Timing Diamond Detector for MIP

G. Chiodini

INFN Lecce

Workshop on picosecond photon sensors for physics and medical applications

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Outlook

- Why diamond sensor
- Working principle
-
- Timing properties
- Diamond detector R&D for timing
- Conclusions

Why diamond?

Can diamond provide a back-up solution to QUARTIC and/or for PHASE II ?

Three Italian groups (Lecce, Bologna, Roma Tor-Vergata) started to explore this options in September 2012 for AFP

Rad-hard
No leakage current
No cooling
Robust
LVL1 trigger
Tracking

Small signal/noise ratio for MIP
Cost
Availability in many pieces of large size and high quality to be proven

But if it works
it is forever

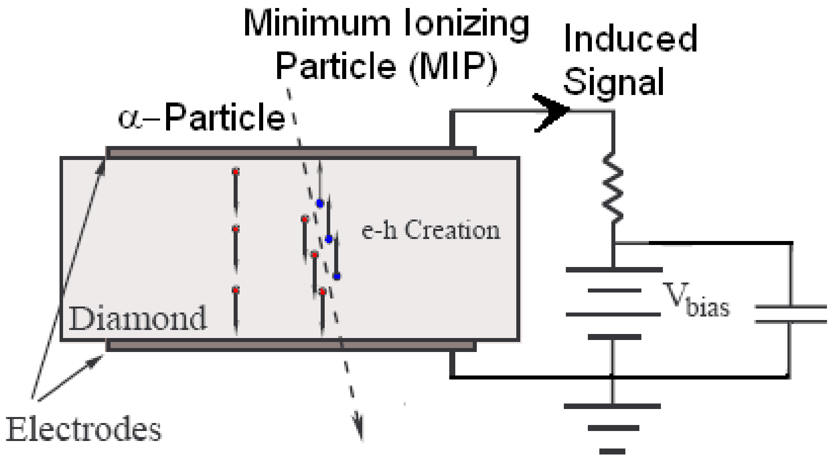
Properties

Property	**Si**	**GaAs**	**4H-SiC**	**GaN**	**CVD Diamond**	**Comments**
Band Gap[eV]	1.12	1.43	3.3	3.44	5.5	**Solar blind**
Displ. Energy[eV/atom]	13-20		25	> 19	43	**Radiation hard**
Mass density[g/cm^3]	2.33	5.32	3.21	6.15	3.52	
Atomic Charge	14	31/33	14/6	31/7	6	**Tissue eq. (Z=7.42)**
Dielectric constant	11.9	12.5	9.7	9	5.7	**Low Noise**
Resistivity[Wcm]	2.3×10^5	10^7	10^{11}	10^6-10^{12}	$>10^{11}$	**No dark current**
Thermal conduc. (W/(cmK))	1.5	0.5	5	1.3	24	**Room T operation**
Nuclear Interact. length[cm]	48.4	26.9	-	-	24.37	**Background**
Saturated e$^-$ velocity [Km/s]	100	100	200	220	270	**Fast signal**
Radiation length[cm]	9.74	2.3	8.1	-	12.13	**Scattering**
Energy to create e-h	3.6		8.4	8.9	13	
MIP Signal [e/100mm]	8900	13000	5100	~5000	3600	**Low Signal**

- **As simple as Silicon**
- **Superior radiation hardness -> SuperLHC candidate**
- **No toxic, in vivo usage, body implantation**

Working principle

Counting mode: ionization chamber. No charge multiplications.



$$dQ_c = Idt = e\frac{dx_e - dx_h}{D} = e\frac{dx}{D}$$

Induced charge

λ_i = free carrier mean free path (trapping and recombination)

$$Q_c = \frac{\int_0^D Q_0 e^{-\frac{x}{\lambda_i}} dx}{D} = Q_0 \frac{\lambda_i}{D}\left(1 - e^{-\frac{D}{\lambda_i}}\right)$$

Alpha source

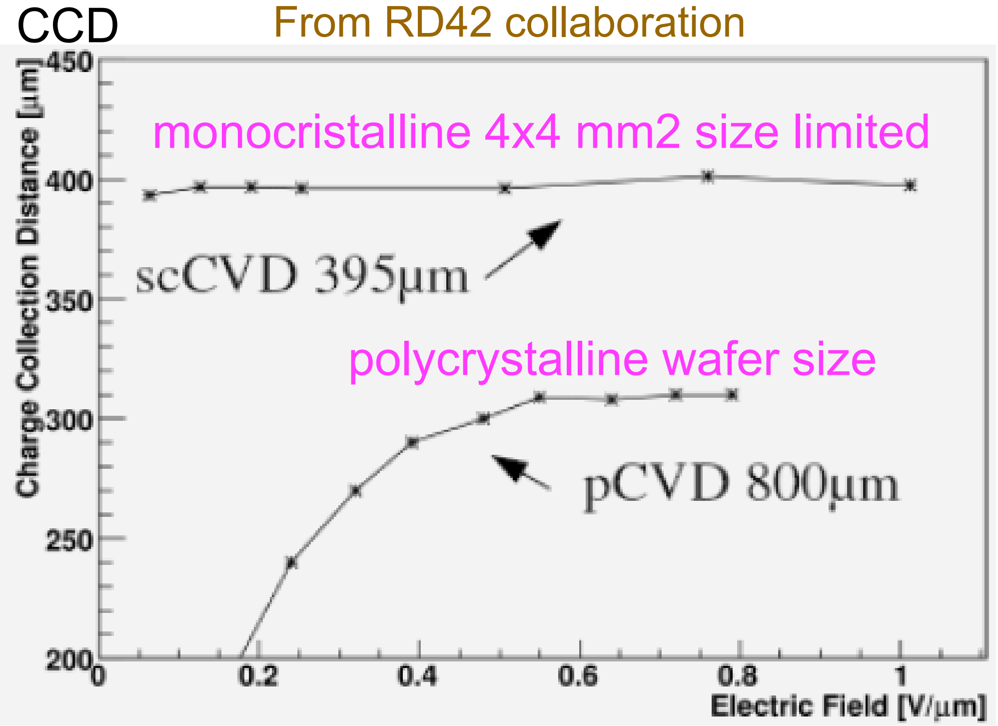
$$Q_c = \sum_i \int_0^D \frac{Q_0}{D}\frac{\lambda_i}{D}\left(1 - e^{-\frac{x}{\lambda_i}}\right)dx = Q_0 \sum_i \frac{\lambda_i}{D}\left[1 - \frac{\lambda_i}{D}\left(1 - e^{-\frac{D}{\lambda_i}}\right)\right] = Q_0 \frac{CCD}{D}$$

MIP

CCD = Charge Collection Distance

Charge collection distance

4'' "freestanding" substrate of polycrystalline diamond are commercially available from two vendors (one in Europe and one in USA) with a CCD of about 300 um (S=10800e-)



From RD42 collaboration

Cost :
Poly : 2x2x0.05 cm3 poly about 6 kCHF
Mono: 0.4x0.4x0.05 cm3 mono about 1.8 kCHF (x 7.5 more expensive than poly)

State of the art

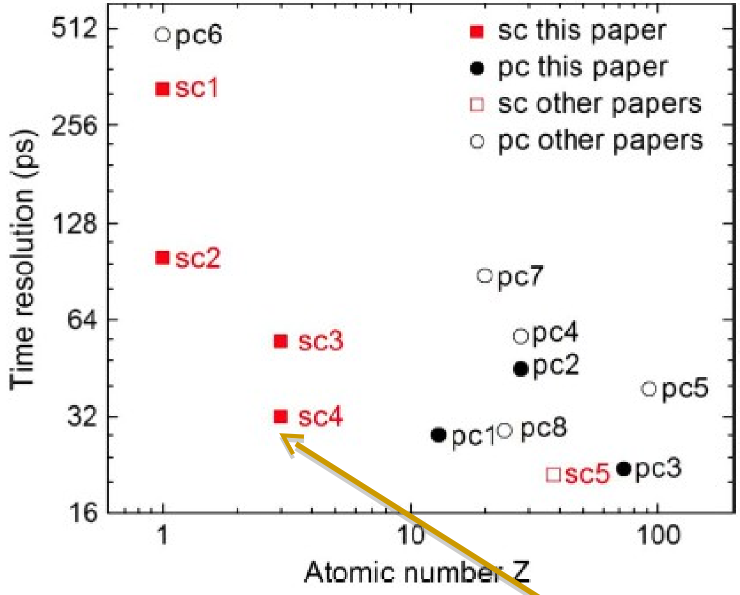


Fig. 22. Comparison of measured time resolutions presented in this paper (full symbols) and other literature values (open symbols) for fast charged particles from protons to U; square symbols denote scDD, round symbols denote pcDD. The added external values for pc-4, pc-5, pc-6, pc-7, pc-8 and sc-5 are taken from the references [21]–[25], respectively.

TABLE I
TIME RESOLUTIONS OF VARIOUS ASSEMBLIES TESTED WITH VARIOUS BEAMS AND BEAM ENERGIES

Ion: Type, Energy	FEE type	σ_t (ps)	EFF (%)	DD No.
p, 1.25 GeV	TCSA+FEE-1	330	96	sc1
p, 3.5 GeV	LCB+FEE HA	117	94	sc2
^{6}Li, 1.8 A GeV	MB+FEE-1	55	no	sc3
^{6}Li, 1.8 A GeV	LCB+FEE HA	32	no	sc4
^{27}Al, 2 A GeV	FEE-1	28	92	pc1
^{58}Ni, 1.9 A GeV	PADI-1	45	no	pc2
^{181}Ta, 1 A GeV	FEE-1	22	94	pc3

TABLE II
DETAILS OF THE TESTED DD

DD No.	Size (mm^2)	d (mm)	No. of Pads	Pad Area (mm^2)	C_{DE} (pF)	C_{DM} (pF)
sc1	4 x 4	0.5	4	1.69	0.165	1.2
sc2	4.7 x 4.7	0.5	8	1.46	0.142	1.5
sc3	4 x 4	0.4	4	1.69	0.2	3.3
sc4	3.5 x 3.5	0.05	4	1.43	1.4	2.5
pc1	10 x 10	0.5	1	52.8	5.14	6.8
pc2	20 x 20	0.15	9	23.8	7.7	9.2
pc3	10 x 10	0.5	1	52.8	5.14	6.8

IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 58, NO. 4, AUGUST 2011 2073

In-Beam Diamond Start Detectors

M. Ciobanu, E. Berdermann, N. Herrmann, K. D. Hildenbrand, M. Kiš, W. Koenig, J. Pietraszko, M. Pomorski, M. Rebisz-Pomorska, and A. Schüttauf

NB. ^{6}Li same MIP charge but 0.5 ns collection time because 50 um thick mono-crystal sensor

Timing vs FE

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$$\sigma_t \approx \frac{t_{drift}}{Q_{collected}} \sqrt{kT(F-1)C_{TOT}} f\left(\frac{t_A}{t_S}\right)$$

F=Amplifier Noise Figure

t_A=electronics rise time

t_S= $R_{INP}C_{TOT}$ detector time constant

$t_A \sim t_S$ best for S/N

f increasing function

$Q_{collected}/t_{drift}$=3600e/100um*V_{drift}

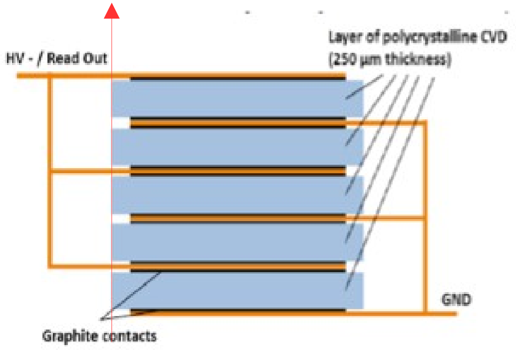
(diamond better than silicon)

http://www-physics.lbl.gov/~spieler/NSS_short-course/NSS02_Pulse_Processing.pdf

$$\sigma_t \approx \frac{Max\left(t_{drift}, t_{rise-time}\right)}{S/N}$$

Boost S/t_{coll} in diamond

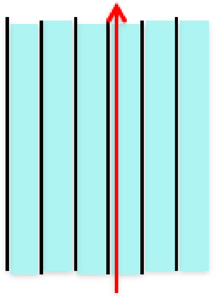
MLCD Multi-Layer Crystal Detector (Roma TorVergata)



N thin layers in parallel:

- $Q_{collected}$ x N
- t_{drift} the same and short (thin layers)

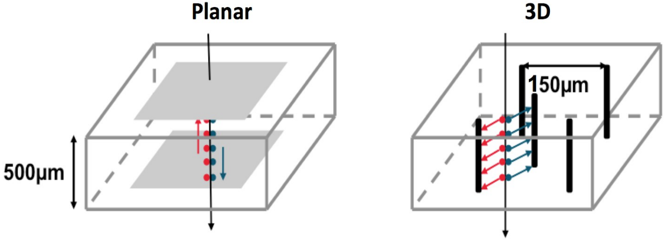
Grazing Diamond Detector (Lecce)

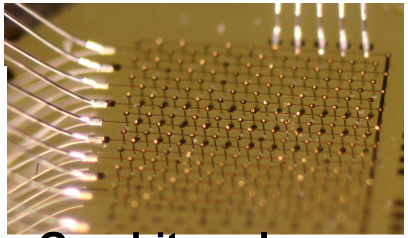


Protons cross the detector along the plane:

- $Q_{collected}$ x $d_{ionization}/d_{electrodes}$
- t_{drift} the same

3D Diamond(RD42)





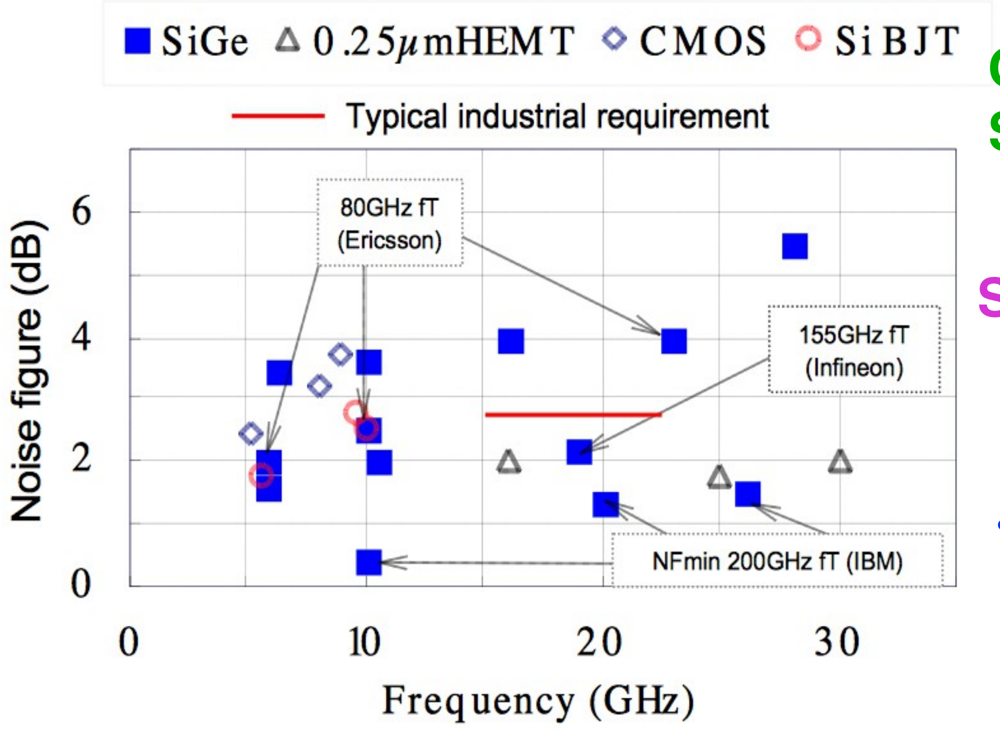
Graphite columns fabbricated by fs laser

Near Vertical Electrods:

- $Q_{collected}$ the same
- t_{drift} very short

Fast and Low Noise FE

Monolithic Microwave IC (**MMIC**) used for Diamond at CERN: InGaP HBT (1st stage) GaAs E-pHEMT (2 stage)



High-frequency SiGe MMICs – an Industrial Perspective (*Invited*)

Yinggang Li, Harald Jacobsson, Mingquan Bao and Thomas Lewin

Ericsson AB, Ericsson Research, MHSERC, SE-43184 Mölndal, Sweden

Graded Ge layer into the base of Si BJT increases β and f_T.

SiGe = III-V Speed + Si integration

MLCD FE (Roma TorVergata):

- Discrete components SiGe CSA with <500 e- noise independent from input capacitance.
- 8 channel SiGe chip just submitted.

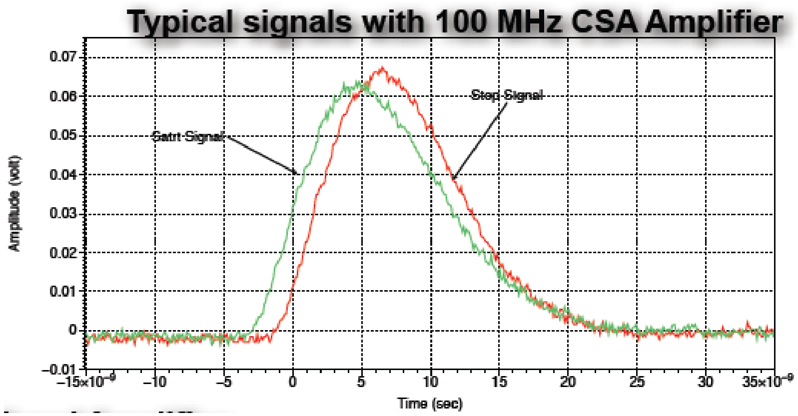
Testbeam performance

- MLCD with 5 layer of 250um polycrystalline diamond at 45deg reached 100 ps with 0.5GeV electrons (submitted to NIM).

- Grazing diamond with one layer of 500um and 6.5mm length reached 71 ps in testbeam with 5 GeV electrons (data collected last month at Desy). Results compatible with our previous published (see next slide)

- With an electronics noise improvement in the future of factor two with can extrapolate at 50 ps and 36 ps (see previous slide)

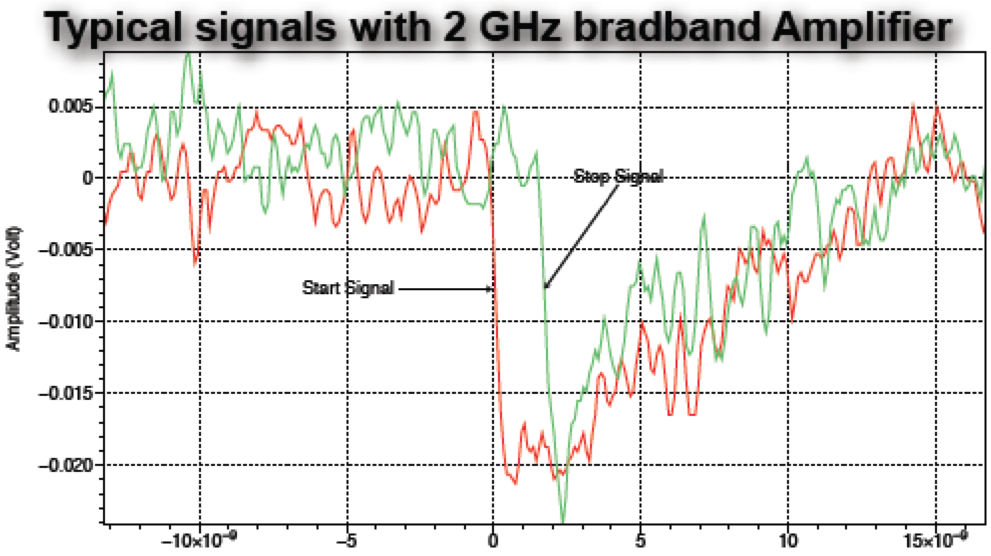
TOF with 62 MeV protons at LNS


Typical signals with 100 MHz CSA Amplifier

Comparative timing performances of S-CVD diamond detectors with different particle beams and readout electronics', N. Randazzo, et al.
IEEE TRANS. ON NUCLEAR SCIENCE, ISSN: 0018-9499. IN PRESS.

- dT=64 ps
- normalized threshold polynomial fit
- walk compensation

62MeV protons = 5 x MIP
500 um thick mono crystal
5 ns collection time
S/N=78 (S/N MIP= 15.6)


Typical signals with 2 GHz bradband Amplifier

- dT=70 ps
- leading edge simple fit
- No walk compensation
- Much worse S/N but similar dT

Cost for 2x2cm2 area

- 20x20x0.5(0.25)mm3 polycrystalline diamond cost 6kCHF.
- MLCD cost at 45deg 1.4x5x6kCHF/side=42kCHF/side to get 50 ps otherwise 210kCHF/side to get 10 ps.
- Grazing diamond cost at 71deg, 3x6kCHF=18kCHF to get 36 ps otherwise at 0deg 40x6kCHF=240kCHF to get 11.7 ps.

Conclusions

- Diamond detector can tag LHC protons at 30 ps but to reach 10 ps level further R&D is needed to keep cost under control
- Diamond detector with ultimate timining performance can fit in 12 cm slot Roman Pot
- It is not going to be a cheap detector but diamond can be reused after the experiment thank to the high radiation hardness