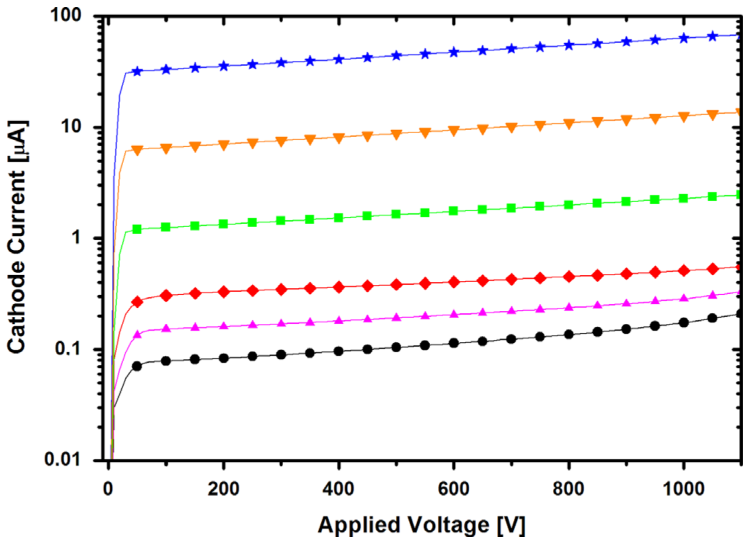


Fig. 6. I–V curves for a sampling of the fabricated device. Each curve corresponds to similar samples located on the same wafer with boron implant dose=1.6*10^{13} cm^{-2}, can be grouped in three ranges, according to their current levels: I<1uA; 1uA<I<10uA; and I>10uA. Voltage capability beyond 1100 V has been shown in all cases.

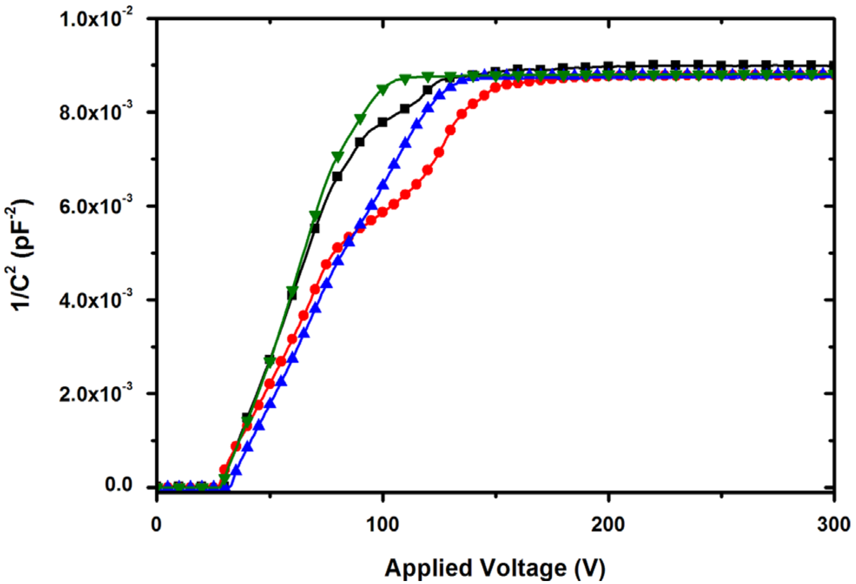


Fig. 7. 1/C2–V curves for a sampling of the fabricated devices. Each curve corresponds to similar samples located on the same wafer with boron implant dose =1.6*10^{13} cm^{-2}

Charge collection measurement

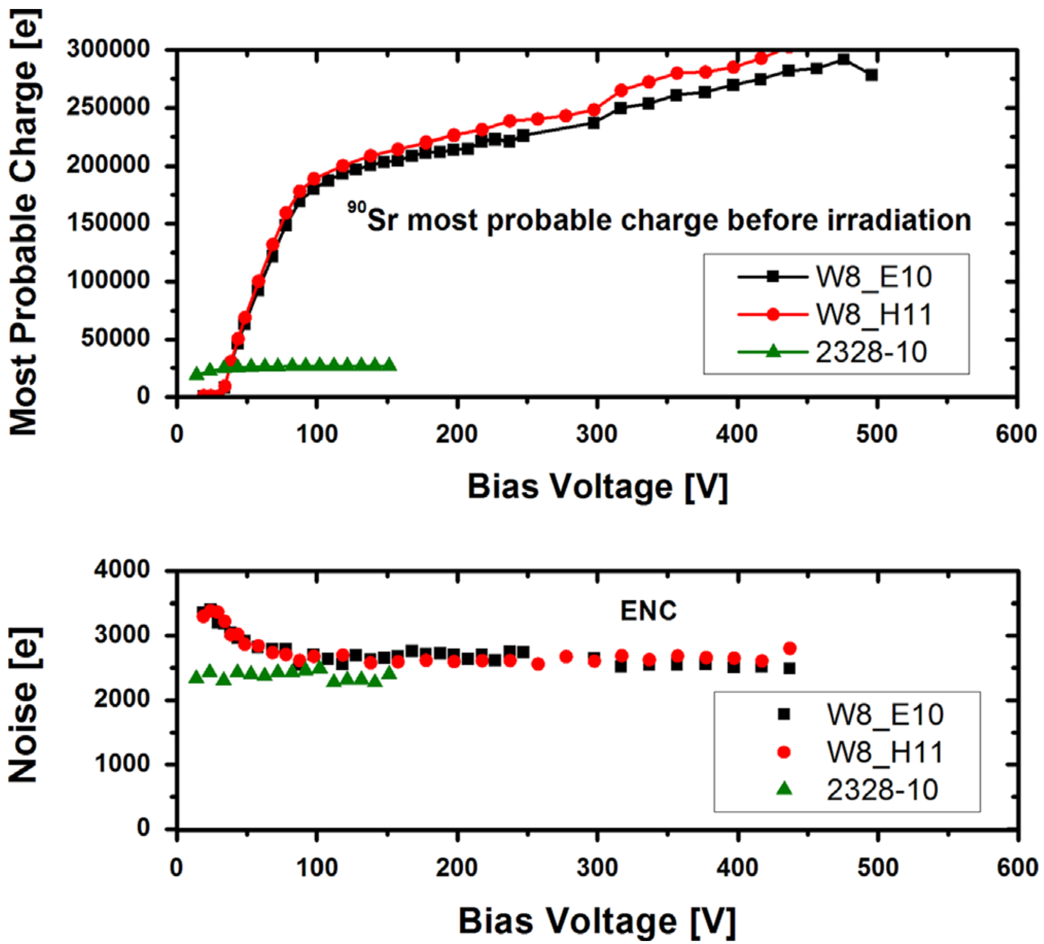


Fig. 8. Absolute collected charge (up) and noise (bottom) signals for two LGAD samples after Sr-90 source MIPs exposure. Measurements are compared with the response of a conventional non-multiplying pad diode (2328-10).

Effect of temperature

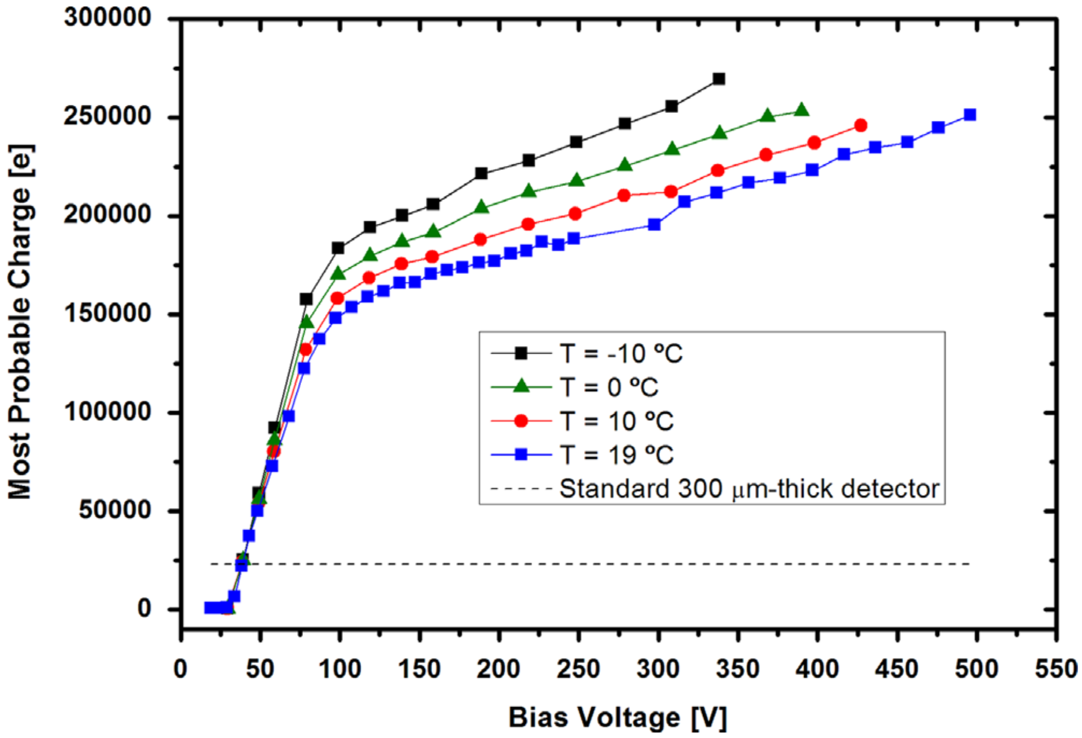


Fig. 9. Temperature dependence of the multiplication factor. Charge collection response for a MIP has been measured at different operational temperatures. The expected signal for a standard 300 mm-thick detector has been depicted with a dashed line to allow the comparison with a non-multiplying detector.

Effect of annealing

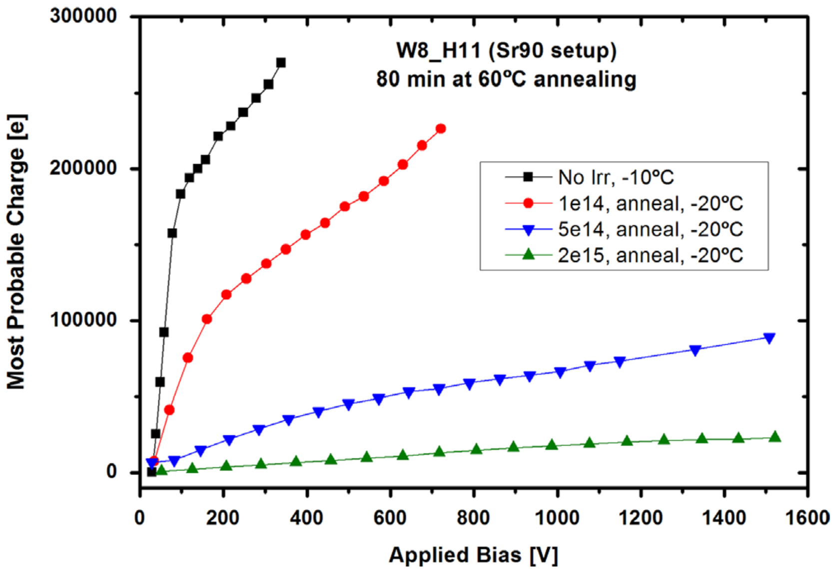


Fig. 10. Measured absolute collected charge as a function of the applied bias for a LGAD sample irradiated to different fluences.

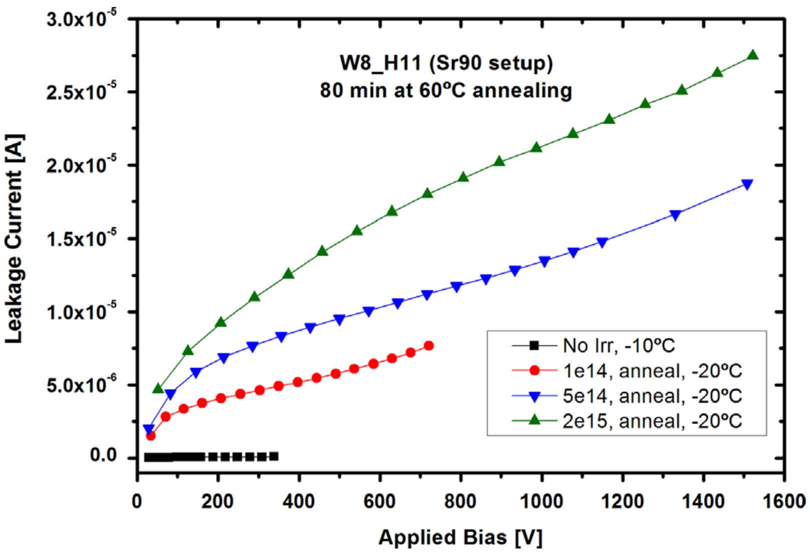


Fig. 11. Measured leakage current as a function of the applied bias for a LGAD sample irradiated to different fluences.

Question

Yuhang:
My Question of JC104 paper:

In this paper :"The measurements were performed on the same device after subjecting it to progressively increasing neutron fluences. Before each measurement, the sample underwent 80 min annealing at 60 ℃." In general, annealing reduces defects, why should they anneal and then measure after irradiation?

A: In my opinion, the annealing will partially recover the effect of irradiation.

Question

Xin: On the last page of the paper, why “The p+ concentration is affected (reduced) by irradiation” ?

A: The irradiation will remove the implanted acceptors of the p+ section at the junction.

Question

Ryuta Kiuchi: Here is my question on this paper:
At page 4, a simple explanation on the temperature dependence of the gain is described as " ... since the impact ionization coefficients exhibit temperature dependence, becoming larger as the temperature is reduced [14]"
I only have heard about this effect, but I do not know why it is.
Could you find/give further explanation ?
(of course, I could check the reference[14] or something else by myself but ...)

A: