

**BREAKDOWN OF SO<sub>2</sub> IN VENUS CLOUD BY ARC-TYPE ELECTRIC DISCHARGE.** Hongkun Qu<sup>1,3</sup>, Alian Wang<sup>1</sup>, and Elijah Thimsen<sup>2</sup>, <sup>1</sup>Dept. of Earth and Planetary Sciences and the McDonnell Center for the Space Sciences, <sup>2</sup>McKelvey School of Engineering, Washington University in St. Louis, MO, 63130, USA. <sup>3</sup>Shandong Key Laboratory of Optical Astronomy and Solar-Terrestrial Environment, School of Space Science and Physics, Institute of Space Sciences, Shandong University, Weihai, Shandong, 264209, China. ([hongkun.qu@wustl.edu](mailto:hongkun.qu@wustl.edu))

**Electric activity in Venus cloud:** The electrification of atmospheric species is very likely a ubiquitous process operating on many planetary bodies [1-3]. On a planet with an atmosphere, a local electrical field (E-field) is produced by the generation of charged particles, such as dust, ice particles, aerosols, or liquid droplets, and by the separation of these charges. An electrostatic discharge (ESD) would occur when the E-field grows beyond the breakdown electrical field threshold (BEFT) of that planet.

In Venus cloud layers where the temperature is above water/sulfuric acid freezing temperature, the atmospheric particles of three modes (aerosols, sulfuric acid droplets, and unknown crystals) can be frictional charged [4] and be separated in convective atmospheric cells [5], thus to maintain a local E-field. The BEFT level on Venus would be a dependent of local atmospheric composition and pressure [6].

Nevertheless, the reports of lightning observations on Venus have been controversial. An excellent review written by Lorenz 2018 [7] re-evaluated the spacecraft and ground-based observations of the past 40 years, and concluded that “*some kind of frequent electrical activity is supported by the preponderance of observations, but*

*optical emissions are not consistent with terrestrial levels of activity*”.

Regardless of the ESD on Venus being Earth-like-lightning or being some kind of electric activity, its effect on Venus atmospheric chemistry can be enormous. The collisions between ESD-electron and atmospheric particles would generate a large variety of free radicals (ions and atoms/molecules at excited states) [8]. With extremely high chemical reactivity and kinetic energy, they will cause further chain reactions in Venus atmosphere.

The composition of the Venusian atmosphere has been detected by the orbiter, atmospheric probes, landers, flyby missions, and Earth-based telescopes, including CO<sub>2</sub>, N<sub>2</sub>, SO<sub>2</sub>, OCS, H<sub>2</sub>S, H<sub>2</sub>SO<sub>4</sub>, HCl, H<sub>2</sub>O, CO, HF, and noble gases He, Ne, Ar, Kr, Xe [9]. In addition to sulfuric acid droplets, chlorine-containing, and phosphoric-acid aerosols were also found [10]. Many mysteries remain between the mission observations and theoretical model studies. Among them, *the source materials for the second UV absorber* have been the targets of many experimental investigations [11,12]. In a review study [13], eight sulfur-bearing species were listed among a total of eleven candidates.

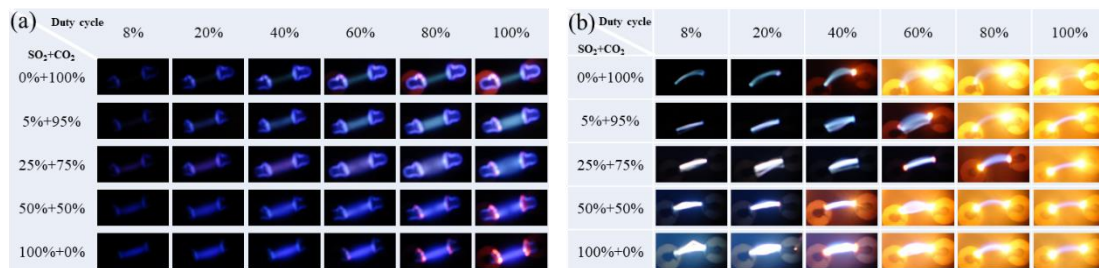


Fig. 1. Comparisons of photos of ESD generated plasma at 28kV driving voltage, 20 kHz, with changing of ESD duty cycles and mixing ratio in the mixtures of CO<sub>2</sub>+SO<sub>2</sub> (a) at 10 mbar, (b) at 750 mbar .

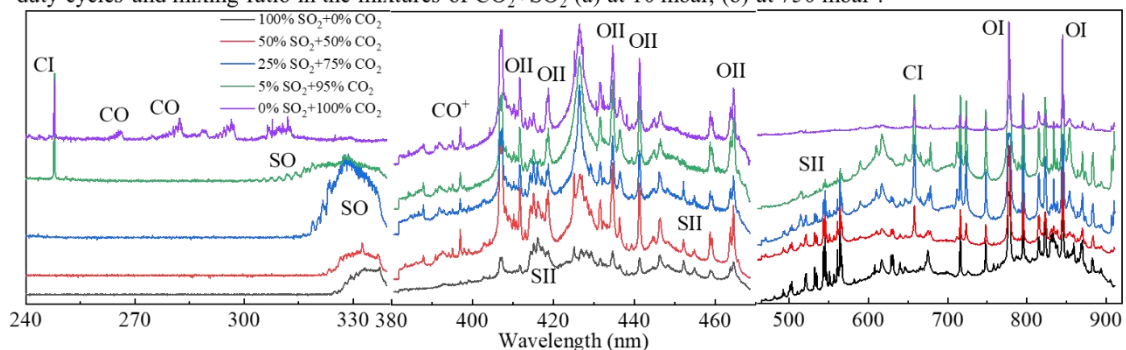


Fig. 2. Plasma spectra obtained in the mixture of CO<sub>2</sub>+SO<sub>2</sub> with different ratios at 20kHz and 28 kV driving voltage at 750 mbar and a 8% duty cycle.

**Experimental study on the chemical effect of ESD at Venus conditions:** We hypothesized that the 2<sup>nd</sup> UV absorption band (320-400 nm) in Venus mission observation could be contributed by the products of electrochemistry, a process that has been studied much less than photochemistry and thermochemistry under Venus conditions.

**Experiment step 1:** We designed and built a Venus-ESD chamber (VEC) with peripheral subsystems, and generated arc-type discharge in a pressure range that corresponds to 50-75 km altitude in Venus cloud layers. We used four optical and non-optical sensors to detect and quantify the generated free radicals.

When using the air to fill the VEC, we observed all free radicals that were observed in terrestrial lightning thus validating our experimental set-up for lightning simulation. When the VEC was filled with pure CO<sub>2</sub> or a mixture of two major Venus gases CO<sub>2</sub>-N<sub>2</sub> at 96.5:3.5 ratio, we detected all free radicals found by previous studies that simulating Venus lightning, plus NO, CN, O<sub>3</sub>, and C<sub>2</sub> that are extremely important for ESD in CO<sub>2</sub>-N<sub>2</sub> system [14].

From *Experiment step 1*, we established a reliable experimental system including technology and procedures and built background knowledge for the free radicals generated by arc-type ESD in CO<sub>2</sub>-N<sub>2</sub> system under Venus conditions.

**Experiment step 2:** We plan to use three gas mixtures, CO<sub>2</sub>-SO<sub>2</sub>, N<sub>2</sub>-SO<sub>2</sub>, and CO<sub>2</sub>-N<sub>2</sub>-SO<sub>2</sub>, to fill the VEC, and to generate arc-type discharge with adjustable average energy and duty cycle. We added an UV sensor to obtain the UV absorbance spectrum (190-890 nm) of the species in the VEC during ESD.

At the time of this abstract submission, we have finished the ESD experiments in the CO<sub>2</sub>-SO<sub>2</sub> system. We selected to use 100%, 50%, 25%, 5%, 0% of SO<sub>2</sub> in the gas mixture to achieve our study goals by steps (1) to learn the types of free radicals generated by arc-type ESD, in pure SO<sub>2</sub> and in SO<sub>2</sub>-CO<sub>2</sub> mixture; (2) to understand the detection sensitivities of various sensors in our set-up with a gradually reducing SO<sub>2</sub> concentration; (3) to evaluate the effect of concentrations of sulfur radicals on the UV absorption band in 190-890 nm spectral range.

### Results of Experiment step 2:

The photos of the ESD plasma taken with the same exposure conditions are shown in Fig. 1. At 10 mbar (Fig. 1a), we found that the discharges become brighter with increasing duty cycles because more energy was delivered to generate the plasma. At a high duty cycle (>80%) and high SO<sub>2</sub> ratio, the “red” glare of electrodes suggests their overheating.

At 750 mbar (Fig. 1b), the ESD at high duty cycle (>60%) heated the electrodes to very high temperature, illuminated by bright yellow emission; while the ESD plasmas at low duty cycles (<60%) consist of many fine streamers, similar to the observation in CO<sub>2</sub>-N<sub>2</sub> mixture [14]. The color of the ESD plasma is bluish at 10 mbar (Fig. 1a) and whitish at 750 mbar (Fig. 1b), which reflects the difference in the wavelength of major lines of the plasma emission spectra (Figure 2).

The plasma spectra (240-900 nm) generated by discharges at 750 mbar are shown in Fig. 2. The band of SO\*(B<sup>3</sup>Σ<sup>-</sup>→X<sup>3</sup>Σ<sup>-</sup>) around 310-340 nm can be seen at an SO<sub>2</sub> concentration of 5%. Following the increase of SO<sub>2</sub> concentration (25%→100%), this band becomes narrower and stronger. More importantly, four bands made of multiple SII\* emission lines (~416.2 nm, 417.2 nm, 452.2 nm, and 454.8 nm) appear in all plasma spectra of the mixture with SO<sub>2</sub> > 5%. The free radicals generated by CO<sub>2</sub> breakdown (CI\*, CO\*, CO<sup>+</sup>) [14] were seen in all mixtures except pure SO<sub>2</sub>. Strong emission lines of OI\* at 777 nm and 844 nm from the dissociation of CO<sub>2</sub> and SO<sub>2</sub>, and multiple lines of OII\* (i.e., O<sup>+</sup> from ionization), appear in the ESD spectra of 400-460 nm of all mixtures.

The observations of plasma lines of SO\*, SI\*, SII\*, OI\*, and OII\* (i.e., O<sup>+</sup>) indicated a gradual breakdown of SO<sub>2</sub> molecule during ESD, to SO\*+OI\*, to SI\*+SII\*+OI\*, and to SII\*+ O<sup>+</sup>.

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