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R&D Towards Cryogenic Optical Links

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A number of critical active and passive components of optical links are successfully tested at 77 K or lower, demonstrating a potential to develop optical links operating inside the Liquid Argon Time Projection Chamber (LArTPC) detector cryostat. Ring oscillators, individual MOSFETs, and a 16:1 5-Gbs serializer fabricated in a commercial 0.25-um Silicon-on-Sapphire (SoS) CMOS technology continue to function throughout the temperature cycling from room temperature to 4.2 K, 15 K, and 77 K respectively. One type of vertical-cavity surface-emitting laser diodes have been observed to lase from room temperature to 77 K. Optical fibers and optical connectors exhibit small insertion loss change from room temperature to 77 K.

Summary

The liquid argon time projection chamber (LArTPC) is a detector proposed for the long baseline neutrino experiment. Optical links operating inside the liquid argon cryostat have the advantage of low thermal load, high data bandwidth, low noise, and low power. This paper presents test results of a number of critical components of such optical links at cryogenic temperature.

Individual MOSFETs, ring oscillators, and a 16:1 serializer fabricated in a commercial 0.25-um Silicon-on-Sapphire (SoS) CMOS technology have been evaluated at cryogenic temperature. NMOSFETs and PMOSFETs continue to function down to 15 K while the absolute value of their threshold voltage |VT| increases when the temperature decreases. Ring oscillators continue to function from room temperature to 4.2 K while the frequency and the output amplitude increase when the temperature decreases. At 77 K, the bit error rate of the 16:1 serializer is less than 1E-12 from 5.10 to 6.19 Gbps. At 77 K, the output amplitude is 38% higher with reduced noise and jitter and the rise and fall times are 15% less than those at room temperature.

Lower power supply voltage VDD can improve the reliability which degrades at cryogenic temperature due to hot carriers. Two samples of the serializers have been tested with lower VDD than the nominal 2.5 V at 5 Gbps and at room temperature. When VDD is reduced down to no less than 1.8 V, the bit error rate is observed to be less than 1E-12. The successful operation of the serializer with a lower VDD than the nominal value points to an operation mode with increased reliability and low power dissipation.

Two 50 meter long optical fibers, one single-mode (SM) fiber SMF28 and the other multimode (MM) SinfiniCor® SX+, both produced by Corning, have been tested from room temperature to 77 K. The fiber attenuations increase 0.034 ± 0.004 ± 0.015 dB/m for MM and 0.005 ± 0.004 ± 0.002 dB/m for SM.

MM and SM Optical connectors (female-to-female LC-LC mating sleeves) have been cooled from room temperature to 77 K. Five sleeves were connected in serial with one-meter optical fibers tested. The connector insertion loss changed 0.139 ± 0.011 ± 0.020 dB per connector for MM and -0.284 ± 0.013 ± 0.014 dB per connector for SM.

Two types of 850-nm MM vertical-cavity surface-emitting laser (VCSEL) diodes have been cooled down to 77 K. They lased at 77 K with increased threshold voltage, increased current threshold, blue shifted wavelength, and decreased spectral width. One type of diodes stopped lasing at around 145 K whereas the other type lased throughout the temperature cycling. All diodes recovered to before-test condition after they were warmed back, indicating that temperature cycling causes no permanent damage to the lasers.

The circuits based on the SoS technology, VCSEL diodes, optical fibers and optical connectors continue to function from room temperature to 77 K, demonstrating a potential to develop optical links operating inside the LArTPC cryostat.

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