Advanced hCMOS Systems

# Commercialized hCMOS imagers for IFE diagnostics

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**Executive Summary:**

Z machine, NIF, Omega, CEA's LaserMegajoule, and in a more limited manner, LCLS (Gleason et al. whitepaper) have all deployed multi-frame, nanosecond shuttered, radiation-hardened hybrid-CMOS (hCMOS) imagers developed at Sandia National Laboratories (SNL). The benefit of acquiring multiple images for a single, non-repeatable experiment while time gating with fast shutters to reduce motional blurring and gate out background radiation significantly improve image quality. The cameras operate in harsh radiation environments comparable to what may be encountered in an IFE facility and offers potential for both target and laser diagnostics. However, existing sensors do not support a 10-20 Hz rep-rate IFE facility.

Advanced hCMOS Systems (AHS) was founded by three of the core developers of hCMOS cameras while previously employed at SNL and LLNL. The explicit goal of AHS is to license the technology from SNL, improve the performance and rep-rate, and commercialize these novel sensors for a customer base beyond the capstone NNSA user facilities.

We will provide an overview of the performance specifications for existing SNL-produced sensors, AHS's proposed improvements for their first-generation commercial variant, and a roadmap of our commercialization plan. Continued investment is needed to demonstrate a commercially available rad-hard process that can match the radiation tolerance of SNL's proprietary CMOS7 process. We have built strong relationships with the NNSA's HEDP/ICF community and look forward to working with the IFE community to better understand their specific diagnostic needs.

**Body:**

IFE will require novel diagnostics on the R&D journey to a commercialized power plant. Once this goal has been achieved, these plants will require monitoring sensors to ensure things are operating properly. Advanced hCMOS Systems believes that ultra-high speed shuttered, high rep-rate image sensors can play a significant role on this journey.

Sandia National Laboratories has invested more than $23 million over 15 years to bring the hCMOS imager technology to a high technology readiness level. These sensors are multi-frame CMOS cameras with fully programmable shutter gates as low as 1.2 ns. They have been fabricated in Sandia's 350 nm CMOS7 radiation-hardened foundry and have had exceptional success being fielded in the extreme environments of Z-machine and NIF. An hCMOS based diagnostic (hDISC) was situated 1.2 m from TCC on the recent 1.3 MJ NIF shot and collected images without suffering any noticeable adverse consequences. This specific use case demonstrated the benefit of fast time gates to gate out significant neutron noise. The Gated Laser Entrance Hole (GLEH-2) has been collecting multi-frame time-gated data since 2020 and has shown the value of a time-gated image sequence vs a single time integrated image [1], Fig 1. More recently, a NIF team used the independently programmable shutters on an hCMOS sensor as a beamline conditioning diagnostic to monitor spatio-temporal fluctuations on a NIF beam [2] as seen in Fig 2.

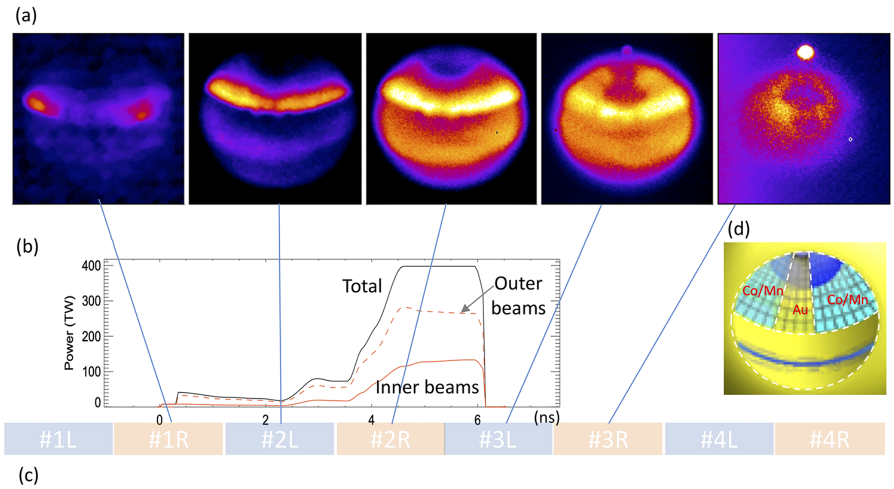



Fig 1, ref [1]

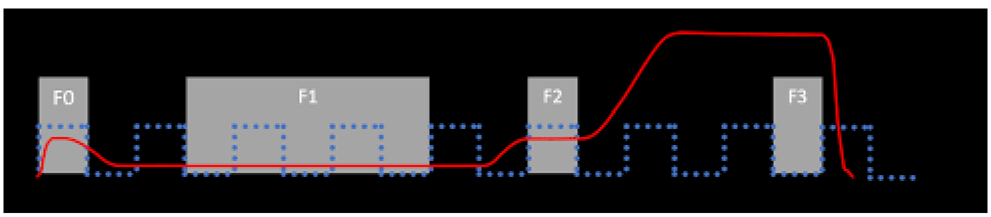



Fig 2, ref [2]

These successful results have led to 17 diagnostics fielding 24 hCMOS sensors being fielded across Z, NIF and Omega and there are more than 19 additional hCMOS based diagnostics requiring over 70 hCMOS sensors in various stages of development.

This tremendous growth of users has strained the production capabilities of the national labs. Significant resources are required to design, fabricate, characterize, and field these sensors. This burden has taken work hours away from the core science mission of laboratory employees and limited availability to a broader user community.

Advanced hCMOS Systems (AHS) was founded by three of the core developers of the hCMOS cameras while previously employed at SNL and LLNL. AHS was founded with the explicit goal of licensing the technology from SNL, transitioning the design to a commercial foundry, improving the overall performance and functionality of the hCMOS design while streamlining the manufacturing process. The goal of these efforts is to provide commercialized sensors to a much larger customer base while continuing to offer a stable supply chain to the capstone NNSA HED/ICF facilities.
AHS is currently structured as a services company providing engineering consultation on all aspects of hCMOS design, characterization, and fielding. We are supporting the existing user community and actively working on two novel ROIC designs for an NNSA customer. ROIC/sensor development requires long lead times. To develop a commercial hCMOS image sensor, our current plans are to bootstrap the initial

development via SBIR funding, but are also seeking direct funding as a path to reducing time to market.

**Gen 1 Sensor Development Plan:**
Table 1 is a comparison between the existing SNL developed “Icarus” camera deployed at Z, NIF and Omega and the proposed first generation AHS commercial variant.

| Specification | Existing SNL Icarus hCMOS | Planned Gen 1 AHS hCMOS |
|---|---|---|
| Number frames | 4 | 4 |
| Min Tint | 1.2 ns | < 1ns |
| Rep rate | 2 Hz | >10 Hz |
| Noise floor | 300 $e^-$ | 300$e^-$ |
| Full Well | 500k $e^-$ | 500k $e^-$ |
| Image plane | 1024 x 512 | 1024 x 512 |
| Spatial resolution | 25 um | 25 um |
| Shutter programmability | yes | yes |
| Rad hard | yes | yes |
| Foundry | SNL/Proprietary | Commercial |

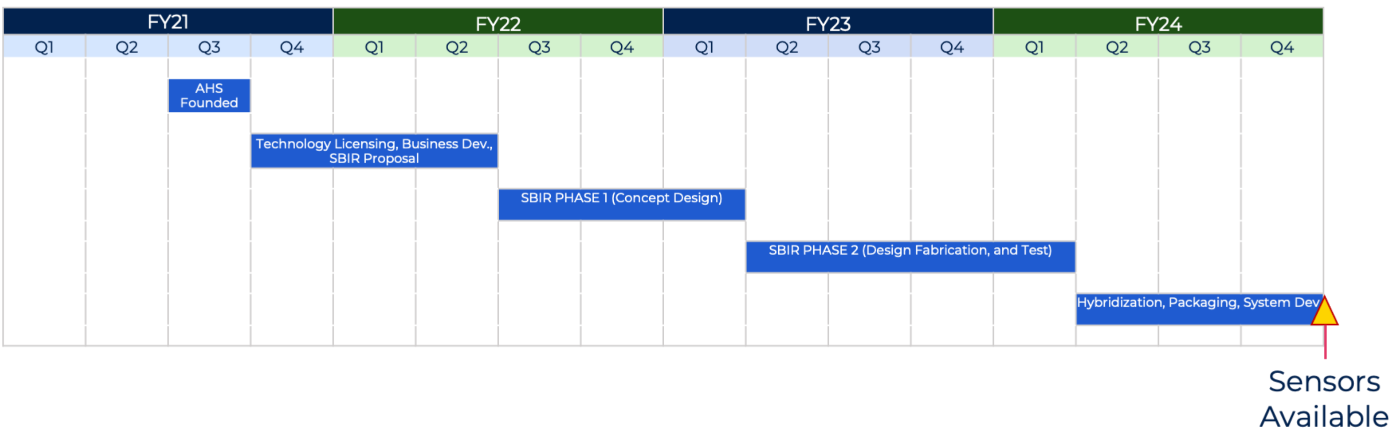
**Table 1**

These laboratory developed sensors have been matured to a reasonable TRL level, but have limitations on their replication-rate. Primary SNL R&D design efforts were focused on fast shutter and pixel performance while high-rep rate was not needed at single shot facilities like Z and NIF. Low rep rate restricts these imagers usefulness to the IFE community. Additionally, they have been fabricated in Sandia’s proprietary 350 nm CMOS7 foundry technology. This limits sensor volume production, diagnostic development timelines, and the potential user space to government-affiliated users due to export control restrictions on the CMOS7 technology.

AHS will port the SNL based design they have licensed from Sandia Labs to a commercially available radiation-hardened semiconductor process and implement design improvements to increase the rep-rate and introduce manufacturing efficiencies to improve yield. Porting an integrated circuit from one foundry to another is a non-trivial task, essentially requiring a complete redesign due to differences in process performance and design rules. AHS is uniquely positioned to perform this task due to our deep understanding of the technology down to the transistor level. Due to our background in the NNSA complex, AHS possesses expertise in radiation hardened microelectronics and system design beyond typical industry focus on Total Ionizing Dose (TID) and Single Event Effects (SEE) usually driven by the space sector. Many HEDP/ICF applications require dose rate and neutron dose-rate hardening in addition to designing for TID and SEE. Bringing expertise in this type of radiation hardening will bridge a gap not filled by most commercially available imagers.

We have built strong relationships with the NNSA's HEDP/ICF community and hope to spark a dialogue with the FES community and better understand their specific diagnostic needs. detector area, wavelength of interest, etc.

**Product Development Timeline:**




**References:**

[1] Hui Chen, B. Golick, N. Palmer, A. Carpenter, L. D. Claus, M. Dayton, J. Dean, C. Durand, B. Funsten, R. B. Petre, C. M. Hardy, J. Hill, J. Holder, E. Hurd, N. Izumi, J. Kehl, S. Khan, C. Macaraeg, M. O. Sanchez, T. Sarginson, M. B. Schneider, and C. Trosseille , "Upgrade of the gated laser entrance hole imager G-LEH-2 on the National Ignition Facility", Review of Scientific Instruments 92, 033506 (2021) https://doi.org/10.1063/5.0041272

[2] T. E. Lanier, S. J. Cohen, J. M. Di Nicola, M. A. Erickson, J. A. Folta, A. Handler, E. R. Hurd, B. L. Olejniczak, T. H. Tate, C. Widmayer, S. T. Yang, P. J. Wegner, "Time-gated measurements of fusion-class laser beam profiles," Proc. SPIE 11259, Solid State Lasers XXIX: Technology and Devices, 1125915 (21 February 2020); https://doi.org/10.1117/12.2546663