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ABSTRACT
In this paper, ultraviolet laser with the wavelength of 248 nm was employed to assess the laser-induced plasma transmission spectroscopy of four kinds of sandstone. The research focused on the interactions between the laser pulse and the component as well as the structure of sandstone. The more complex metal ion content the rock has, the larger voltage signal the sandstone shows with the same bias current applied. The metal ion can stimulate the formation of plasma excited by the laser. Meanwhile, the excited plasma moves faster in the sandstones with more pores and gives the rock a shorter rise time. The measured voltage effect in sandstone indicates that ultraviolet laser is an approach to identify lithology of stratum by the peak values and rising times.

I. INTRODUCTION
Laser pulses have been extensively used to study fundamental physical processes in solids. The interactions between short laser and matter lead to energy localization bond-breaking and, ultimately, atomic and ionic motion. The interaction of light with solids comes through electronic excitation and thereafter to electron-phonon coupling. The absorption of a photon in the visible or ultraviolet typically produces both electronic and vibration excitation in the surface and near-surface region of an irradiated solid (Ummadisingu et al., 2017; Liu et al., 2016). Infrared laser photons may be absorbed in harmonic phonon modes of the solid or in specific vibrational modes corresponding to natural frequencies of constituent molecular groups (Liang et al., 2017). Besides absorption of low-energy infrared photons, which generally does not excite the system out of the electronic ground state, excitons are not formed and the energy is transferred directly into lattice excitation.

As an important research object of geology, rock has been tested by lasers on the induced voltage. Laser induced voltage was employed to assess the Dember effect, the layered structure, and oil content of a dielectric rock due to the potential difference caused by the difference in mobility between holes and electrons (Lu et al., 2015; Miao et al., 2017a; 2017b; 2018; and Esirkepov et al., 2002).

Sandstone as a major constituent of reservoir rock plays an important role in energy storage and geological evolution. The determination of its composition is important for tectonic setting. When the sandstone sample surface is irradiated by an ultraviolet laser beam, a part of the energy of the laser beam will be absorbed by the surface. When the sample receives a nanoscale pulsed laser, the energy of photons of laser radiation in the very beginning of a pulse is also transferred to the surface particle, an oscillating electric field is formed on the surface of the particle, the free conducting electrons in the particle collectively oscillate under the excitation of the oscillating electric field, the incident photon frequency is equal
to the collective vibration frequency of the free electron cloud of the particle, and surface plasma is generated on the sample surface (Haberberger et al., 2011; Wilks et al., 2001; Joshi and Corkum, 1995; and Di Pietro et al., 2013). Plasma has equal probability of motion in all directions without applied electric field. By setting bias voltage at both ends of the sample, the separation of positive and negative charges can be achieved, and the transmission distance of plasma on the surface can be increased, so as to detect the voltage effect. Therefore, the transport mechanism of plasma can be analyzed through the detected voltage spectra. We call this method laser-induced plasma transmission spectroscopy (LIPTS).

In this paper, four sandstone samples have been studied under the ultraviolet (UV) laser irradiation. The relationships of peak of LIPTS signal \(V_p\), rise time and component, and the structure of the four sandstone samples were investigated.

### II. EXPERIMENTAL METHODS

The sandstone samples were obtained from Sichuan basin, including rock sandstone (R), feldspar sandstone (F), and two kinds of quartz sandstone (Q1 and Q2), respectively. Component and structure information of the sandstone samples were examined with x-ray diffraction (XRD), infrared (IR) spectrometer, and scanning electron microscopy (SEM). Based on the result of XRD, R, F, and Q1 were composed of quartz, calcite, and microcline; in contrast, Q2 consisted of quartz and dolomite (Fig. 1). Besides, on the basis of the infrared image, the peaks at 1080 cm\(^{-1}\) and 797 cm\(^{-1}\) were assigned as quartz, which was the common component of the four sandstone samples. A broad absorption band of microcline was centered at about 3480 cm\(^{-1}\). The peak at 878 cm\(^{-1}\) and 1440 cm\(^{-1}\) of Q1 attributed to the presence of calcite (Fig. 2). The mass fraction and atom fraction of these elements are listed in Table I. According to the EDS result, Si and O are the major elements in four samples. Al, K, Mg, and Fe can be identified in the R, F, and Q1, and there is no ion content in Q2. Particles consist of agglomerated bulks, which show different shapes. Under SEM observations of sample R, the vermicular or “booklet” quartz are abundant in intercrystal micropores.

### TABLE I. Composition table of four samples.

| No. | O Wt. % | O At. % | C Wt. % | C At. % | Al Wt. % | Al At. % | Si Wt. % | Si At. % | K Wt. % | K At. % | Mg Wt. % | Mg At. % | Fe Wt. % | Fe At. % |
|-----|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| R   | 30.99   | 44.84   | ...     | ...     | 4.93    | 3.23    | 55.93   | 46.10   | 8.16    | 4.83    | ...     | ...     | ...     | ...     |
| F   | 31.26   | 36.23   | 23.20   | 35.83   | 9.25    | 7.11    | 16.63   | 10.98   | 0.39    | 0.19    | 9.32    | 7.11    | 9.95    | 3.30    |
| Q1  | 26.59   | 40.84   | ...     | ...     | 18.22   | 16.60   | 32.1    | 28.08   | 6.18    | 3.89    | 5.53    | 5.59    | 11.38   | 5.01    |
| Q2  | 37.72   | 51.53   | ...     | ...     | ...     | ...     | 62.28   | 48.47   | ...     | ...     | ...     | ...     | ...     | ...     |
and the average particle size was 20 μm (Fig. 3). The spherical particle size of Q2 was about 80 μm. More abundant pore structure was exhibited in Q2 and R compared with Q1 and F.

The sandstone samples for the LIV measurement, which have the size of 3 × 10 mm² with a thickness of 2 mm, are mechanically fabricated by a rock-cutting machine. The end surfaces were ground to make them parallel using the grinding machine. The four colloidal silver electrodes were prepared on the sample surface. Bias current was applied to the sample through the outer electrodes by a Keithley 2400 source meter, and the inner pair of probes was used to capture voltage signals by a digital oscilloscope with a 350 MHz bandwidth and 1 MΩ input impedance. A 248 nm, 20 ns KrF pulsed laser was used to irradiate the central portion of the surface, and the environment temperature is 25 °C.

The sandstone samples for the LIV measurement, which have the size of 3 × 10 mm² with a thickness of 2 mm, are mechanically fabricated by a rock-cutting machine and then polished by sandpaper. The four colloidal silver electrodes were prepared on the sample surface.Bias current was applied to the sample through the outer electrodes by a Keithley 2400 source meter, and the inner pair of probes was used to capture voltage signals by a digital oscilloscope with a 350 MHz bandwidth and 1 MΩ input impedance. A 248 nm, 20 ns KrF pulsed laser was used to irradiate the surface.

III. RESULT AND DISCUSSION

The four sandstone samples are irradiated by UV pulsed laser, and the voltage signals were observed as shown in Fig. 4. Higher $V_p$ were observed with larger bias current. The $V_p$ of R, F, Q1, and Q2 increased from $-0.089$ V to $0.038$ V, $-0.02$ V to $0.03$ V, $-0.071$ V to $0.032$ V, and $-0.007$ V to $0.014$ V with the bias currents from $-0.15$ μA to $0.15$ μA, $-0.08$ μA to $0.08$ μA, $-0.15$ μA to $0.15$ μA, and $-0.07$ to $0.07$ μA, respectively. When the laser was irradiated on the surface of the sample, the particles absorb a part of the energy of laser and induced surface plasma. The more metal ion content leads to more likely break through the barrier, favoring the occurrence of plasma. The bias current is essential to explain the behavior of plasma in this material. A transient LIV can be generated under the application of a bias current. Different from R, F, and Q1, there is no metal ion content in Q2. Therefore, samples R, F, and Q1 can generate more plasma than sample Q2 (Shahmansouri et al., 2018), thereby producing larger LIV value as shown in Fig. 5.

After the plasma was generated, the transmission process can convey the message of the sample. As presented in Fig. 6, the rise time of the sample is on the order of microseconds and the averaged value are about 0.26 ms, 0.22 ms, 0.12 ms, and 0.03 ms for F, Q1, Q2, and R. The rise times of F and Q1 are relatively close and significantly longer than those of R and Q2.
UV pulsed laser and the voltage signals were observed. The more of four kinds of sandstone samples. The samples are irradiated by laser and complex samples (such as natural sandstone) and opens up new experimental methods for the identification of rock sample structures.

IV. CONCLUSION

In summary, this study focused on the laser-induced voltage of four kinds of sandstone samples. The samples are irradiated by UV pulsed laser and the voltage signals were observed. The more metal ion content of the sample leads to more likely generate surface plasma, favoring the occurrence of high $V_p$. The generated plasma moves faster in more porous samples and gives the samples a shorter rise time. Therefore, the experimental results in this paper suggest possible reasons for the interaction mechanism between laser and complex samples (such as natural sandstone) and opens up new experimental methods for the identification of rock sample structures.

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