

Supplementary information

Beamstop-free small-angle X-ray scattering for multiscale structure measurement of high-energy-density plasma

Masato Ota^{1,2,3*}, Ryutaro Matsui^{4,5,3*}, Melanie Rodel⁶, Shunsuke Egashira¹, Tomohiro Izumi¹, Yoshiharu Nakagawa¹, Yushiro Matsumoto¹, Otono Kuramoto¹, Hiroki Ishiara¹, Kosuke Maeda¹, Tatiana Pikuz⁷, Alexander Pirozhkov⁸, Alejandro Laso Garcia⁶, Lingen Huang⁶, Alessio Morace¹, Takumi Minami⁹, Kentaro Sakai^{2,3,9}, Yuji Fukuyama¹, Yuto Maeda¹, Kohei Endo⁹, Soma Nitta⁹, Genki Kamimura⁹, Tomoya Taguchi⁹, Yuki Abe⁹, Hideaki Habara⁹, Hirotaka Nakamura⁹, Bruno Albertazzi¹⁰, Michel Koenig¹⁰, Toshinori Yabuuchi^{11,12}, Tadashi Togashi^{11,12}, Yuichi Inubushi^{11,12}, Keiichi Sueda¹², Kohei Miyanishi¹², Takeshi Matuoka¹³, Norimasa Ozaki⁹, Naoki Uehara⁴, Yasuhiro Kuramitsu⁹, Keisuke Shigemori¹, Motoaki Nakatsutsumi^{13,14}, Yuji Fukuda⁸, Hiroshi Sakaguchi¹⁵, Takumi Yasuda¹⁶, Kazuhiro Fukami¹⁶, Thomas E. Cowan⁶, Thomas Kluge⁶, Yasuaki Kishimoto^{4,5,15*}, and Youichi Sakawa^{1*}

¹Institute of Laser Engineering, Osaka University, Osaka, Japan.

²National Institute for Fusion Science, Gifu, Japan.

³SOKENDAI (The Graduate University for Advanced Studies), Gifu, Japan.

⁴Graduate School of Energy Science, Kyoto University, Kyoto, Japan.

⁵Nonlinear and Non-equilibrium Plasma Science Research UNIT, Kyoto University, Kyoto, Japan.

⁶Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany.

⁷Institute for Laser Technology, Osaka University, Osaka, Japan.

⁸Kansai Institute for Photon Science (KPSI), National Institutes for Quantum Science and Technology (QST), Kyoto, Japan.

⁹Graduate School of Engineering, Osaka Univ, Osaka, Japan.

¹⁰LULI-CNRS, Sorbonne Universités, Ecole Polytechnique, Institut Polytechnique de Paris, Palaiseau, France.

¹¹Japan Synchrotron Radiation Research Institute, Hyogo, Japan.

¹²RIKEN SPring-8 Center, Hyogo, Japan.

¹³Institute for Open and Transdisciplinary Research in Initiatives, Osaka University, Osaka, Japan.

¹⁴European XFEL, Schenefeld, Germany.

¹⁵Institute of Advanced Energy, Kyoto University, Kyoto, Japan.

¹⁶Department of Materials Science and Engineering, Kyoto University, Kyoto, Japan.

* Corresponding authors:

Y. S. (sakawa-y@ile.osaka-u.ac.jp)

M. O. (ota.masato@nifs.ac.jp)

R. M. (matsui.ryutaro@nifs.ac.jp)

Y. K. (kishimoto.yasuaki.84r@st.kyoto-u.ac.jp)

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Supplementary Note 1: Fabrication and characterization of silicon nanorod targets

Highly ordered silicon nanorod arrays were fabricated using a dry-processing sequence applied to a p-type Si (100) wafer with a resistivity of 10–20 $\Omega\cdot\text{cm}$. The overall fabrication flow is shown in Supplementary Fig. 1. Prior to patterning, the wafer was cleaned using an SPM process, consisting of sulfuric acid, hydrogen peroxide, and ultrapure water, and then dried at 120°C for 3 min.

A 50-nm-thick Cr layer was deposited by electron-beam evaporation. The surface was treated with hexamethyldisilazane (HMDS) to promote adhesion between Cr and the electron-beam (EB) resist. An organic EB resist was coated using a stepwise spin-coating process and baked. A conductive ESPACER layer was added to prevent charging during EB exposure.

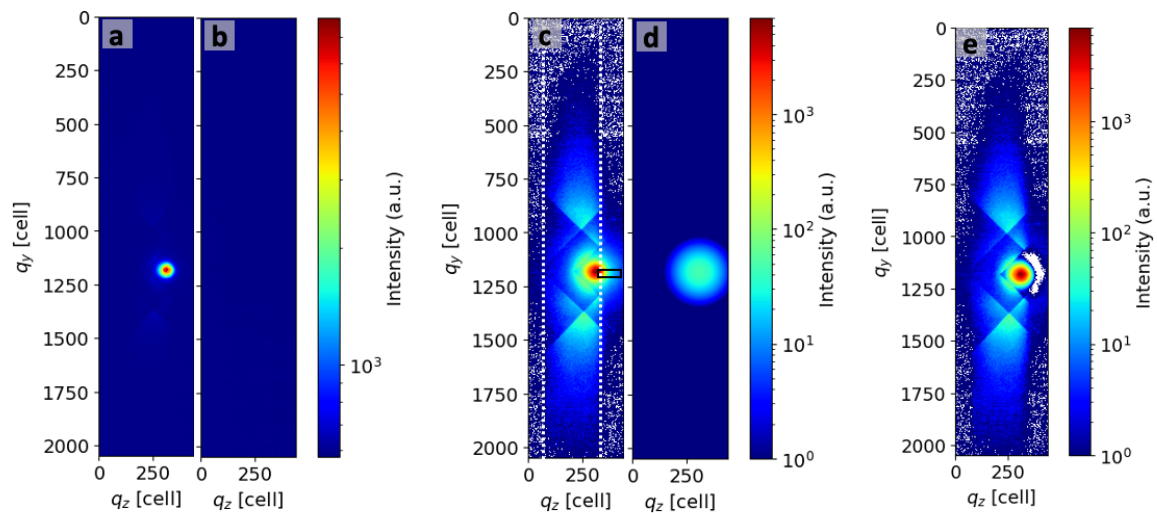
EB lithography was performed at 50 kV with an exposure dose of 30 $\mu\text{C}/\text{cm}^2$. After exposure, ESPACER was removed, and the resist pattern was developed in TMAH solution. Unmasked Cr was removed using neutral loop discharge (NLD) plasma etching.

Finally, silicon nanorods were fabricated using a Bosch deep reactive-ion etching process. Alternating cycles of isotropic Si etching, sidewall protection, and anisotropic removal were repeated. In this study, 100 cycles produced nanorods approximately 10 μm long. Etching power was gradually reduced from 70 W by 0.1 W per cycle up to 200 cycles, after which it was held at 60 W. SF_6 flow was maintained at 100 sccm.

The Si wafer thickness was $\sim 500\ \mu\text{m}$. For compatibility with laser-irradiation experiments, patterned regions were located near a corner of a 22,000 $\mu\text{m} \times 1,400\ \mu\text{m} \times 500\ \mu\text{m}$ cuboid target. Arrays of rods with a lattice symmetry were fabricated while keeping the nanorod diameter at 500 nm and spacing at 1000 nm. The silicon nanorods were characterized using SEM. Images confirm highly ordered arrays with uniform geometry. The nanorods were about 10 μm long, cleanly etched, and free of debris.

Supplementary Note 2: Background subtraction of images with a beamstop-free SAXS filter

Supplementary Fig. 2a shows the raw X-ray CCD camera image corresponding to Fig. 1b in the main text: the XFEL beam profile with the beamstop-free SAXS filter, with no target attached to the target holder. Shadows cast by the layered filter system appear as triangular shapes (refer to the geometry of the experimental setup in Fig. 1a of the main text). The data include the dark current and the scattering from the layered filter system. Supplementary Fig. 2b shows the image of a dark current taken with the camera covered to block all light. Supplementary Fig. 2c shows the image after dark current subtraction, obtained by subtracting Supplementary Fig. 2b from Supplementary Fig. 2a. The white dashed lines indicate the open window of the aluminum (Al) holder for the filters, while the surrounding 1.4-mm-thick Al regions have a transmission of approximately 10^{-12} . Therefore, we conclude that the signal outside the window, especially near the X-ray beam spot, is caused by scattering from the beamstop-free SAXS filter during the passage of the X-ray pulse. The stack of triangular filters has a maximum thickness of 300 μm in total. The signal profile was fitted assuming a Gaussian blurring profile on the camera using the 1D line profile surrounded by a black rectangle and the central beam position of the X-ray beam, as shown in Supplementary Fig. 2c. Using the fitting results and assuming the blurring effect is isotropic, the two-dimensional Gaussian pattern is estimated, as shown in Supplementary Fig. 2d. Supplementary Fig. 2e shows the image after the blurring signal subtraction (i.e., the difference between Supplementary Fig. 2c and Supplementary Fig. 2d). Fig. 1b in the main text shows a cropped section of Supplementary Fig. 2e. The attenuated parts of Supplementary Fig. 2e were divided by the transmission corresponding to the total thickness of the Al plates for each section to generate Fig. 1c in the main text.

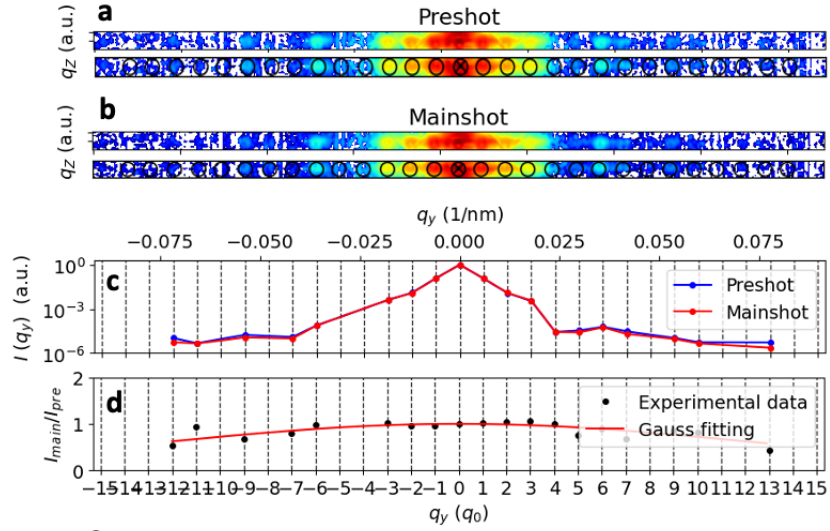


Supplementary Fig. 2 | Background subtraction of an image with the beamstop-free small-angle X-ray scattering system. a. Raw data of X-ray beam profile with the filter. **b.** The dark current taken with a cover on the camera. **c.** An image with subtraction of the dark current. The difference between a and b. **d.** X-ray scattering from the filter estimated from the fitting results. **e.** An image with subtraction of the blurring, that is, the difference between c and d.

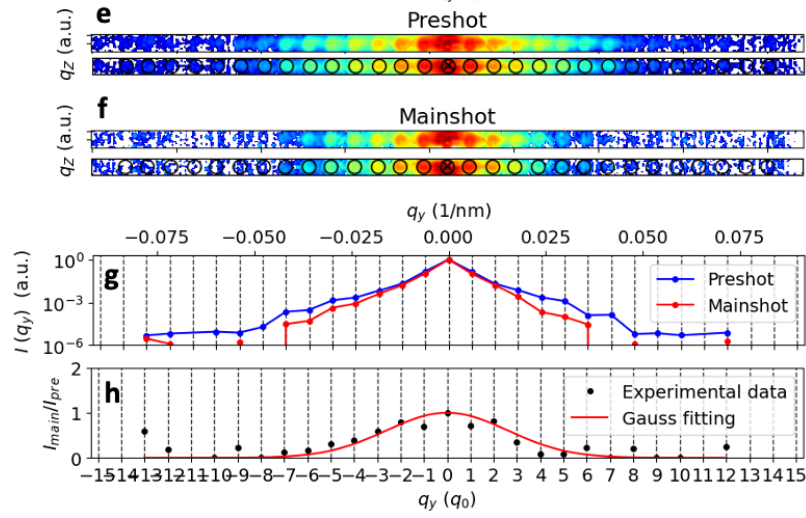
Supplementary Note 3: Derivation of plasma scale length via the analysis of SAXS signals

In principle, SAXS signals, or diffraction patterns, correspond to the Fourier transform of real-space density profiles of objects. Therefore, it is possible to extract structural information of objects from the SAXS profiles. The detailed theory is explained in Section 4, and the analytical method in the experiment is discussed here. Supplementary Fig. 3a,b show the recovered beamstop-free SAXS images of XFEL-only probe shot and HI-laser-driven shot. In the lower panels, the SAXS peaks are enclosed by black circles. Supplementary Fig. 3c shows the overplot of SAXS peak values given by the integration of signals inside the circles. In the experiment, the SAXS signals were primarily blurred by scattering from the layered filter system when the XFEL beam passed through it. However, taking the integral solves this problem and enables quantitative analysis of the data. In principle, placing the filter system as close to the detector as possible suppresses scattering from the filter. In Supplementary Fig. 3d, the black solid circles show the ratio of the SAXS signals between the XFEL-only probe shot and the HI-laser-driven shot. The red curve is given by Eq. (4) in the main text and is fitted to the black solid circles. Some peaks were excluded from the fitting when their signals were as low as the background in XFEL-only probe shots. The fitting yields the plasma scale length ($2\sigma_r$). Supplementary Fig. 3a–d,e–h,i–l are the result of the delay time (dT) of 0, 7.5, and 12.5 ps, respectively. These show the increase in the scale length over time, corresponding to the monotonic rarefaction. We evaluated shot-to-shot fluctuations in the SAXS signal arising from XFEL pointing and beam-profile variations using the same rod-assembly targets before pumping. The ratio of SAXS peak intensities between two consecutive XFEL-only probe shots preceding the HI-laser shot was used to estimate the uncertainty in the mean scale length at delays of $dT = -2.56$ and 0 ps in Fig. 4, yielding an uncertainty of 5.2 nm. The initial plasma scale length derived from these data (26.4 nm) is therefore considered reliable.

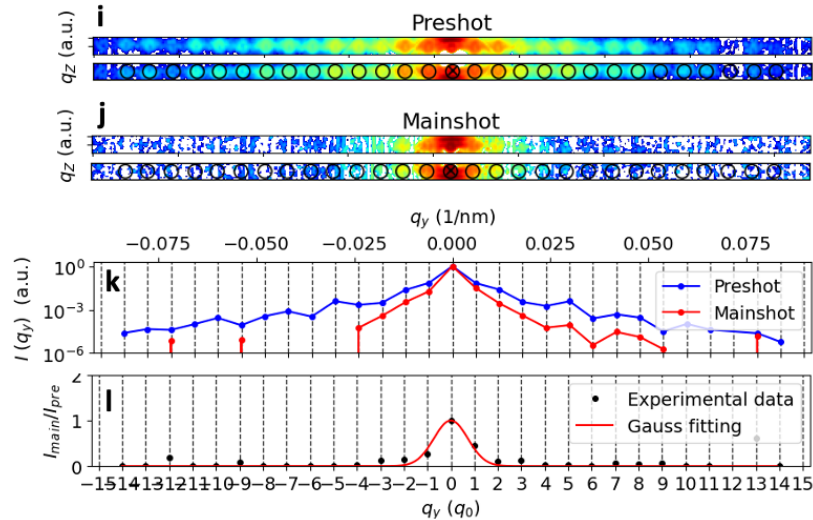
$dT = 0$ ps



$dT = 7.5$ ps



$dT = 12.5$ ps



Supplementary Fig. 3 | The analysis procedure of plasma scale length on the rod's surface by small-angle X-ray scattering signals. a,b. Recovered beamstop-free SAXS image of XFEL-only probe shot and HI-laser-driven shot, respectively. The lower panel is the upper image with circels located at each SAXS peak. **c.** SAXS peak values integrated inside the circels for XFEL-only probe shot and HI-laser-driven shot. **d.** The ratio between SAXS peaks between HI-laser-driven shot and XFEL-only probe shot. a–d, e–h, and i–l correspond to delay time (dT) of 0, 7.5, and 12.5 ps, respectively.

Supplementary Note 4: Diffraction formula for rod assembly target

Diffraction theory

The diffraction pattern, including SAXS, is a Fourier transform of the electron density profile of objects in space under proper conditions. The 3D spatial density profile is integrated along the wave-propagation direction; thus, the 2D spatial profile is converted to the 2D reciprocal space via diffraction. In the following discussion, we assume two conditions: Fraunhofer diffraction and kinematical scattering. In the former condition, the distance between the detector and the object is large enough so that the wavefront is regarded as a plane at the detector. In the latter condition, the scattering is not so strong and multiple-scattering effects can be neglected. The projected 2D spatial density profile of the object, $\rho_{2D}(x, y) = \int \rho_{3D}(x, y, z) dz$, can be modeled as a convolution of three factors:

$$\rho_{2D}(x, y) = f(x, y) * s(x, y) * e(x, y), \quad (1)$$

where the functions $f(x, y)$, $s(x, y)$, and $e(x, y)$ correspond, respectively, the square roots of the inverse Fourier transforms of the form factor, the structure factor, and the expansion (rarefaction) factor in real space. From a perspective of crystallography, $f(x, y)$ characterizes the composition of the electrons bound in a unit cell, and $s(x, y)$ describes the periodic lattice structure of the cells, and $e(x, y)$ accounts for the smoothness of the surface of the object. The details of each contribution are discussed below.

The total amplitude of the diffraction scattered by electrons in 2D reciprocal space $\mathbf{q}$ (i.e., (q_x, q_y)) is given by the Fourier transform of the 2D density profile $\rho_{2D}(x, y)$, and it can be written as:

$$A(\mathbf{q}) \propto \mathcal{F}[\rho_{2D}(x, y)]. \quad (2)$$

Here $\mathbf{q}$ is called the wave vector transfer defined by the difference of the wave vector of the incident and scattered waves. The absolute value of q is defined by:

$$q = \frac{4\pi \sin \theta}{\lambda}, \quad (3)$$

where 2θ is the scattering angle, i.e., angle between the wave vectors of the incident and scattered wave, and λ is the wavelength of the incident wave. The diffraction intensity function $I(\mathbf{q})$ is the product of the amplitude $A(\mathbf{q})$ and its conjugate $A^*(\mathbf{q})$ and written as

$$I(\mathbf{q}) = A(\mathbf{q}) \cdot A^*(\mathbf{q}). \quad (4)$$

Inserting Eqs. (1) and (2) into Eq. (4) and utilizing the Fourier transform of convolution, we get

$$I(\mathbf{q}) = I_0 \cdot F(\mathbf{q}) \cdot S(\mathbf{q}) \cdot E(\mathbf{q}), \quad (5)$$

where I_0 is a constant. $F(\mathbf{q})$, $S(\mathbf{q})$, and $E(\mathbf{q})$ denote the form factor, the structure factor, and the expansion factor, respectively, in reciprocal space, and they can be written as:

$$F(\mathbf{q}) = \{\mathcal{F}[f(x, y)]\}^2, \quad (6)$$

$$S(\mathbf{q}) = \{\mathcal{F}[s(x, y)]\}^2, \quad (7)$$

$$E(\mathbf{q}) = \{\mathcal{F}[e(x, y)]\}^2. \quad (8)$$

Diffraction from the grating target

For the grating target, we assume that the X-ray is injected perpendicularly to the grating surface. The 2D density profiles as seen by the X-ray and the corresponding top view are shown in Supplementary Fig. 4a,b, respectively. In the latter case, the X-ray comes from the bottom. The components of the 1D projected density profile of the periodic gratings at $y = 0 \mu\text{m}$ are shown in Supplementary Fig. 4c. This profile is given by convolutions of three factors written as:

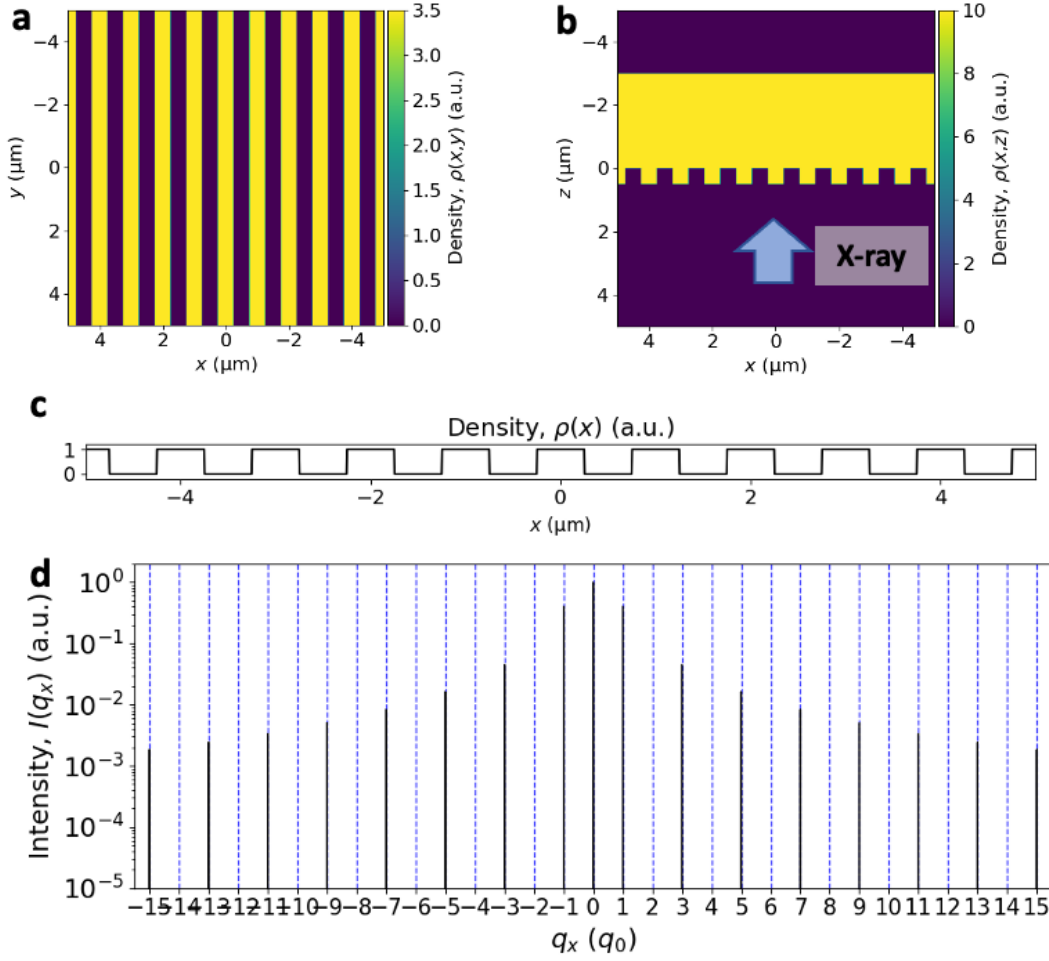
$$f(x) = \rho_0 \left\{ H\left(x + \frac{l}{2}\right) - H\left(x - \frac{l}{2}\right) \right\}, \quad (9)$$

$$s(x) = \sum_{n \in \mathbb{Z}} \delta(x - n \cdot g), \quad (10)$$

$$e(x) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{x^2}{2\sigma^2}\right), \quad (11)$$

where ρ_0 is the density difference between the grooves and the substrate, $H(x)$ is the Heaviside function, l is the ridge width, g is the grating period, and σ (standard deviation of the distribution function) denotes the smoothness of the ridge side surface corresponding to half of the plasma scale length. The Fourier transform of the 1D density profile of the ridges is shown in Supplementary Fig. 4d. In Supplementary Fig. 4a-d, for simplicity, we set $\sigma = 0 \text{ nm}$, that is, the gratings are not ionized but a solid state.

Let us focus on one of the ridges and discuss the physical meaning of the convolution between the form and expansion factors in real space. Here, the convolution can be represented as

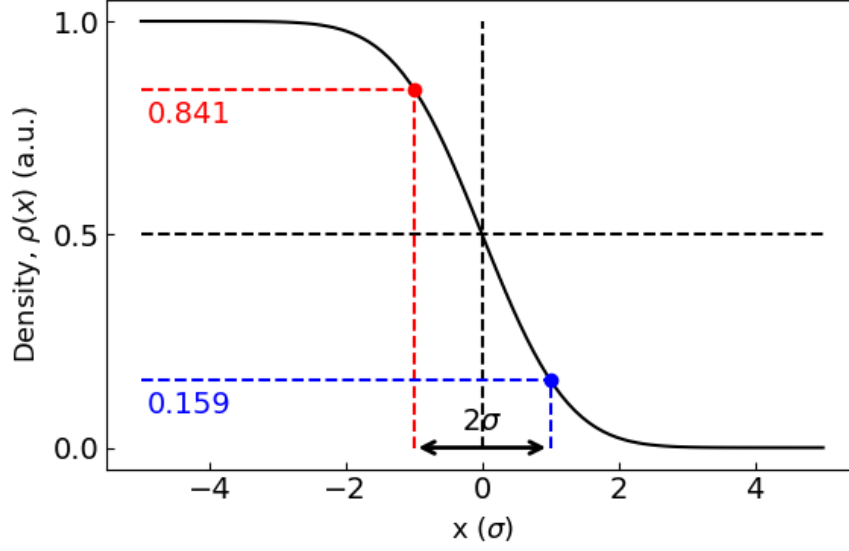


Supplementary Fig. 4 | Two-dimensional (2D) fast Fourier transform of a grating. a.

The 2D density profile of the solid-state grating from a view of the incoming X-ray. **b.** The top view of the grating. **c.** One-dimensional (1D) lineout of the density profile of the gratings at $y = 0 \text{ } \mu\text{m}$. **d.** The power spectrum obtained by squaring the FFT of the 1D density distribution.

$$f(x) * e(x) = \frac{\rho_0}{2} \left(1 + \operatorname{erf} \left(\frac{x + \frac{l}{2}}{\sqrt{2}\sigma} \right) - \operatorname{erf} \left(\frac{x - \frac{l}{2}}{\sqrt{2}\sigma} \right) \right). \quad (12)$$

Equation (12) depicts a groove expanding laterally, or in the x -direction, which is induced via laser-solid interactions. In this paper, the standard deviation σ of the error function defines the plasma scale length as 2σ , as shown in Supplementary Fig. 5. Substituting the Eqs. (9)–(11) into Eqs. (6)–(8) is written as



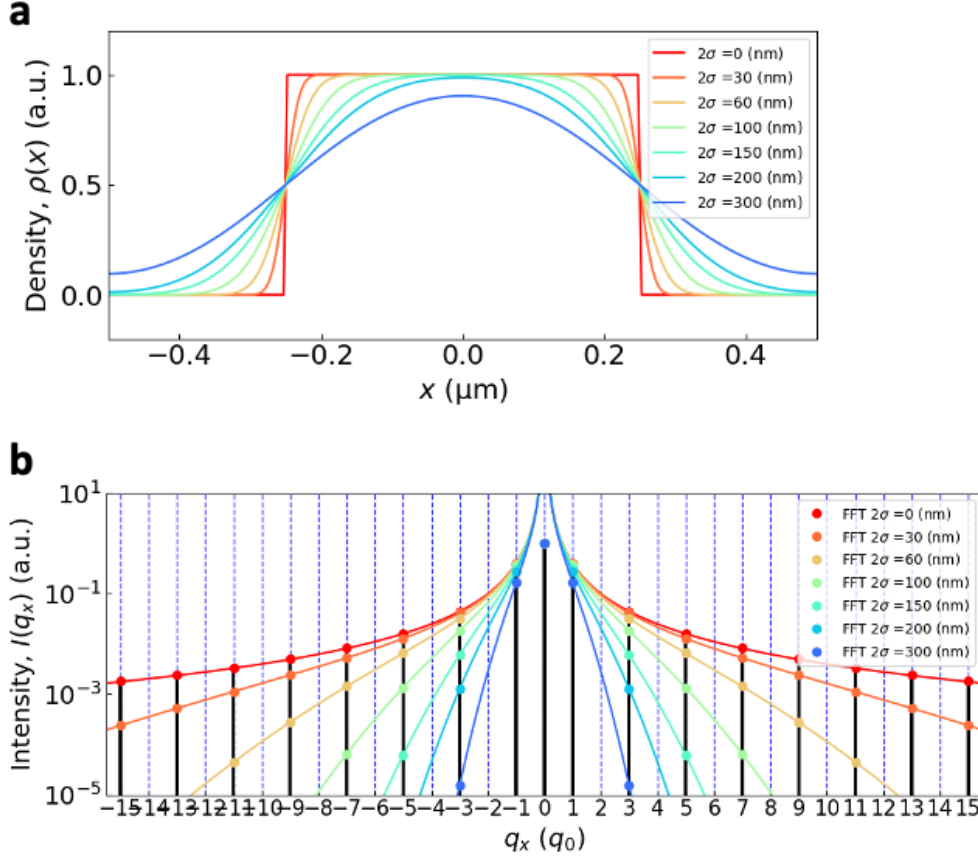
Supplementary Fig. 5 | Definition of the plasma scale length of the ridge's side surface in the transverse direction. The black solid curve denotes the error function.

$$F(q) = \sin^2(ql/2)/q^2, \quad (13)$$

$$S(q) = \frac{\sin^2(Nqg/2)}{N^2 \sin^2(qg/2)}, \quad (14)$$

$$E(q) = \frac{1}{2\pi} e^{-q^2 \sigma^2}. \quad (15)$$

We need to obtain the intensity function (Eq. (5)) that consists of Eqs. (13)–(15) for the fitting of the experimentally obtained SAXS signals. The fitting results allow us to evaluate the parameters of the gratings: the ridge width l , the groove period g , number of the groove N , and the expansion scale length of the ridge surface 2σ (see Ref. 39). The dependence of the diffraction patterns on the surface plasma scale length is shown in Supplementary Fig. 6a,b.

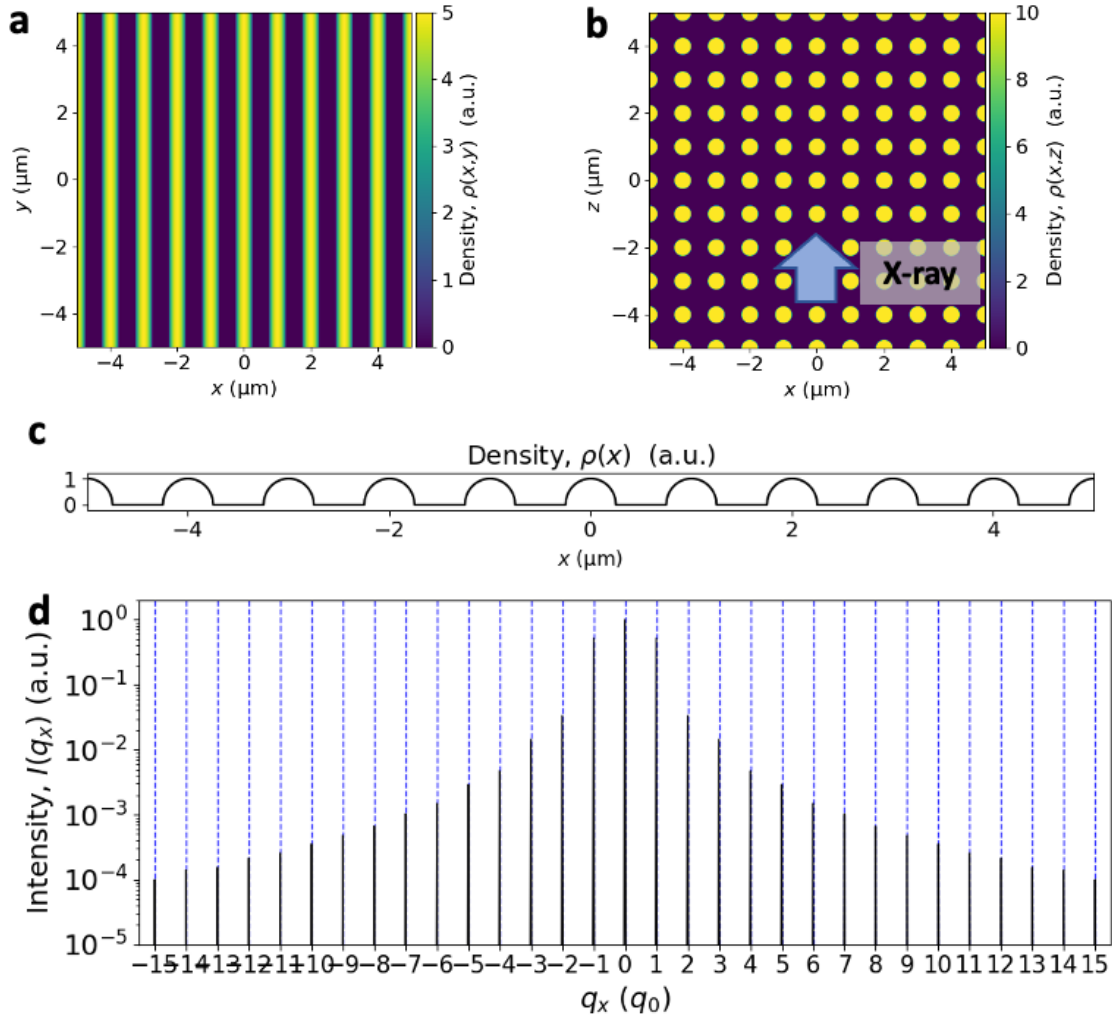


Supplementary Fig. 6 | One-dimensional (1D) fast Fourier transform of a grating. a. 1D density profile of ionized grating in real space with various scale length ($2\sigma = 0 - 300$ nm). **b.** The power spectrum obtained by squaring the FFT of a one-dimensional density distribution; the circles denote the peaks of the diffraction patterns for different scale lengths. The envelopes are proportional to $e^{-q_x^2 \sigma^2} / q_x^2$, obtained by multiplying Eqs.(13) and (15). The black spikes are the diffraction pattern for $2\sigma = 0$ nm, plotted in Supplementary Fig. 4d.

Diffraction from the rod assembly target

Let us assume that the rods are perfectly aligned to form a 2D array with a symmetric lattice and that the X-ray beam is incident perpendicular to the rod assembly (i.e., parallel to the substrate). The beam propagates along the rows, such that only the transversely aligned rods in the front row are visible. Although the X-ray transmission is sufficiently high to probe rods beyond the front row, the projected images of the rods overlap along the beam direction. As a result, the rods behind the front row cannot be distinguished individually. The 2D density profiles observed by X-ray and the corresponding top view are shown in Supplementary Figs. 7a and 7b, respectively. The 2D spatial density profile of a rod in the x - z plane can be defined as:

$$f_{2D}(x, z) = \rho_0 H(\sqrt{r_0^2 - x^2 - z^2}), \quad (16)$$

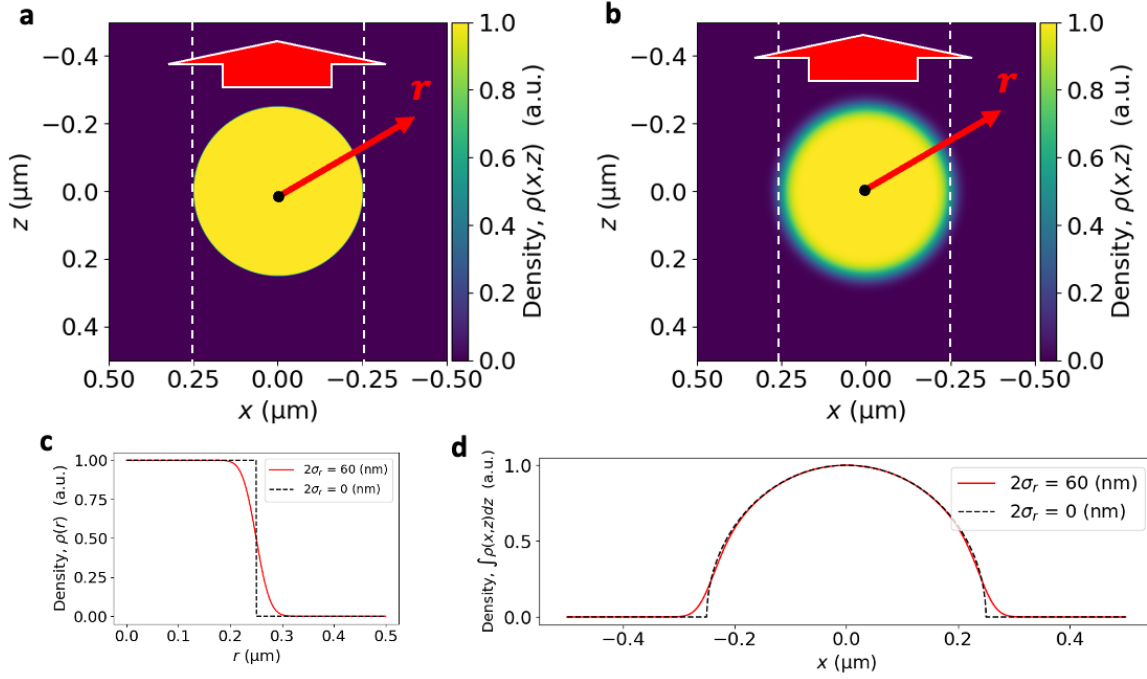


Supplementary Fig. 7 | Two-dimensional (2D) fast Fourier transform of a rod assembly. **a.** The 2D density profile of the solid-state rod assembly from a view of the incoming X-ray. **b.** The top view of the rod assembly. **c.** One-dimensional (1D) lineout of the density profile of the gratings at $y = 0 \mu\text{m}$. **d.** Fourier transform of the 1D density profile of ridges.

where ρ_0 is the density difference between the rods and the surrounding vacuum, and r_0 is the radius of a rod. Therefore, the 1D spatial density profile of the rods projected in the z -axis at $y = 0 \mu\text{m}$ is given by

$$f_{1D}(x) = \int_{-\infty}^{\infty} dz f_{2D}(x, z) = 2\rho_0\sqrt{r_0^2 - x^2}. \quad (17)$$

as shown in Supplementary Fig. 7c. The Fourier transform of the 1D density profile (i.e., SAXS signal) is shown in Supplementary Fig. 7d. The traced line along the diffraction peaks in Supplementary Fig. 7d is proportional to q^{-3} , while that of gratings in Supplementary Fig. 7d is given by q^{-2} (see Ref. 46 in main text).



Supplementary Fig. 8 | Ionization on the surface of a rod. **a.** Top view of a solid rod. **b.** Top view of an ionized rod with a scale length ($2\sigma_r$) of 60 nm. **c.** Sliced one-dimensional (1D) density profile of the solid and ionized rods along the r -direction in a,b, as shown by the black dashed line and the red solid curve, respectively. **d.** 1D density profile of the solid and ionized rods projected in the z -direction in a,b, as shown by the black dashed and the red solid curves, respectively.

The structure factor of the rod assembly target is the same as the grating, as shown in Eq. (10). The form factor is given by Eq. (17). Therefore, for the rod assembly target, the only missing factor in Eq. (2) is the expansion factor. While each ridge of the grating expands in 1D (laterally), the ionized rod expands in 2D (radially), as shown in Supplementary Fig. 8a-d; therefore, it is necessary to consider if the expansion factor is the same as the ionized gratings (Eq. (11)) is applied to the ionized rods.

First, let us focus on the density profile of a rod for simplicity, and assume that the density profile of an ionized rod in the radial direction can be given by using the error function:

$$\rho(r) = \frac{\rho_0}{2} \left(1 + \operatorname{erf} \left(-\frac{r}{\sqrt{2}\sigma_r} \right) \right), \quad (18)$$

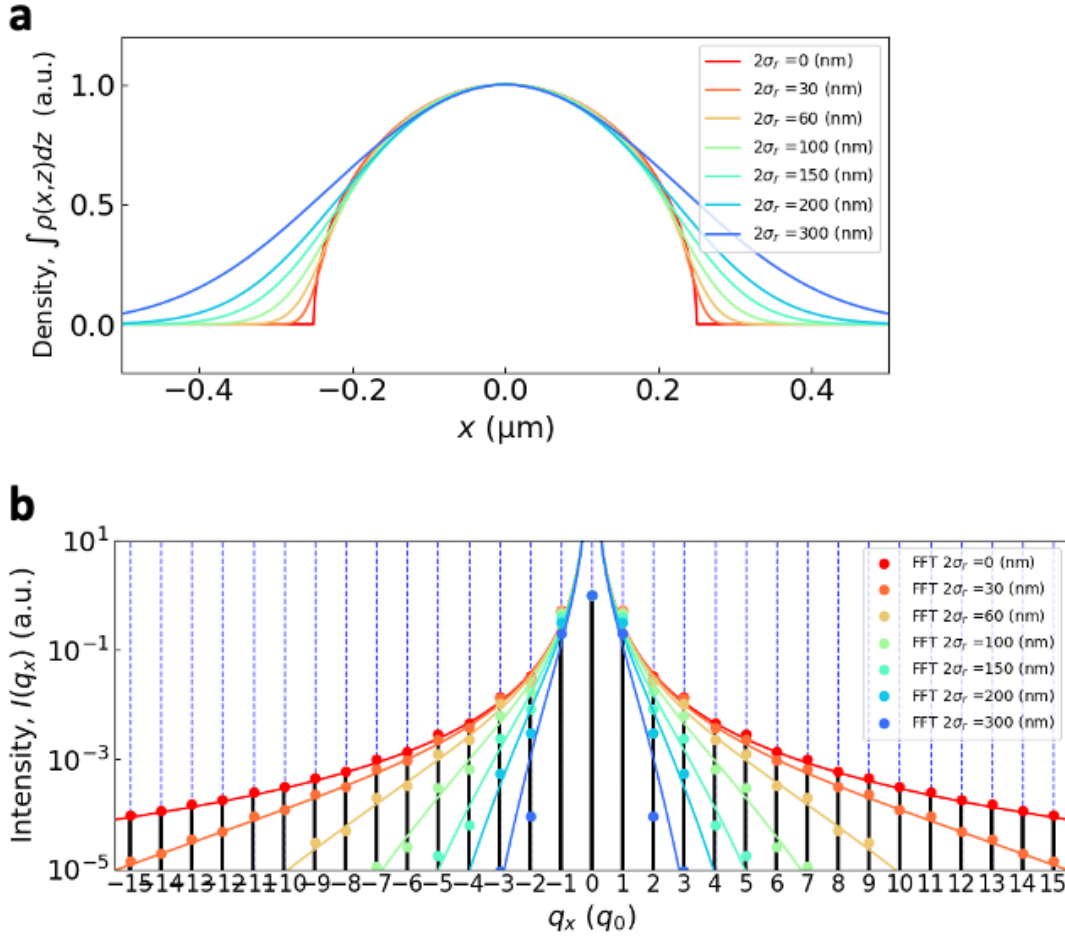
which corresponds to Eq. (12). Under this condition, the 2D density profile of an ionized rod is given by

$$\begin{aligned} \rho_{2D}(x, z) &= f_{2D}(x, z) * e_{2D}(x, z) \\ &= \rho_0 H \left(\sqrt{r_0^2 - x^2 - z^2} \right) * \frac{1}{2\pi\sigma_r^2} \exp \left(-\frac{x^2 + z^2}{2\sigma_r^2} \right), \end{aligned} \quad (19)$$

where the 2D Gaussian function $e_{2D}(x, z)$ is assumed to have no covariance. The projected 1D profile of the rod is given as

$$\begin{aligned}
\rho_{1D}(x) &= \int_{-\infty}^{\infty} \rho_{2D}(x, z) dz \\
&= \int_{-\infty}^{\infty} (f_{2D}(x, z) * e_{2D}(x, z)) dz \\
&= \left(\int_{-\infty}^{\infty} f_{2D}(x, z) dz \right) * \left(\int_{-\infty}^{\infty} e_{2D}(x, z) dz \right) \\
&= \left(2\rho_0 \sqrt{r_0^2 - x^2} \right) * \left(\frac{1}{\sqrt{2\pi}\sigma_r} \exp\left(-\frac{x^2}{2\sigma_r^2}\right) \right),
\end{aligned} \tag{20}$$

as shown by Supplementary Fig. 9a, while the diffraction pattern is shown by Supplementary Fig. 9b. The second term in the last line of Eq. (20) reveals that the expansion factor of the projected 1D density profile of an ionized rod is described by



Supplementary Fig. 9 | One-dimensional (1D) fast Fourier transform of a rod. a. 1D density profile of ionized rod in real space with various scale length ($2\sigma_r = 0 - 300$ nm). **b.** The power spectrum obtained by squaring the FFT of a 1D density distribution; the circles denote the peaks of the diffraction patterns for different scale lengths. The envelopes are proportional to $e^{-q_x^2 \sigma_r^2} / q_x^3$, where the difference in the q -dependence of denominator between the grating and the rod (i.e., q_x^{-2} vs q_x^{-3}) (see Ref. 46 in main text) arises from the dimensionality of the shapes. The black spikes are the diffraction pattern for $2\sigma = 0$ nm, plotted in Supplementary Fig. 7d.

the same exponential function ($e(x) = \frac{1}{\sqrt{2\pi}\sigma_r} \exp\left(-\frac{x^2}{2\sigma_r^2}\right)$) as that used for gratings (i.e., Eq. (15)). Meanwhile, the first term in the last line is defined as the form factor ($f(x) = 2\rho_0\sqrt{r_0^2 - x^2}$). Here, we utilized Fubini's theorem¹ to exchange the order of the integration of z and the convolution in the third line of Eq. (20) because integrals of $f_{2D}(x, z)$ and $e_{2D}(x, z)$ with regard to x are finite. Therefore, the expansion factor of the rod assembly target is obtained by

$$\begin{aligned} E(q) &= (\mathcal{F}[e(x)])^2 \\ &= \frac{1}{2\pi\sigma_r^2} \exp(-q^2\sigma_r^2), \end{aligned} \quad (21)$$

where the surface density gradient (blurring) of a cylindrical rod in three-dimensional space and the corresponding gradient in the 1D-projected profile are both described by a Gaussian function.

By comparing the diffraction patterns obtained in the cases with and without surface expansion, corresponding to the XFEL-only probe shot and the HI-laser-driven shot, respectively, in our experiment, we can evaluate the scale length of the plasma expansion at the rod surface using SAXS. Taking the ratio between the intensity functions of the HI-laser-driven shot and XFEL-only probe shot, one obtains the pure expansion factor of the HI-laser-driven shot:

$$\begin{aligned} \frac{I_{\text{main}}(q)}{I_{\text{pre}}(q)} &= \frac{E_{\text{main}}(q)}{E_{\text{pre}}(q)} \\ &= \exp(-q^2\sigma_r^2), \end{aligned} \quad (22)$$

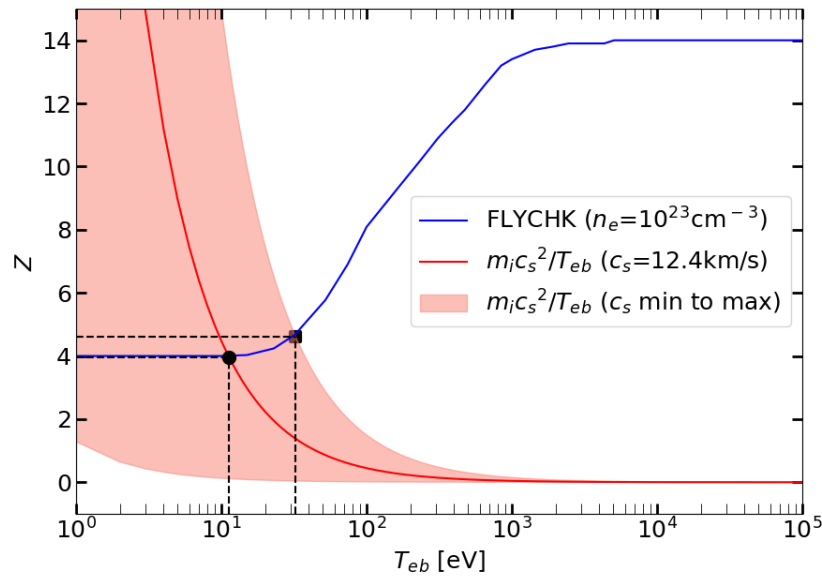
where we assume that $E_{\text{pre}}(q) = 1$ by ignoring the initial surface roughness (i.e., $\sigma_r = 0$ nm). The ratio between the values of the SAXS peaks with and without the plasma scale length obtained by FFT calculations (i.e., $I_{\sigma_r \neq 0}(q)/I_{\sigma_r = 0}(q)$, which corresponds to $I_{\text{main}}(q)/I_{\text{pre}}(q)$ in the experiment) are plotted by the black solid circles in Supplementary Fig. 3d,h,l to conduct the Gauss fitting and estimate the plasma scale length induced by laser-plasma interactions.

Supplementary Note 5: Derivation of bulk electron temperature and ionization rate

The velocity of the rarefaction propagates radially inward through the rod plasma is described by the ion sound velocity when the electron temperature is much larger than that of the bulk ions ($T_{ib} \ll T_{eb}$):

$$c_s \approx \sqrt{ZT_{eb}/m_i}, \quad (23)$$

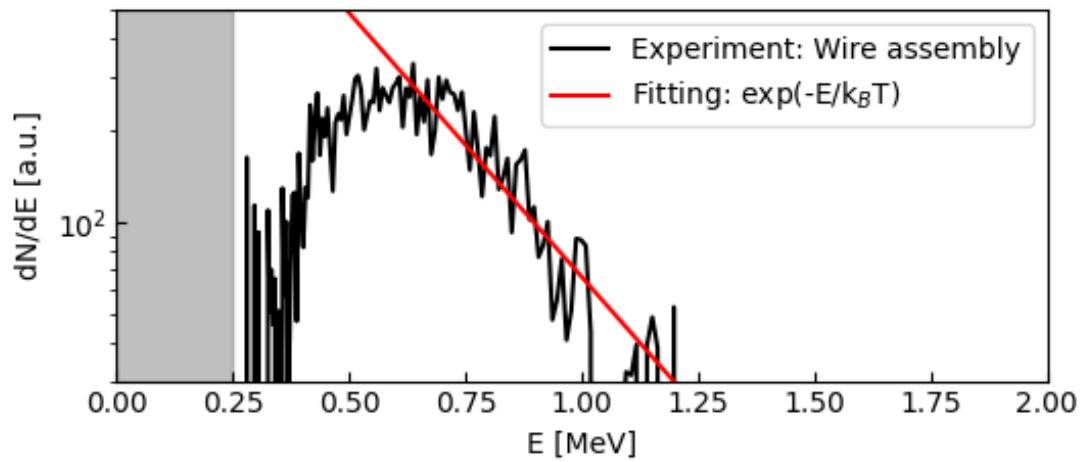
where Z is the charge number, T_{eb} is the bulk electron temperature, m_i is the mass of Si. The ionized rod can be regarded as having a solid density if the electrons around a Si atom are fully stripped ($Z=14$), leading to an electron density of $7 \times 10^{23} \text{ cm}^{-3}$, while the density becomes $Z/14$ smaller if electrons are partially stripped. Assuming that the measured expanding Si rod plasma has the order of solid density (10^{23} cm^{-3}), the bulk electron temperature T_{eb} and the ionization rate Z are estimated as 11 eV and 4.0, respectively, by using the experimentally obtained plasma rarefaction speed (c_s) of 12.4 km/s, as shown in Supplementary Fig. 10.



Supplementary Fig. 10 | Charge number of silicon (Si) with regard to the bulk electron temperature. The blue curve is plotted by using the table of atomic physics code FLYCHK for Si with density of 10^{23} cm^{-3} . The red curve is derived by the Eq. (23). A black rigid circle is plotted on the intersection, where the charge number and the temperature are given as $Z = 4.0$ and $T_{eb} = 11 \text{ eV}$ for $c_s = 12.4 \text{ km/s}$, respectively. A black rigid square is plotted for the maximum estimation of $c_s = 22.7 \text{ km/s}$, which gives $Z = 4.6$ and $T_{eb} = 38.7 \text{ eV}$, respectively. The ionization rate in the lower temperature is asymptotic to $Z = 4.0$, therefore; the intersection for the minimum rarefaction speed and the electron temperature were estimated as $c_s = 2.1 \text{ km/s}$ and $T_{eb} = 0.33 \text{ eV}$, respectively.

Supplementary Note 6: Derivation of fast electron temperature by ESM

Supplementary Fig. 11 shows the energy spectrum of the energetic electrons generated by the laser-solid interaction. The data were obtained at each HI-laser-driven shot using an electron energy spectrometer (ESM) located 0.6 m downstream of the rod assembly along the propagation direction of the HI laser. We fitted the results obtained by integrating the electron energy spectra acquired for each data point used in Fig. 4 of the main text, and the electron temperature was determined to be 0.25 ± 0.02 MeV, reflecting that of the fast electrons. It is evident that the bulk component of the energetic electrons, which have energies less than 0.7 MeV, did not reach ESM. This is likely due to the electromagnetic potentials that trap electrons around the solid being stronger than the kinetic energy of the electrons. On the other hand, our SAXS measurement obtained the electron temperature of the bulk cold electron components.



Supplementary Fig. 11 | Energy spectrum of the electrons obtained by the electron energy spectrometer. Black curve denotes the experimental data. The red line is a fitted line.

Reference

1. deLeeuw, K. The Fubini Theorem and Covolution Formula for Regular Measures. Math. Scand. 10, 201–206 (1962).