Photoacoustic SO_2 gas sensor in SF_6 buffer gas employing a 266 nm LED

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A ppb-level SO_2 photoacoustic sensor for SF_6 decomposition analysis by use of a compact light emitting diode (LED) ultraviolet (UV) and a differential photoacoustic cell (PAC). The mW-level UV laser emits at 266 nm due to a strong electronic SO_2 spectrum as well as effectively avoiding interference from SF_6 absorption bands in the infrared spectral region. A symmetrical differential PAC was designed to address the issue of SF_6 flow noise. As a result, the reported SO_2 photoacoustic sensor system can achieve real-time, on-line measurements with a continuous sample gas flow 7 times larger than that with a single resonator PAC. A new optical source, a novel PAC design and a strong target spectrum result in a SO_2 minimum detection limit of ~74 ppb, which meets the requirement for monitoring of electric power systems.

Background – High voltage gas insulated apparatus such as the gas insulated switchgears (GIS) and the gas insulated lines (GIL) have been widely used in power transmission and distribution systems around the world. Due to the high dielectric strength, chemically inactive and environmentally acceptable property, sulfur hexafluoride (SF_6) was widely chosen as the preferred dielectric gas for electrical insulation or interruption purposes in electric power systems. However, GIS/GIL failures occur from time to time from manufacturing defects [1-2]. The monitoring of decomposed by-products can efficiently identify and determine the occurrence of fault types in electrical equipment and thus minimize security risks. When the SO_2 concentration is > 8 ppm, the power equipment must be overhauled [1-3]. Currently the most research of diagnosis is focused on photoacoustic spectroscopy combined with the incoherent excitation source, which limits the detection sensitivity to reach <1 ppm. Health monitoring of gas insulated apparatus is critical to improve the reliability and to reduce the life cycle cost. Among the various methods for the monitoring, optical sensing developed fast in recent years due to their highly sensitive and anti-electromagnetic interference characteristic [3-4].

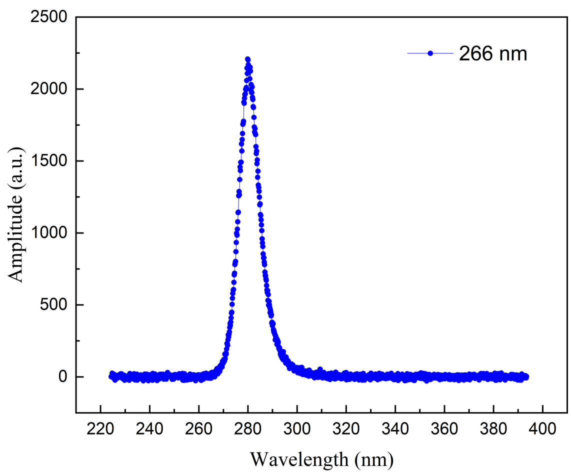

Fig. 1. Spectral emission of the 266 nm LED

Light source – A low-cost LED was employed as the excitation light source, which emitting at 266 nm. The output power was ~ 5mW at the room temperature. An optical spectrum analyzer (Avantes, AVS-DESKTOP-USB2) was used to measure the emission spectrum of the laser. As show in Fig. 1, the laser linewidth is < 8 nm. The corresponding SO_2 absorption cross section is ~ 4.8×10^{-19} cm^2/$molecule^{-1}$.

Experiment – A differential photoacoustic cell was designed for the detection of SO_2 acoustic signal. Two identical cylindrical acoustic resonators (Φ5×90 mm in size) were arranged independently and in parallel. Two buffer volumes (Φ20×10 mm) were added at both ends of the resonators to constitute two identical open-open resonators. At the outsides of the buffer volumes, two quartz windows (Φ25.4×5 mm) and two rubber O-type rings were used to seal the PAC. The measured resonance frequency of the PAC was 683.6 Hz with a FWHM of 8.1 Hz in SF_6. In order to verify the linearity of the sensor performance, the average signal amplitudes of 100 data points were plotted in Fig. 2(a) for different gas concentration levels. The linear fitting R-Square value >0.9995 confirms the linearity of the sensor response to concentration. In PAS, the pressure is a critical parameter, since the Q-factor of the acoustic cell, the V-T relaxation rate of target gas and the intensity of the absorption spectrum are pressure dependent. The relationship between the signal amplitude of a 100 ppm SO_2/N_2 and the pressure are plotted in Fig. 2 (b). A linear increase of the signal amplitude with the total gas pressure was observed.

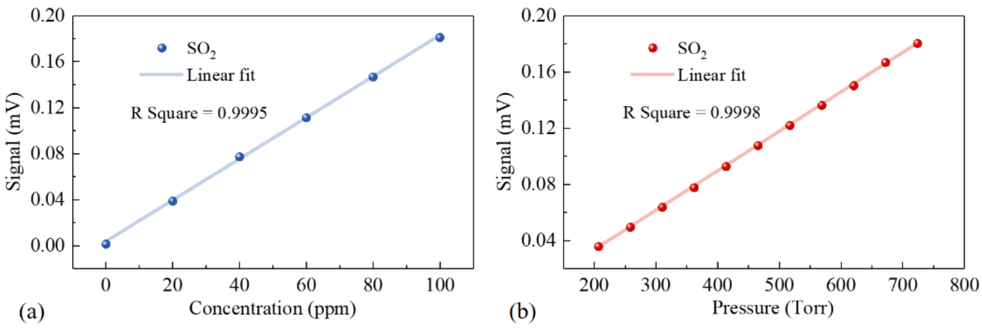

Fig. 2. The linearity of the SO_2 photoacoustic signal under different concentrations (a) and pressures (b).

A 266 nm LED was used for SO_2 detection in SF_6 buffer gas. Based on the data of the 100 ppm SO_2/SF_6 gas sample, the noise equivalent (1σ) concentration is ~1.3 μV, which corresponds to a signal-to-noise ratio (SNR) of 143 and a detection limit of 695 ppb.

References

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