Effect of gas composition on the properties of electron beams from few-TW laser wakefield acceleration with a sub-mm gas cell

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Focusing few-TW laser pulses into a thin, dense gas target [1] represents a valid approach for realizing future high-repetition-rate laser wakefield acceleration (LWFA), aimed at generating 10- 20 MeV electron beams with an average current exceeding 1 nA. Our previous studies have demonstrated the feasibility of utilizing a sub-mm gas cell [2], featuring a plasma density around 4×10^{19} cm^{-3}, to create appropriate gas targets for conducting few-TW LWFA. While using pure nitrogen gas in the cell ensures ionization-induced injection and facilitates the routine generation of electron beams in few-TW LWFA, our recent findings demonstrate that by introducing a gas mixture consisting of 99% helium and 1% nitrogen (99% He-1%N_2) as the target medium, electron beams can be generated with even smaller divergences, improved pointing stability, and a higher proportion of high-energy electrons.

By using 1-TW, 40-fs pump pulses, Fig. 1(a) illustrates the setup employed for conducting the LWFA experiment. The gas cell here was fabricated by shaping a stainless-steel tube with an inner gap length of 450 µm, as shown in Fig. 1(b), while its entrance and exit channels, with a diameter of ≈ 300 µm, were created by laser ablation. Probe pulses were also introduced to pass transversely through the gas cell and provide shadowgrams, as shown in Fig. 1(b), which serve as supportive measurements to observe the produced plasmas. In operation, the pulsed valve installed underneath the cell opened for 2 ms to allow gases to flow into the cell, and the pump pulse entered the cell 6 ms after valve closure. By scanning the backing pressures p_b of gas fed into the cell, routine generation of electron beams was found when p_b = 10 psi for the pure nitrogen gas and p_b = 15 psi for the 99% He-1% N_2 gas mixture. Compared to the electron beams generated with pure nitrogen, results shown in Figs. 1(d) and 1(e) indicate that using the 99% He-1% N_2 gas mixture helps to reduce beam divergences to θ_z = 21.4 mrad and θ_y = 4.6 mrad and, more importantly, mitigates beam pointing fluctuations to $\Delta\theta_z$ = 0.8 mrad and $\Delta\theta_y$ = 3.1 mrad. The dispersed electron distributions shown in Fig. 1(f) reveal that while electron beams generated with the gas mixture exhibit a lower charge of 9 ± 1.6 pC (> 3 MeV) compared to 13.4 ± 3.4 pC for beams generated with pure nitrogen, those produced with the gas mixture contain more high-energy electrons with energies > 10 MeV. Additionally, a distinguishable peak around ≈ 12 MeV highlights the unique characteristics of few-TW LWFA with a gas mixture.

References
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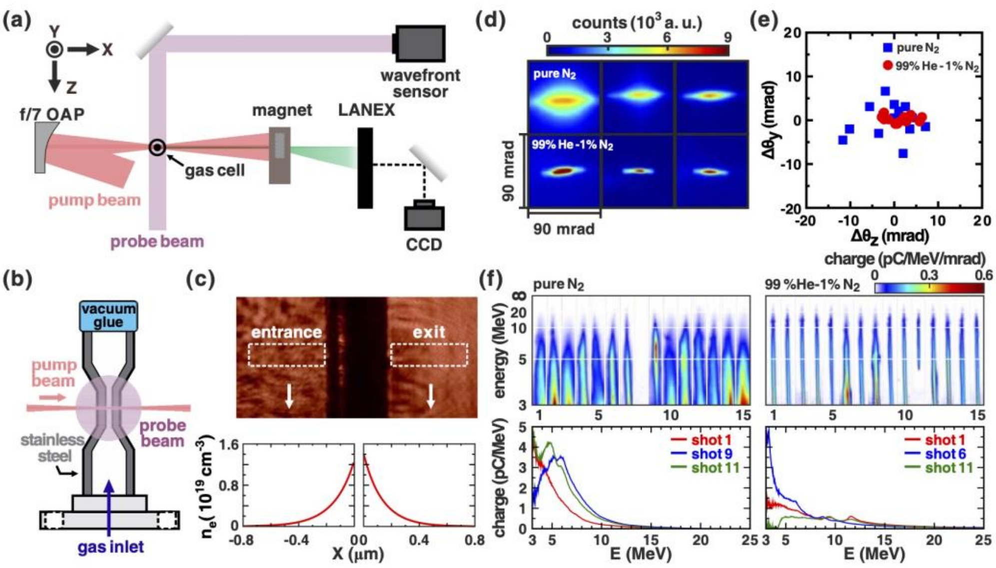

Figure 1. (a) Schematic diagram of LWFA experiment. (b) Structure of stainless-steel gas cell., (c) Shadowgrams for the plasmas produced outside the entrance and exit channels (with line-out density profiles below) when 1-TW pulse and 15-psi gas mixture of 99% He-1% N_2 were applied. (d) Comparison of transverse profiles of electron beams produced with 10-psi pure nitrogen and 15-psi gas mixture. Corresponding comparisons for (e) pointing distributions and (f) images of dispersed distribution of 15 consecutive electron beams and representative energy spectra.