

Novel Optogalvanic Spectroscopy of Semiconductor Atoms with a Frequency-tripled ns Ti:sapphire Laser Injection-seeded by a cw Frequency-scanning Ti:sapphire Laser

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Novel optogalvanic spectroscopy of silicon atoms was conducted with the narrow-linewidth nanosecond pulsed deep-ultraviolet coherent light source which was comprised of the frequency-tripled nanosecond pulsed Ti:sapphire laser injection-seeded by another frequency-scanning cw Ti:sapphire laser. Only when the laser frequency of the seed laser matched with the cavity frequency of the slave laser, signals increased remarkably. The individual spectral widths derived from the injection-seeding effect should be the tolerance for successful injection-seeding in the axial mode of the slave laser, and indicated the linewidth of the injection-seeded ns pulsed deep-ultraviolet laser. So the cavity performances of the slave laser can be seen from the spectrum. The envelope of these peaks indicated the absorption spectrum of silicon atoms. This spectral width had the FWHM of 4.8 GHz in the Gaussian fitting and was equivalent to nearly the pure Doppler width, which could not be measured with the system without the injection seeding.

Key Words: Deep-ultraviolet, Injection seeding, Optogalvanic spectroscopy, Single frequency

1. Introduction

There has recently been increased interest in atom optics, where atoms are treated as conventional light. In atom lithography¹⁾ and atom holography²⁾, atomic beams can be reflected, diffracted and focused with lasers tuned to the atomic resonance. For example, the periodic focusing of atomic beams by means of light field of the standing wave leads to the periodicity of half the wavelength of the light and provides the high resolution of only several tens of nanometers³⁾.

In particular, atom optics of semiconductor atoms⁴⁾ has attracted our interest for its potential applications to novel material devices such as a quantum computer⁵⁾, which operates with their nuclear spins. However their low abundance rates in natural semiconductors prevent us from developing these devices. It is a key issue how to separate and collect only atoms with nuclear spins from the others. Therefore, we proposed the optical control of them with an atomic mirror, which controls neutral atoms with the dipole force in evanescent wave induced by a light source⁶⁾.

The following performances of the light source are required: 1) the wavelength in the deep-ultraviolet (deep-UV) region of which the light is resonant with the $^3P_1 - ^3P_0$ cyclic transition for laser cooling of semiconductor atoms; 2) the narrower linewidth than frequency separations of their isotopes; and 3) as high intensity as possible the system can provide. In general, however, it is difficult that one laser source acquires both features of the high intensity and the narrow linewidth at 252 nm. Therefore, we have developed a frequency-tripled nanosecond pulsed Ti:sapphire laser injection-seeded by a frequency-scanning cw Ti:sapphire laser⁷⁾.

In this study, we demonstrate a novel method for obtaining optogalvanic spectra of semiconductor atoms with the light

source. These results provide laser-cooling transition of silicon atoms with pure Doppler broadening which does not include the effect of the resolution broadening by the linewidth of the light source.

2. Experimental setup

The experiment was carried out with a single-frequency deep-UV coherent light source⁷⁾, which was comprised of a pulsed deep-UV light source as a slave laser and another single-frequency Ti:sapphire laser as a seed laser, as shown in Fig. 1. In addition, a piezoelectric transducer (PZT), which stretched at 8 nm per voltage, was equipped at the output mirror of the slave cavity and coaxial so as not to block the light. Through the PZT, the slave cavity mode was varied with a power supply without any feedback.

The optogalvanic signal was obtained with a commercial hollow-cathode discharge cell (Hamamatsu inc. L2783), which contained neon buffer gas of about 6 Torr. The bore diameter and the length of the hollow cathode were 3 mm and 1.5 cm, respectively. When the high voltage was applied, neon ions were accelerated toward the negative electrode incorporating silicon atoms, and then they were evaporated. The change in discharge impedance in the hollow-cathode cell was detected as the optogalvanic signal when resonant laser light passed through the cell.

The lowest voltage was limited at breakdown of discharge. The highest voltage was limited in the voltage avoiding the damage of the electrical circuit for the optogalvanic signal. So this experiment was carried out in the range between 180 V and 400 V of the discharge voltages.

3. Results and discussion

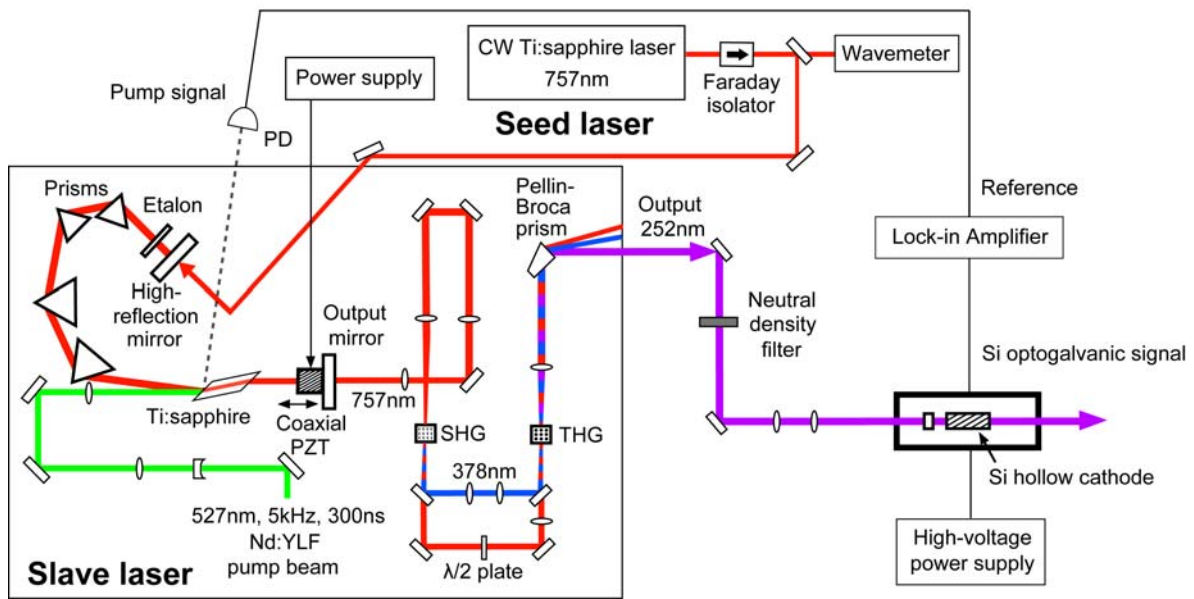


Fig. 1 Schematic diagram of the optogalvanic spectroscopy with a frequency-tripled nanosecond pulsed Ti:sapphire laser injection-seeded by a frequency-scanning cw Ti:sapphire laser.

Novel optogalvanic spectroscopy of silicon atoms was conducted with the single-frequency deep-UV coherent light source, which was injection-seeded by another frequency-scanning seed laser (Fig. 2). The baseline indicates the optogalvanic signal of the slave laser itself. Only when the optical frequency of the seed laser matches with the cavity frequency of the slave laser, the optogalvanic signal increases remarkably. The individual spectral widths derived from the injection-seeding effect should be the tolerance for successful injection-seeding in the axial mode of the slave laser, and

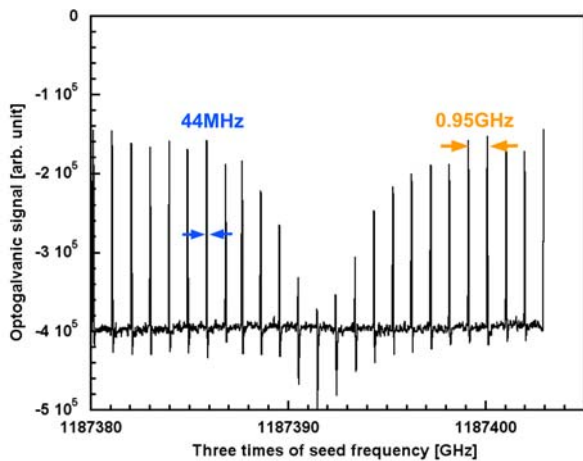


Fig. 2 Optogalvanic spectrum of silicon atoms with ns pulsed deep-UV coherent light source injection-seeded by another frequency-scanning seed laser. The incident power is 19 mW and the discharge voltage is 300 V.

indicate the linewidth of the injection-seeded ns pulsed deep-UV coherent light source. Its width agreed nearly with the laser linewidth estimated from the pulse duration if the ns Ti:sapphire laser realizes Fourier-transform-limit characteristics. So the cavity performances of the slave laser can be seen from the spectrum.

Multiple frequency scans of the seed laser with varying the cavity length of the slave laser lead to the optogalvanic spectroscopy of silicon atoms without taking into account the laser linewidth (Fig. 3). This spectral width has the FWHM of

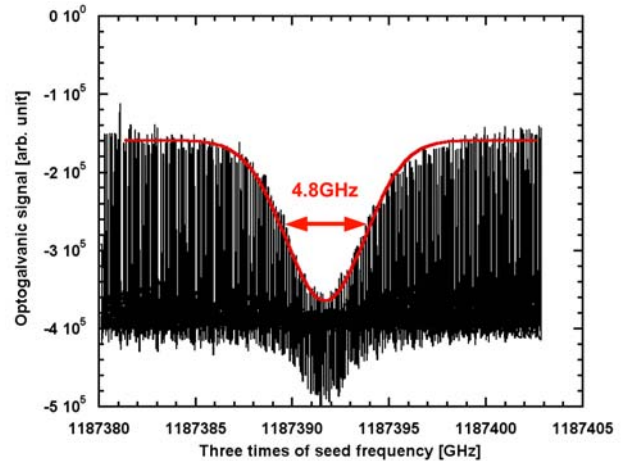


Fig. 3 Optogalvanic spectrum of silicon atoms with ns pulsed deep-UV coherent light source injection-seeded by another multiple-frequency-scanning seed laser. The incident power is 19 mW and the discharge voltage is 300 V.

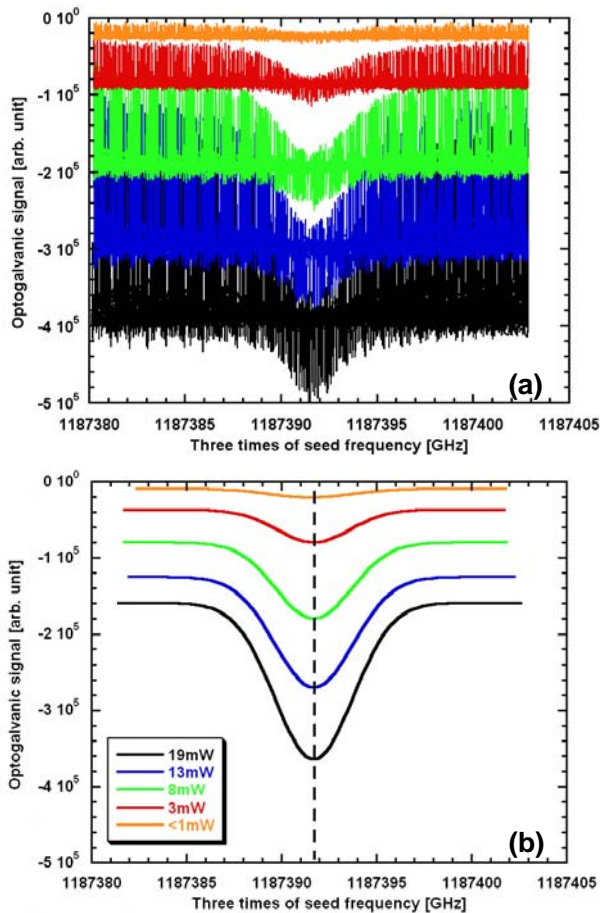


Fig. 4 (a) Optogalvanic spectra of silicon atoms and (b) Gaussian fits of them with various incident powers of the light source. The discharge voltage is 300 V.

4.8 GHz in the Gaussian fit and then is equivalent to nearly the pure Doppler width, which the system without the injection seeding could not provide. From this width, the mean temperature of silicon atoms in the hollow-cathode cell was estimated as 890 K. While the spectrum and the Gaussian fit are qualitatively similar in the low frequency side, the difference in the high frequency side between them may arise from not only an experimental error but also isotopes of silicon atoms such as ^{29}Si and ^{30}Si , which frequency-shift to the high frequency side.

Figure 4(a) presents optogalvanic spectra in various incident powers of light source, which were adjusted with neutral density filters and detected in front of the hollow-cathode cell with a power meter (Coherent inc. LM10 HTD). For comparison of each spectrum, only Gaussian fits of them are plotted in Fig. 4(b). The optogalvanic signal increases as the incident power of the light source increases because the high intensity enables more silicon atoms in the hollow cathode to be excited. The power of 19 mW barely causes the Stark effect, which is the shifting and splitting of spectral lines of atoms due to the presence of not only an external static electric field but also an optical field. The base level of Gaussian fits rises as the incident power increases. These noises arise from photoelectric effects from the hollow cathode in which electrons are emitted by a part of incident light.

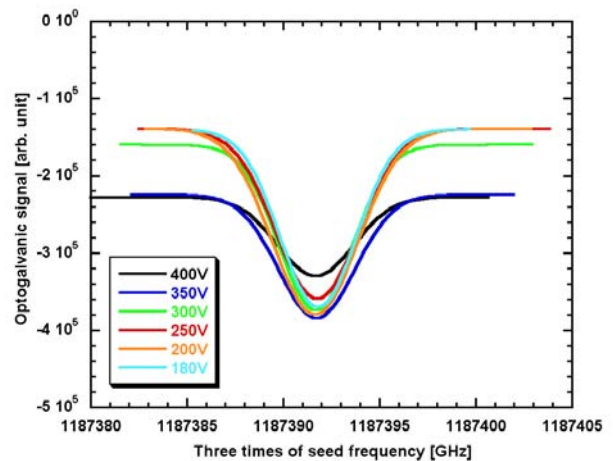


Fig. 5 Gaussian fits of optogalvanic spectra silicon atoms with various discharge voltages. The incident power is 19 mW.

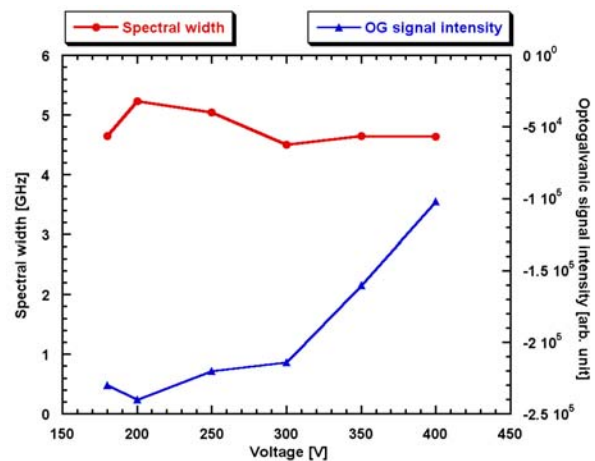


Fig. 6 Spectral widths and optogalvanic signals as functions of the discharge voltage.

Figure 5 shows Gaussian fits of optogalvanic spectra which were obtained with various discharge voltages. The base level of Gaussian fits rises stepwise as the discharge voltage increases. But increasing the discharge voltage decreases the optogalvanic signal because neon ions accelerated in the high electric gradient may excite silicon atoms up to higher states, where silicon atoms can not be laser cooled, than the ground state (Fig. 6). At the lower limitation of the discharge voltage (180 V), the data is unreliable because of the unstable discharge. The spectral widths, which agree with the Doppler broadenings, are almost constant. In other words, the mean temperature of silicon atoms in the discharge is almost constant within these voltages, where the optogalvanic signals decrease significantly.

4. Conclusion

We have proposed the novel optogalvanic spectroscopy of semiconductor atoms with the single-frequency

frequency-tripled ns pulsed Ti:sapphire laser injection-seeded by another frequency-scanning Ti:sapphire. Only when the optical frequency of the seed laser matched with the cavity frequency of the slave laser, the seed laser achieves the single mode operation. The trace of injection seeding indicates the linewidth of the injection-seeded ns pulsed deep-UV laser. Because this width is much narrower than frequency separations of semiconductor isotopes, this light source has a high potential application for controlling them individually. Furthermore, multiple frequency scans of the seed laser with varying the cavity length of the slave laser lead to the optogalvanic spectroscopy of silicon atoms without taking into account the laser linewidth and provide the laser-cooling transition of silicon atoms around 252 nm with pure Doppler broadening, which the previous system without injection seeding could not.

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