MPI-PhE/2000-12
19 May 2000

Semi-Transparent Silicon Strip Sensors for the Precision Alignment of Tracking Detectors ⋆

M. Fernandez Garcia, S. Horvath, H. Kroha [1],
A. Ostapchuk and S. Schael

Max-Planck-Institut für Physik, Föhringer Ring 6, D-80805 Munich, Germany

Abstract

Novel semi-transparent optical position sensors ('ALMY sensors') have been developed for the alignment monitoring systems of modern large-area tracking detectors. More than 10 sensors can be aligned along one laser beam. The thin-film amorphous silicon strip sensors provide up to 90% transmittance for red laser light combined with minimum beam distortion and a typical position resolution of 1 μm over a sensitive area of several square centimeters.

⋆ Proceedings of the 8th Pisa Meeting on Advanced Detectors, May 21–27, 2000, Isola d'Elba, Italy, to be published in Nucl. Instr.&Methods.
[1] Corresponding author, e-mail: kroha@mppmu.mpg.de

ATL-MUON-2000-025
18/12/2000

Semi-Transparent Silicon Strip Sensors for the Precision Alignment of Tracking Detectors

M. Fernandez Garcia, S. Horvath, H. Kroha [1],
A. Ostapchuk and S. Schael

Max-Planck-Institut für Physik, Föhringer Ring 6, D-80805 Munich, Germany

Abstract

Novel semi-transparent optical position sensors ('ALMY sensors') have been developed for the alignment monitoring systems of modern large-area tracking detectors. More than 10 sensors can be aligned along one laser beam. The thin-film amorphous silicon strip sensors provide up to 90% transmittance for red laser light combined with minimum beam distortion and a typical position resolution of 1 μm over a sensitive area of several square centimeters.

Modern large-area tracking detectors require increasing precision for monitoring the relative positions of the detector components. For example, for the muon spectrometer of the ATLAS experiment [1] misalignment corrections of the track curvature of 30 μm (rms) accuracy have to be provided by an optical alignment system over distances of up to 15 m.

A novel high-precision optical alignment monitoring system has been developed for such applications. It uses collimated laser beams and semi-transparent optical position sensors ('ALMY sensors'). Tests under laboratory conditions as well as at the TESLA Free Electron Laser test facility at DESY have shown that more than 10 sensors can be aligned along a laser beam. The light emitted by laser diodes is distributed via single-mode optical fibers with collimator optics producing diffraction limited laser beams with Gaussian beam profile limited to $2-3$ mm diameter over 10 m.

ALMY sensors consist of a $0.2-1.0$ μm thick layer of hydrogenated amorphous silicon (a-Si:H) between two about 100 nm thick transparent indium-tin oxide (ITO) electrodes segmented into orthogonal strip rows covering the whole sensitive area (see Fig. 1 and Table 1). The layers are deposited on a 0.5-2.0 mm

[1] Corresponding author, e-mail: kroha@mppmu.mpg.de

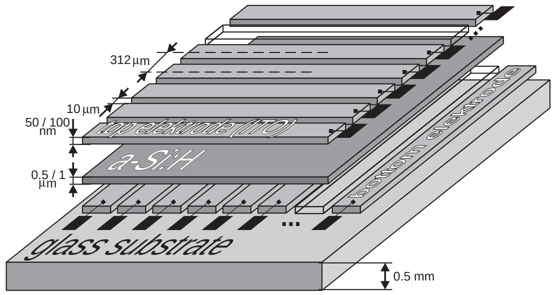

Fig. 1. Structure of ALMY sensors.

Fig. 2. ALMY sensor module with integrated readout electronics.

thick glass substrate. High-quality polished parallel glass wafers minimise uncertainties in the deflection of the traversing laser beam. The layer thicknesses are optimised for minimum reflection. For 780 nm laser light, $80 - 90\%$ transmittance of the sensors has been reached depending on the a-Si:H thickness. The sensor sensitivity at this wavelength is about 0.01 A/W.

The ALMY sensors have been introduced in 1994 [2]. Since then extensive tests have been performed on 150 sensor modules (see Fig. 2) which have lead to significant improvements of the performance.

Without anti-reflective coating of the glass substrate, interference effects in sensor response and transmittance due to finite wedge angles of the glass have been observed. The interference patterns across the sensor surface not only deteriorate the uniformity of the sensors but also lead to time dependent variations of the local position measurement and transmission due to shift of the pattern with the small, order 0.1 nm changes of the laser wavelength caused by temperature variations of the laser diode.

With standard anti-reflective coating of the back side of the glass substrate, the reflectivity of the glass surface can be reduced from about 4% to less than 0.5% such that variations of light absorption and transmission caused by interference in the glass become negligible even for finite wedge angles. Over the whole sensor surface of 20 mm^2 a position resolution (linearity) of 1 μm has been achieved. The sensor resolution is insensitive to high magnetic fields due to the very low Hall conductivity of amorphous silicon.

Custom designed integrated readout electronics has been developed for the ALMY sensors (see Fig. 2). The signal-to-noise ratio is > 1000 for laser intensities of about 30 mW/cm^2 at $\lambda = 780$ nm. The readout speed of the fully multiplexed strips is 10 ms.

It is well known from the investigation of thin-film solar cells that the light

Table 1
Properties of ALMY sensors

Active area	20×20 mm^2
Number of strips	64×64
Strip pitch	312 μm
Strip width	300 μm
a-Si:H thickness	$0.2 - 1$ μm
Bias voltage	$1 - 3$ V
Hall mobility $\mu^H_{p,n}$	$10^{-2} - 10^{-4}$ [cm^2/Vs]
Effective band gap	0.82 eV
Transmittance at $\lambda = 780$ nm	$80 - 90\%$
Position resolution (linearity)	1 μm
Beam deflection error	≤ 3 μrad

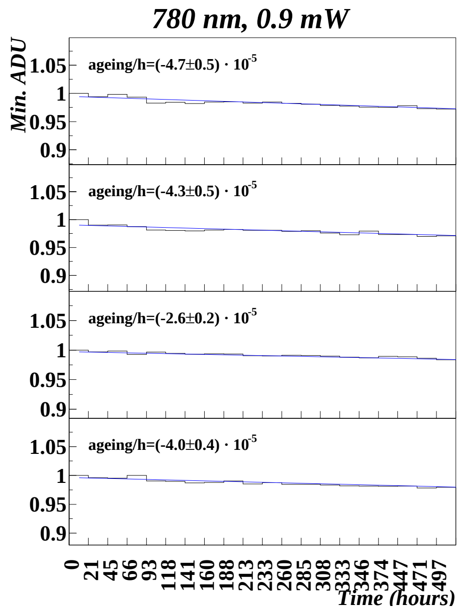

Fig. 3. Long-term monitoring of the sensitivity loss of ALMY sensors under illumination.

sensitivity of a-Si:H deteriorates under illumination [3]. Under illumination with 690 nm laser light of about 30 mW/cm^2 intensity, local degradation of the sensitivity, not the optical transmittance, of the amorphous silicon sensors has been observed which leads to significant local position measurement errors. The amount and rate of degradation depend strongly on the light intensity and appear to saturate.

In the normal operation mode of the sensors, illumination with 780 nm laser light of ≤ 30 mW/cm^2 intensity, the degradation rate was found to be tolerable. After 500 hours of continuous illumination, the sensitivity loss is only 2% (see Fig. 3). This corresponds to a local absolute position measurement error of not more than ± 5 μm after 20 years of operation in the alignment monitoring system of the ATLAS muon spectrometer.

Amorphous silicon detectors are expected to be more radiation hard than crystalline silicon devices. The ALMY sensors have been irradiated with neutrons and γ-rays at various sites for applications in the ATLAS and CMS experiments. The sensitivity and optical transmission did not deteriorate for γ irradiation doses of up to 10 MRad and for neutron fluences of up to 10^{14} n/cm^2. A complete system of several sensor modules with readout electronics (see Fig. 2) and a laser diode for monitoring the sensitivity has been irradiated up to a neutron fluence of 10^{13} n/cm^2 without degradation.

The ALMY sensors are currently under development for the optical alignment systems of the the ALICE, ATLAS and CMS experiments. The performance is studied in real-size test stands. The sensors are already in use in the HERA-B detector and under investigation for the ZEUS and LHC-B experiments as well as for the TESLA linear collider.

References

[1] *ATLAS Muon Spectrometer Technical Design Report*, A. Airapetian et al., CERN/LHCC/97-22, May 1997.

[2] W. Blum, H. Kroha and P. Widmann, Nucl. Instrum. and Methods **A367** (1995) 413; Nucl. Instrum. and Methods **A377** (1996) 404; IEEE Transactions on Nuclear Science, Vol. **43**, No. 3 (1996) 1194; H. Kroha, Nucl. Phys. B (Proc. Suppl.) **54B** (1997) 80.

[3] D. Staebler and C.R. Wronski, Appl. Phys. Lett. **31** (1977) 292.