Diamond UV photoconductive devices: high gain, high speed and solar-blind

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Properties of Diamond

- Hard, chemically resilient
- Wide band gap (5.5eV)
- High carrier mobilities
- Highest saturated carrier velocities
- Highest electric field breakdown strength
- Highest thermal conductivity
- Low dielectric constant
- High electron ionisation energy
- High atomic displacement energy
- Highest acoustic wave velocity
- Negative electron affinity

Ideal diamond is a device engineers dream!

Technology base immature

Real diamond far from ideal
Types of Diamond: Breakthrough - $\mu$ & $\rho$ values
Photoconductive devices

External quantum efficiency

Ratio of the flow of electrons per second from the device to the rate of generation

Generation Recombination Trapping

\[ G = \frac{\tau_c (\mu_e + \mu_h) V}{L^2} \]

Shallow traps enhance gain
Recombination centres decrease it

Long carrier lifetimes give poor response times
UV photodetectors

Photoconductive design

- Interdigitated structure
- Gold electrodes
- 25µm pitch
- Free standing CVD diamond
  (~100µm thick)

Many regions are pseudo single crystal
• As fabricated device responsive in the visible

• Treated device shows true ‘visible blindness’

• Sharp cut off at band edge (225nm)
Varying the grain size

Type III: 10-30µm grains
Type II: 20-40µm grains
Type I: 40-60µm grains

Identically treated devices

Differing film thicknesses, leading to variation in grain size
Gain level vs grain size

Type I: 40-60\(\mu m\) grains
Type III: 10-30\(\mu m\) grains

High levels of gain can be realised
Implies increased carrier lifetime in large grain material

Field strength 40- 4\times 10^4 V/cm
**Device speed:** 193nm laser pulse detection

- 15ns pulse
- 1T - SLOW
- 5T - FAST
- No pulse ‘build-up’

Can be used for MHz operation
Can ‘engineer’ speed as well
Diamond is considered radiation ‘hard’

BUT

Excimer laser Radiation (193nm) causes damage to detectors (fluence ~ 10mJcm^{-2})
Multiply treated devices

Five times Treated device

- As fast as VPD
- Not degraded by $10^7$ pulses
- Priming effect
Effect on device dark current

Singly treated devices show a considerable increase.

Multiply treated devices do not!
Imaging arrays - do they work?

150µm pixels

Suitable for beam tracking and profiling of expanded beams

Higher resolution devices under test
Imaging arrays - yes, they do!

![Graph showing voltage (V) versus time (s) for 9V 0.1mJcm-2]
Imaging arrays - excellent uniformity

Single Pulse on elements 6 & 7
Fluence ~1mJcm$^{-2}$

Voltage (V)

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.
Response of Vacuum Photodiode
to $F_2$ Laser Radiation

157nm - detector needed by semiconductor industry
Temporal Response of Diamond Detector to F₂ Laser Radiation

Diamond detectors a good 157nm solution
Imaging Performance at 157nm

Isolated and 1:1 lines

Photoresist: 60nm thick Shipley XP-98248-S optimized for use at 248nm
What have we achieved?

The application of post-growth treatments have enabled us to ‘engineer’ the properties of the devices:

- Spectral characteristics
- Speed
- Gain
- Radiation hardness
- Dark current

Changes are very stable.
Concluding Remarks

- Relatively low cost free-standing CVD grown polycrystalline diamond can be engineered to produce highly effective deep UV detectors

  Current price of 50mm diamond wafer ~$2000 (sufficient for ~100 3x3mm devices)

- Gem market is causing new sources of single crystal material to emerge

  *May* enable even higher performance levels at realistic cost