University of Leicester

Development of Terahertz and X-ray Radiation Detectors

Executive Summary

A number of technologies are pushing at the boundaries at what existing state of the art photodetectors are capable of. With its unique combination of properties, such as potentially exceptionally high carrier mobility and conductivity that can be tuned by the application of an electric field, graphene provides an interesting route to future photodetector techniques across a wide range of energies.

Previous research has already demonstrated that graphene field effect transistors can be operated at incredibly high bandwidths, demonstrating 25+GHz with a theoretical limit of up to 500GHz for visible photodetection. Ultrafast photodetection has also been demonstrated on the 10s of femtosecond scale via the photothermoelectric effect for visible photodetection. Detection at X-ray energies has been achieved using a graphene field effect transistor structure for pulsed X-ray photons, but has not been achieved for single X-ray photons; this would provide a route to faster and easier X-ray photodetection in medical physics and X-ray astronomy, among other areas. For terahertz detection, techniques have been used to detect terahertz photons but with slow bandwidths (as low as 1Hz) using a number of techniques; these have often investigated frequencies up to 100s GHz. Little research investigates detection for frequencies greater than 1THz – this would open up new areas for exploitation by industry and scientific research such as security and communications applications.

We looked to investigate the development of a single X-ray photodetector and a passive terahertz detector. These were designed in Leicester, and manufactured at state of the art facilities at the University of Cambridge. The graphene manufacture and device fabrication processes are areas of intense active research, with techniques being constantly refined to improve the quality and reproducibility of the devices. As such it is still an imperfect art, but it is improving rapidly with great prospects for future device possibilities. However the current state of the art for device fabrication has limited our options for some areas that we could consider investigating; we provide a roadmap to the future in the final report that outlines routes that we propose.

Our single X-ray photodetector was characterised in Leicester using pulsed optical photons to mimic the absorption of X-ray photons in a silicon wafer. The pulsed optical laser was characterised using an SiPM, which allowed us to demonstrate a potential sensitivity to as few as 1000 photons, or approximately 3keV, by using a lock-in amplifier. We have some initial results suggesting sensitivity to Fe-55, which needs further verification. More energetic X-ray sources such as Cd-109 and Am-140 were tested but at these X-ray energies our detector is highly transparent; further iteration of the absorber thickness will allow for improved absorption of these photons.

Our passive terahertz detector was tested using pulsed terahertz lasers at the Aston Institute of Photonic Technologies and at the National Physical Laboratory. We demonstrated proof of principle

for the ability to passively detect a broadband terahertz source using a GFET device with a lock in amplifier, and demonstrated sensitivity controlled by the application of a gate voltage and also modulated by the incident terahertz power. We also demonstrated sensitivity to different terahertz frequencies by using band pass filters that showed varying sensitivity at frequencies above and below 1THz, giving scope for passive narrowband detectors.

Our research has demonstrated potential for both a single X-ray photodetector and passive broadband and narrowband terahertz detectors. These have applications in a number of areas of scientific research and industrial use such as astronomy, medical sciences, communications and security, among others. They certainly have scope to be manufactured into imaging arrays, with the prospect of great and rapid improvements in required techniques. These are now being brought about by the enormous investment and research effort being put into graphene manufacture and fabrication processes. The devices we have developed require further iteration and research, but we have demonstrated promise for new graphene-based photodetector technologies that could push the state of the art further still.

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