Snowmass2021 - Letter of Interest

Thin Film Detectors

Thematic Areas:

☐ (IF1) Quantum Sensors
☐ (IF2) Photon Detectors
■ (IF3) Solid state tracking
☐ (IF4) TDAQ
☐ (IF5) MPGD
☐ (IF6) Calorimetry
☐ (IF7) Electronics ASICs
☐ (IF8) Noble elements
■ (IF9) Cross Cutting

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Abstract:

Nanoscience technologies are developing new cutting edge materials and devices for a wide range of applications. HEP can take advantage of the many advancements by looking toward thin film fabrication techniques to implement a new type of particle detector. Thin Film Detectors have the potential to be fully integrated, large area, low power, low dead material, and low cost. This letter proposes to investigate potential research paths using thin film technologies and to identify and characterize the performance benefits for future particle experiments.

Introduction: The ultimate goal of particle physics is to find the next new particle. However, the field lacks a clear road map to predict where the next new physics will manifest. Discoveries often occur when technologies extend the reach of scientific measurement. Now is the time to advance accelerator and detector technologies by leaps and bounds in order to enable new discovery in the next generation of accelerator experiments. Therefor, I propose a new detector technology based on thin films that is aimed at dramatically improving the precision of particle detectors by greatly reducing the mass of the detector.[6] Cleaner signatures of the particles from the primary collision will be obtained by reducing those particle's interactions with dead material, which will improve reconstruction efficiencies and resolutions.

Thin Film technologies could potentially replace the entire detector including all the services. If a thin film detector could be 'printed' in large areas (m^2), it is estimated that the cost would be reduced to $<1\%$ of the current cost. If the nuclear interaction length can be decreased by a factor of 10, then the track reconstruction efficiencies would reach 99% and enable a host of new measurements and searches.

Thin Film Detector Concept: Thin Film (TF) technology presents one possible solution to achieve these performance milestones. TF transistors (TFT's) were first conceived in the 1960's by Paul Weimer.[8] However, it was not until this century that fabrication technologies improved enough to make it competitive with existing technologies. TFT's are the basis of technologies such as Liquid Crystal Display (LCD) screens, solar cells, and light emitting diodes. It is a rapidly growing technology area with a large market base and has corresponding investment in large scale fabrication and industrialization. Ultimately, the broader interest of these technologies enables HEP to leverage the investments in commercialization as well as the R&D into materials, tools, and techniques.

Some of the advantages of TF's are optical transparency, mechanical flexibility, high spatial resolution, large area coverage, and low cost over traditional silicon based semiconductor technology. TF technology uses crystalline growth techniques to layer materials. Monolithic sensors can be fabricated using layers of thin film materials for particle detection with layers for amplification electronics. The advantages of a detector made with this type of technology include single piece large area device (on the order of a few m^2), high resolution ($<10\ \mu$m), low cost ($\times 100$ less than Si-CMOS), low mass, and high curvature for a cylindrical, edgeless design[2;3;7].

Fabrication processes such as chemical bath deposition and close-space sublimation on a substrate material can produce thin films with a high degree of precision. Here, the crystalline structure is grown in layers rather the using drilling and etching techniques standard in traditional silicon fabrication, therefor, TF processing is much less expensive.

Monolithic: Thin film electronics can be vertically integrated with a thin film sensor if the fabrication techniques are compatible. This would allow vertical integration of sensor and pixel electronics. Further vertical integration using through-vias would enable signals to pass from one layer to the next thus enabling several levels of electronic processing. Typical Front-End ASIC functions could be integrated into the monolithic structure as well as higher end processing to perform functionalities such as data aggregation, region-of-interest processing, etc. Such processing would reduce the number of transmission lines integrated into a top layer and further reduce the material inside the detector volume. Figure 1 shows a potential vertical stack-up.

Low Power: The transistor is the most basic unit that determines the power consumption in electronics followed by the complexity of the functions the circuit performs. Complementary Metal Oxide Semiconductor (CMOS) is typically touted as a low power technology and is the current mainstay for most of the commercial electronics. However, there are many types of transistor technologies that can outperform CMOS. Silicon Germanium (SiGe) Heterojunction Bipolar Transistors (HBT's) are another class of transistor that typically boast faster speeds and lower power consumption.[1;4;5] Fin-Field Effect Transistors (FinFET's) are

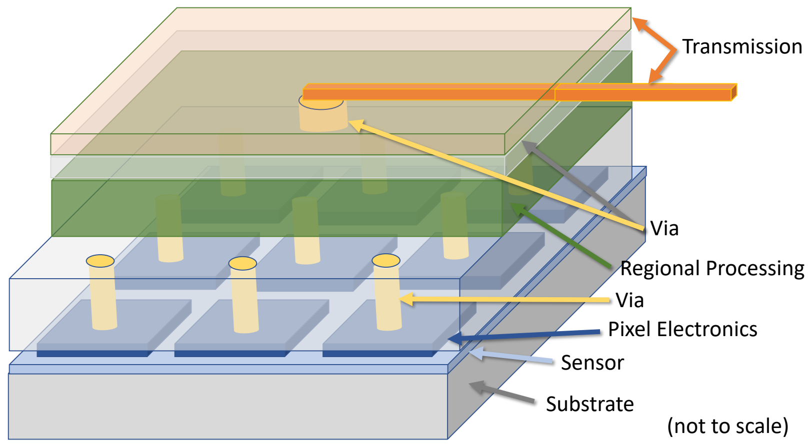

Figure 1: The conceptual stack-up of a monolithic thin film detector that incorporates support structure, sensor, pixel electronics, regional processing electronics, and power/data transmission. Potentially, no other structures would be needed in the detector volume.

being pursued as the next ultra-low power technology and are manufactured by companies such as IBM and Motorola. However, the most cutting edge transistor is the Thin Film Transistor (TFT), which is breaking records in terms of size and power. All of these technologies have the potential for reducing the power (and the copper in the transmission lines) over the current technologies.

Future Applications: Thin Film Detectors have the potential to replace a wide range of detector types from tracking to calorimetry. The intent of this letter is to propose to identify key areas of research within Thin Film technologies, quantify the key requirements from different types of experiments, and evaluate the potential physics impact.

References

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