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New Detection Systems for UV Solar Reference Scanning Spectroradiometers

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Abstract. Current state of the art for UV solar reference spectroradiometers reaches a total uncertainty of 5% which adversely affects long term analysis of atmospheric changes. A significant contribution to this uncertainty is due to the nonlinearity and quantum efficiency stability of the photomultiplier tubes (PMT) chosen to satisfy the demanding constraints in terms of sensitivity and dynamic range required by solar UV scanning spectroradiometers. A solid state detection system (SSDS) composed by a solid state detector in conjunction with optimized low noise and high sensitive readout electronics is presented as an alternative to PMT to reduce the total uncertainty of QASUME [1].

Keywords: Solar radiation, UV scanning spectroradiometers.
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INTRODUCTION

Reference measurement systems for UV solar spectra such as QASUME are based on scanning double monochromator which offers stray light rejection as high as 10^6 and wavelength scale accuracy better than 0.05 nm [1]. The negligible stray light level at the output of the double monochromator is reached at the expenses of the low optical radiation output power that can be well below pW level for the sun spectrum in the UVB region. Currently the device of choice to measure the double monochromator output optical radiation of reference scanning spectroradiometers is the photomultiplier tube (PMT) because of its high sensitivity and large dynamic range necessary to cover the 6 orders of magnitude of the solar spectrum in the UV region. State of the art for UV solar reference spectroradiometers are able to perform with a total uncertainty of 5% of which PMT poor spectral response stability and non-linearity account for a large fraction [2].

Recent improvements in the manufacturing process of low noise solid state detectors and high sensitive low noise readout electronics are narrowing the gap between the photon counting regime (optical radiation below 1pW) and the analog regime (typically above 1nW). Furthermore new semiconductors materials with wide band gap are emerging as promising low noise, higher response detectors particularly suitable for measurement at UV wavelengths [3]. Such technological advancements are making the replacement of PMT with a traditional analog solid state detector based detection system (SSDS) a concrete possibility. The main advantages of this new approach include: linearity better than 100 ppm [4], negligible memory effects and very stable UV responsivity that can be measured with uncertainty below 0.1%. The target uncertainty for the solar reference scanning spectroradiometers with the new detection system is 1%.

SOLID STATE DETECTION SYSTEMS

There are three main requirements for the detection system for UV scanning spectroradiometer. The first is obviously the high sensitivity necessary to measure UV solar radiation at wavelengths shorter than 300nm. In fact the optical radiation power at the output at the exit slit of the double monochromator of QASUME has been recently measured: it ranges from about 1 fW at 280 nm to about 1 nW starting from 320 nm to 400nm (see Figure 1). The second requirement is the dynamic range of the UV solar spectrum which means that the detection system must be able to cover more than 6 orders of magnitude with ideally linear behavior in all range. The third requirement concerns measurement time: UV scanning spectroradiometer must be able to measure the spectrum of interest within

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a few minutes in order to be able to cope with sky variability, which means that for typical wavelength steps of 0.5 nm each measurement cannot take more than 1 second.

Switched Integrator and Silicon Detector

A system that fulfills QASUME requirements for most of the UV solar spectrum is composed of a low dark current silicon photodiode in conjunction with a switched integrator amplifier (SIA) [5] that stores the charge generated by the photodiode on a capacitor placed to form a negative feedback of an operational amplifier. The longer it integrates the higher is the output voltage according the equation (1).

$$V_{out}(t) = -\frac{i_p \cdot t}{C} \quad (1)$$

Where V_{out} is the output voltage, i_p is the current generated by the photodiode t is the integration time and C is the integration capacitor. Among the advantages of such approach is that once the value of C is calibrated, with typical uncertainty better than 100ppm, it is possible, measuring the integration time t, to know the current to voltage conversion factor up to 10^{12} with the same low uncertainty given for C.

A microcontroller-driven SIA has been developed by the Czech Metrology Institute which offers up to 7 order of magnitude of dynamic range and integration time generated on board that can be set by a controlling PC. The SIA has been successfully used in conjunction with a silicon trap detector for very low flux measurements at few hundred fW level [6] and has been shown to be linear (better than 10^{-4}) from 40 pW to 400 μW [4].

In order to further extend the sensitivity of the SIA-based detection system to lower power levels a small area/low dark current silicon detector has been selected (Hamamatsu 1227 33BQ). The noise equivalent power of this silicon detector in conjunction with the SIA has been measured to be as low as 10 fW/Hz$^{1/2}$ at 400 nm.

In the following figure the calculated relative noise of SSDS, with a maximum integration time of 0.1 s, is shown for a typical solar UV spectrum measured by QASUME.

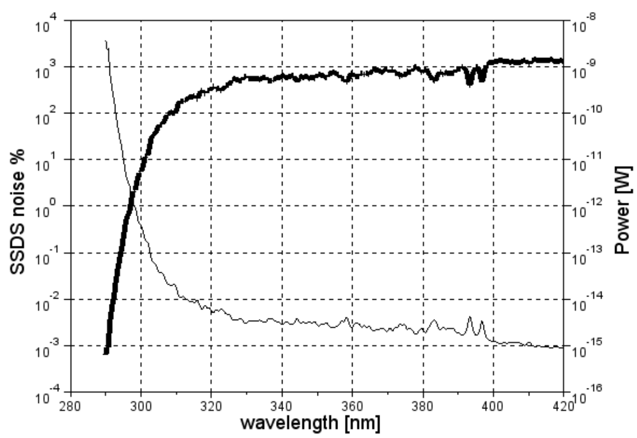

FIGURE 1. Calculated relative noise for typical UV solar spectrum measured with QASUME with SSDS (thick line : measured power, thin line : calculated SSDS noise) using integration time < 0.1s.

It appears that the noise of this SSDS with fixed 0.1 second integration time reaches the level of 1% of the signal at about 298 nm in a typical UV solar spectrum measured by QASUME. Optimizing the integration time according the signal level i.e. increasing it up to 10s it is possible to extend the range with noise below 1% to 295 nm where the power at the output slit of QASUME double monochromator is 100fW.

Wide Band Gap Energy Semiconductors

The main contribution of the noise generated by semiconductor based detectors is the random generation of the electron holes pair due to the thermic energy present in the crystal. In recent years a new generation of semiconductors materials with high energy band gap have been studied and manufactured. They offer band gap more than 3 times larger than Si with potential noise floor many orders of magnitude lower than Si [3].

In particular, ZnO thin films have generated great interest thanks to its large excitation binding energy (60 meV), suitable direct energy gap of 3.37 eV at 300 K, high internal gain and high responsivity [7], excellent radiation hardness that make zinc oxide especially attractive and competitor of GaN. Moreover, ZnO-based photoconductors have already shown dark currents as low as 400 pA and responsivity in the range of 1-10 A/W [8].

In perspective of fabricating a ZnO UV photodetector, ZnO thin films properties that must be optimized are good crystallinity, low surface roughness, high purity, good homogeneity on large areas, reproducibility and stability. In the choice of the fabrication technique among all that available for good quality ZnO thin films (sputtering, Moleculare Beam Epitaxy, chemical vapor deposition, etc.), it should be taken in to account the possibility of fabricating ZnO thin film at relatively low temperatures and by a cheap procedure. At INRIM, electron gun technique has been used because it allows the growth of large areas (2×2 cm^2) high quality ZnO films. Two different approaches have been experimented, one based on the evaporation of ZnO powder in vacuum, then followed by an ex-situ annealing in ambient atmosphere at 500°C (two-steps method), the other based on the evaporation in oxygen atmosphere at a partial pressure $P(O_2)$ of about 2.5×10^{-4} mbar (single-step method). X-Ray Diffractometer (XRD), Scanning Electron Microscope (SEM) and Atomic Force Microscope (AFM) analysis has been carried out to characterize the morphological and structural properties of the samples. By VASE (Variable Angle Spectroscopic Ellipsometry) the optical constants of the ZnO films grown by this technique have been obtained together with an estimation of roughness. The roughness values obtained by VASE have been then compared to those measured by AFM analysis. The conductivity values have been then measured by electrical characterization of the ZnO thin films after patterning and definition of an interdigited circuit with Ti/Au Schottky type contacts. The preliminary optical and electrical characterization showed that the most promising result can be achieved by the single-step method. Devices fabrication based on this method is in progress.

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