21pC1-1

Increase of ultra intense laser absorption by surface plasmon resonance
表面プラズモン共鳴による高強度レーザー吸収の向上

H. Habara[1], Y. Mishima[1], P.K. Singh[2], A. Adak[2], G. Chatterjee[2], P. Brijesh[2], M. Dalui[2], M. Inoue[3], J. Jha[2], T. Taguchi[3], M. Krishnamurthy[2], G. R. Kumar[2], and K. A. Tanaka[1]
羽原英明[1]，三島陽介[1]，P.K. Singh[2], A. Adak[2], G. Chatterjee[2], P. Brijesh[2], M. Dalui[2], 井上雅彦[3], J. Jha[2], 田口俊弘[3]， M. Krishnamurthy[2], G. R. Kumar[2], 田中和夫[1]

[1]*Graduate School of Engineering, Osaka University, 2-1, Yamadaoka, Suita, Osaka 565-0871, Japan*
[2]*Tata Institute of Fundamental Research, Mumbai 400 005, India*
[3]*Department of Electrical and Electronic Engineering, Fucalty of Science and Engineering, Setsunan University, 17-8, Ikeda-nakamatchi, Neyagawa, Osaka 572-8508, Japan*
[1]大阪大学大学院工学研究科 〒565-0871 大阪府吹田市山田丘2-1
[2]Tata Institute of Fundamental Research, Mumbai 400 005, India
[3]摂南大学理工学部電気電子工学科 〒572-8508 大阪府寝屋川市池田中町17-8

Increase of high-energy electron production was demonstrated using grating targets via resonant absorption of ultra intense laser energy. We conclusively establish the role of surface plasmon resonance in addition to the structural effect such as local field concentration.

1. Introduction

Due to recent progress of ultra intense laser beam enables a creation of high-energy particles for not only scientific purposes but also several applications. It however needs further improvements in respect to production efficiency or control of beam energy or quality. As the former effort, the enhanced surface electric field has been demonstrated for such lasers impinge on a solid target having a modulated surface structure such as nano-size spheres or nano-wires [1,2]. The experiments using these targets actually showed the enhancement of coupling efficiency from laser to particle energies, however, the structures have been not optimized yet due to the difficulty of fabrications. From this reason, the improvements mainly relay on expansion how the interaction surface or field concentration at the edge of the structure increase.

On the other hand, the interaction of light with nano-size structure target is well established as "nano-photonics". In this scheme, resonant excitation of surface plasma wave (plasmon) of conduction electrons on the material surface can achieve nearly 100% laser energy deposition on the material. However, for the ultra intense laser light, such fine nano-structure could disappear quickly because of rapid ionization of material. It is therefore unclear the effect of surface plasmon resonance on the absorption of ultra intense laser light against the nano-structure material. For this point of view, we investigated a generation of highly coupling of femtosecond laser pulse onto grating targets at relativistic intensities. The grating has a precise groove density and thus well-defined resonance conditions. We compare our results with planar targets to confirm the enhancements.

2. Experiment

The experiment was performed using an intense, femtosecond laser system (~10^{19} Wcm^{-2}, 30 fs, 800 nm) at Tata Institute of Fundamental Research (TIFR), Mumbai. We used three types of targets, (a) and (b); sinusoidal gratings (500 and 1000 lines/mm with 100 nm amplitude) composed of 1 µm thick Au coating on a thin (76 µm thickness) polyester substrate and (c) 2.5 µm thick Au foil. The *p*-polarized laser pulses are focused on targets at 40° incidence (this angle satisfies the surface plasmon resonance condition for the 500 lines/mm grating target). The resonance angle of the grating is confirmed by the reflection of laser light at low intensity pulse form the oscillator, resulting in the reflection dip at around 40°, given the agreement with the calculated resonant angle for the 500 lines/mm grating at 800 nm.

As the diagnostics, angular distributions of fast electrons are measured with imaging plates, placed at 6 cm behind the target which covers the angular range from 0 to 180°. The energy of electrons emerging at the back of the target is measured with three electron spectrometers located along specific directions to the normal.

3. Results

The angular distributions of fast electrons for 500, 1000 lines/mm and Au foil targets were shown in Figures 1(a)-(c). The signal shows two peaks at 150° and 40° for the 500 lines/mm grating target and only one peak at 130°, corresponding to laser axis for both 1000 l/mm (non-resonant) grating and plane foil. It is important to note that there is no clear peak at 40° for *s*-polarized light even for the 500 lines/mm grating. This clearly indicates that the extra peak at 40 degrees is caused by the excitation of surface plasmons by *p*-polarized light at the resonance incidence of intense laser light to the 500 lines/mm grating. In addition, we notice two strong signals along the surface at 0 and 180° for the grating targets, which are absent in the data for plain foil targets. These are presumably indicative of surface acceleration of fast electrons.

Here, IPs are covered in Al filters to prevent x-ray and direct light exposure. In order to reduce strong background noise a 165 μm thick filter is used for 500 and 1000 lines/mm gratings whereas 11 μm thick for plane targets. These thicknesses correspond to the electron energy thresholds for detection of 175 keV and 10 keV, respectively. Taking into account of this signal reduction, the signal intensity around laser axis in the resonant case shows 2 times enhancement for non-resonant case and 4 times for plane target. On the other hand, signal intensity around 40° in the resonant case is 4-5 times increase compared with other conditions.

4. Discussion

The experimental results clearly exhibit the existence of surface plasmon resonance for ultra intense laser light. If one can consider only the geometrical effect, field concentration at the edge, the number of accelerated electrons from 1000 lines/mm grating should be larger than that from 500 lines/mm grating. This result indicates the laser energy absorption by surface plasmon resonance might be much effective for the simple geometrical effect. On the other hand, the electron emission directions, 150° and 40°, can be derived from the directions for tangential lines of grating sine curve as already shown in some PIC calculations [3].

The previous experiments insist the increase of laser energy coupling to fast electrons [4,5] or ions [5]. However, these experimental results only compared with the results from a flat surface target, so that the enhancement of energy coupling could not be identified by the surface resonant acceleration because even our non-resonant 1000 lines/mm grating actually shows the increase of fast electron creation compared to the foil target.

5. Summary

We have demonstrated enhanced high-energy electron generation using grating targets excited by ultra intense laser pulse. We conclusively establish the role of surface plasmons in the excitation and show the emergence of fast electron beam at a definite angle decided by the grating. Resonant absorption of laser energy would be very interesting for applications in a variety of areas of science and technology, especially creation of ultra hot and dense plasma similar to the center part of the sun [7].

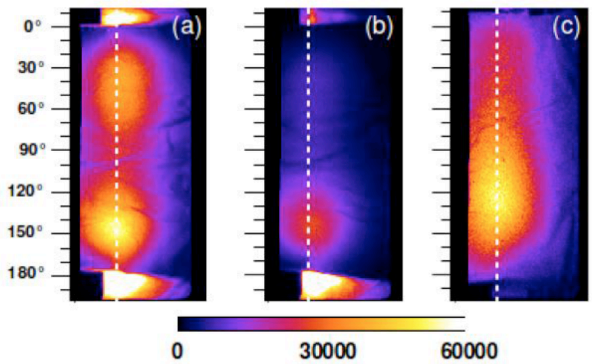

Fig.1. Electron emission distribution around the target rear surface for (a) 500 lines/mm grating, (b) 1000 lines/mm grating, and Au foil target [8].

Acknowledgments

This work was fully supported by "ASHULA", Asian Core Program, and Grants-in-Aid for Scientific Research, type A (Grant No. 22246122) and type B (Grant No. 23360412) by Japan Society for the Promotion of Science.

References

[1] P. P. Rajeev, P. Taneja, P. Ayyub, A. S. Sandhu, and G. R. Kumar, Phys. Rev. Lett. **90** (2003) 115002.

[2] S. Bagchi *et al.*, Phys. Plasmas **18** (2011) 014502.

[3] M. Raynaud, J. Kupersztych, C. Riconda, J.C. Adam and A. Heron, Phys. Plasmas **14** (2007) 092702.

[4] S. Kahay *et al.*, Phys. Rev. Lett. **101** (2008) 145001.

[5] W.M. Wang *et al.*, Phys. Plasmas **15** (2008) 030702.

[6] T. Ceccotti, V. Floquet, A. Sgattoni, A. Bigongiari, O. Klimo *et al.*, Phys. Rev. Lett. **111** (2013) 185001.

[7] M.A. Purvis, *et al.*, Nature Photon. **7** (2013) 796.

[8] Y. Mishima, *et al.*, submitted to Phys. Rev. Lett. (2004).