On the influence of size factors and spectral properties of plasmonic nanorods for hot electron generation in optically modulated current sources

A.N. Yakunin[1], S.V. Zarkov[1], Yu.A. Avetisyan[1], G.G Akchurin[1,2], V.V. Tuchin[1,2,3]

[1] Institute of Precision Mechanics and Control, Federal Research Centre "Saratov Scientific Centre of the Russian Academy of Sciences", Saratov, Russia;

[2] Department of Optics and Biophotonics and Science Medical Center, Saratov State University , Saratov, Russia;

[3] Laboratory of Laser Molecular Imaging and Machine Learning, Tomsk State University, Tomsk, Russia

ABSTRACT

This paper presents the results of solving the problem of localizing the electric field intensity in the vicinity of plasmonic nanorods irradiated with an intense polarized electromagnetic wave and evaluating the efficiency of generating "hot" photoelectrons from their surface. Simultaneous calculation of the power of electrons induced by an external field, thermalized in the volume of the nanorod material, ensures correct determination of the optoelectronic and photothermal conversion coefficients. These parameters are critically important for identifying the maximum permissible irradiation modes for nanorods that differ in material and size, in terms of amplitude, duration, and pulse duty cycle. The obtained results are of interest to developers of optically controlled current sources for electronic devices with ultra-fast modulation.

Formulation of the problem and accepted designations

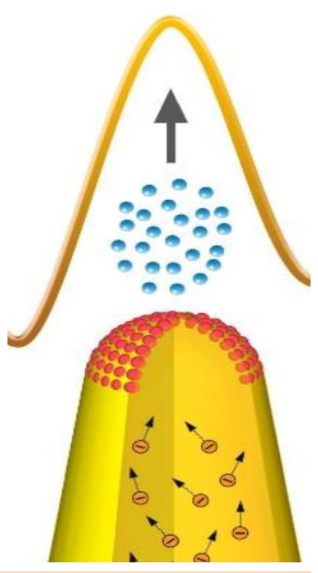

Fig. 1.

In this study, we investigate the problem of **generating hot electrons (HE)** with wide **wavelength tunability**, which is important for the synthesis of an ultrafast electron gun [2025, arXiv:2507.11811v2] with laser-driven photofield emission (Fig. 1). Such electron sources have the prospect of generating beams with an ultrashort time structure, extremely low emittance, and a narrow energy spread, which provides sufficient resolution to capture ultrafast transformations with precision time accuracy. Gold and silver nanorods were used as objects of research. The simulations were based on the work ratios [Govorov et al, 2020, DOI: 10.1021/acsphotonics.0c01065].

Designations: **d** - cross-sectional diameter of the nanorod (NR); **AR** - form factor, which is equal to the ratio of the nanorod's length **L** to its diameter d; A_s - surface electron scattering constant, taking into account the influence of the size effect on the dielectric function of the material (A_S=0 corresponds to the properties of the bulk material); the solid curves in Fig. 2-9 correspond to A_S=0, the dashed ones to $A_S \neq 0$, the solid curves in Fig. 10-11 correspond to $A_S \neq 0$.

C_{abs} - total absorption cross section of NR; $C_{abs,HE}$ - the cross section of radiation absorption converted into HE generation power; $C_{abs,HE}/C_{abs}$ characterizes the thermal efficiency of converting the total absorbed radiation power into the power of HE; $Rate_{HE,eff}$ – rate of radiation absorption converted into HE generation; I_0 - intensity of incident radiation.

Simulation results and discussion

Spectral dependences of C_{abs} value of nanorods with different AR and A_s

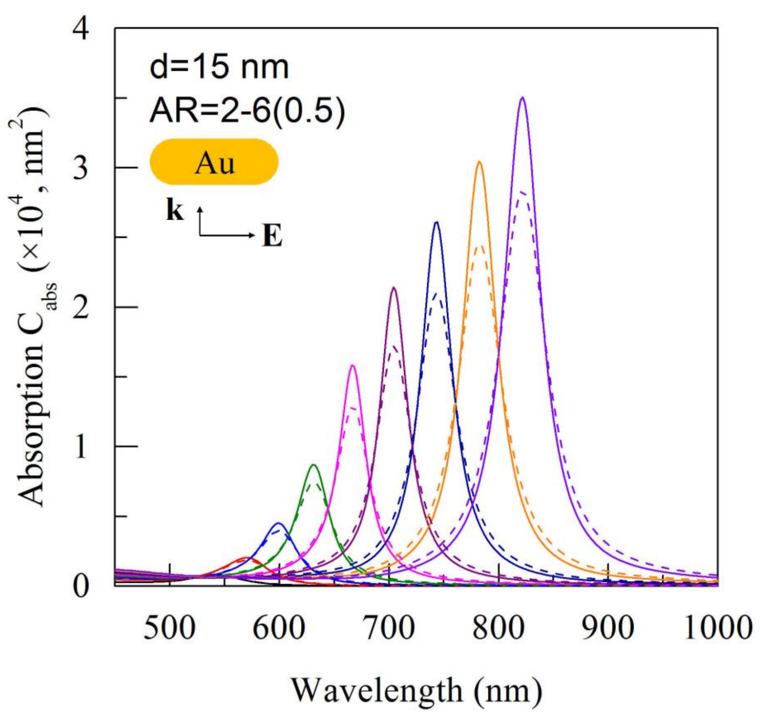

Fig. 2.

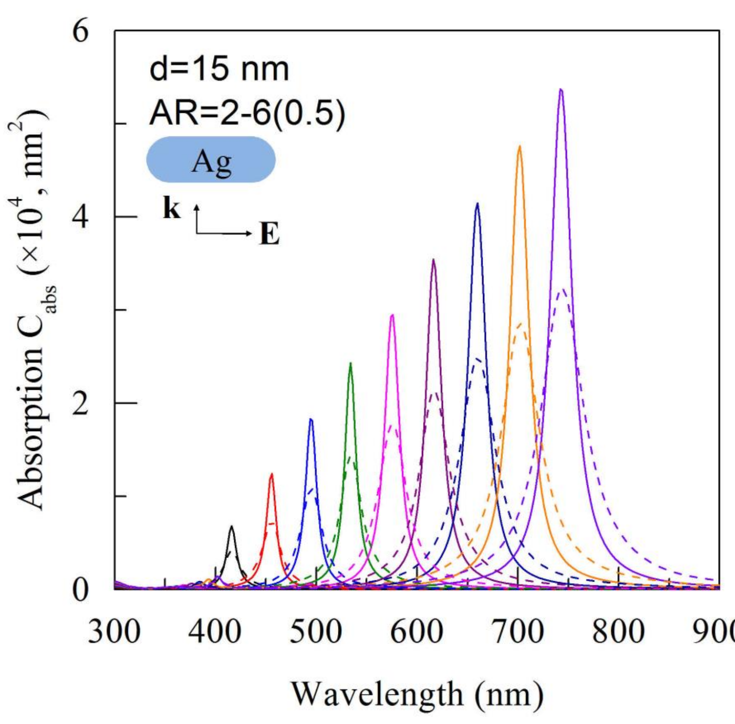

Fig. 3.

Spectral dependences of $C_{abs,HE}$ value of nanorods with different AR and A_s

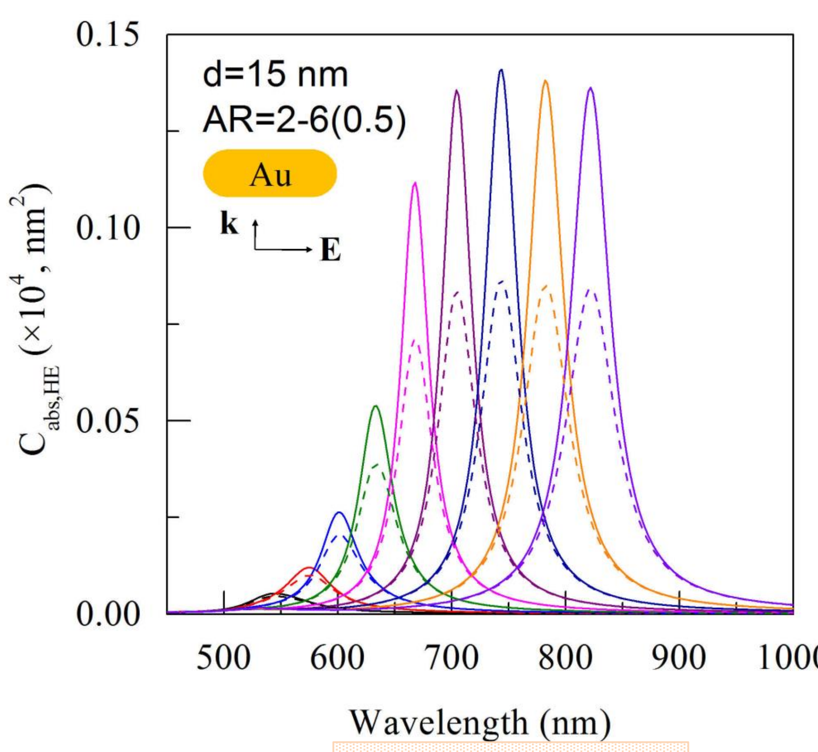

Fig. 4.

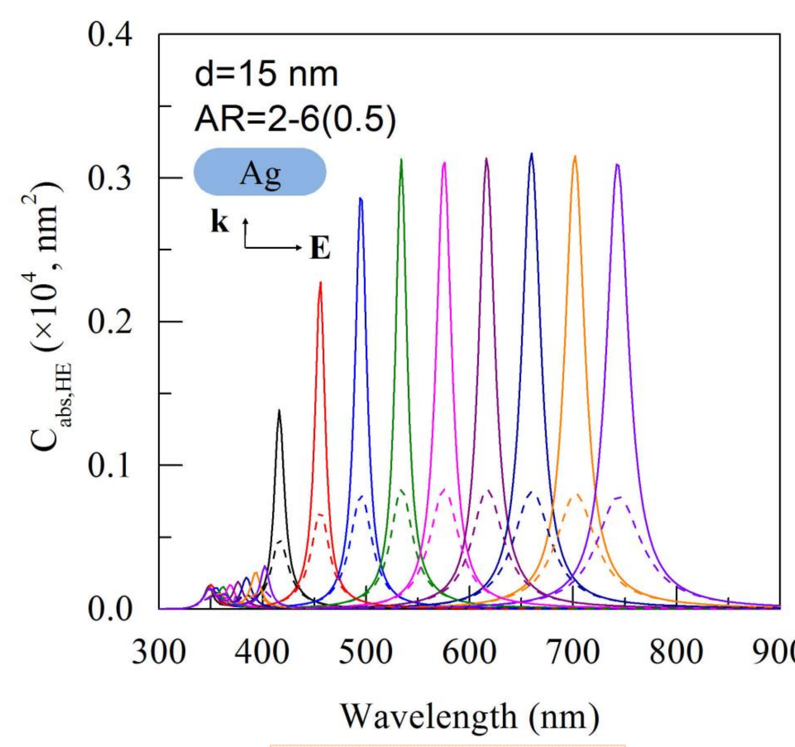

Fig. 5.

Ag

Au

Spectral dependences of $C_{abs,HE}/C_{abs}$ value of nanorods with different AR and A_s

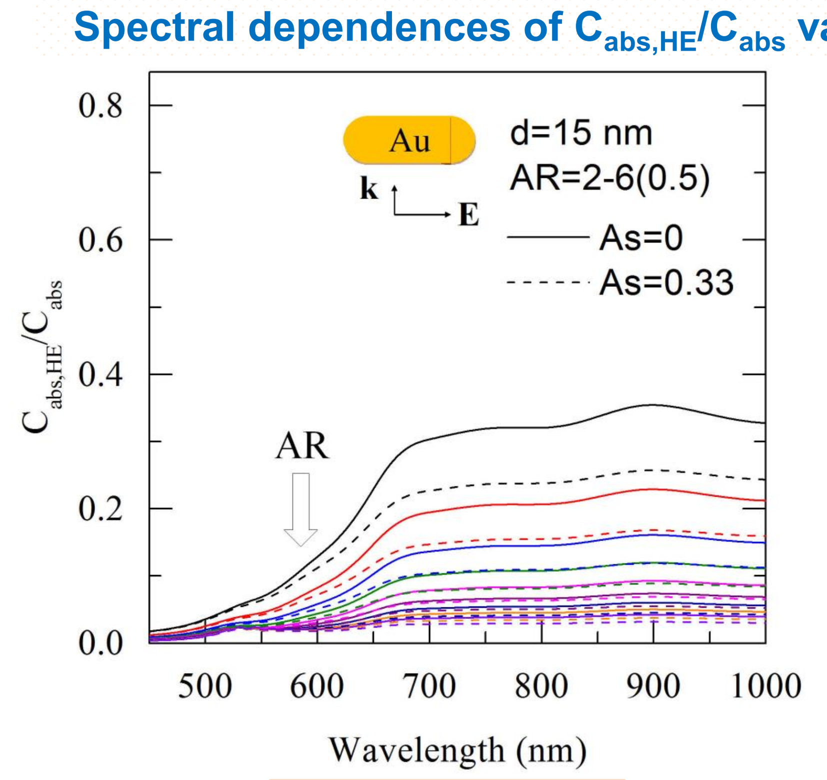

Fig. 6.

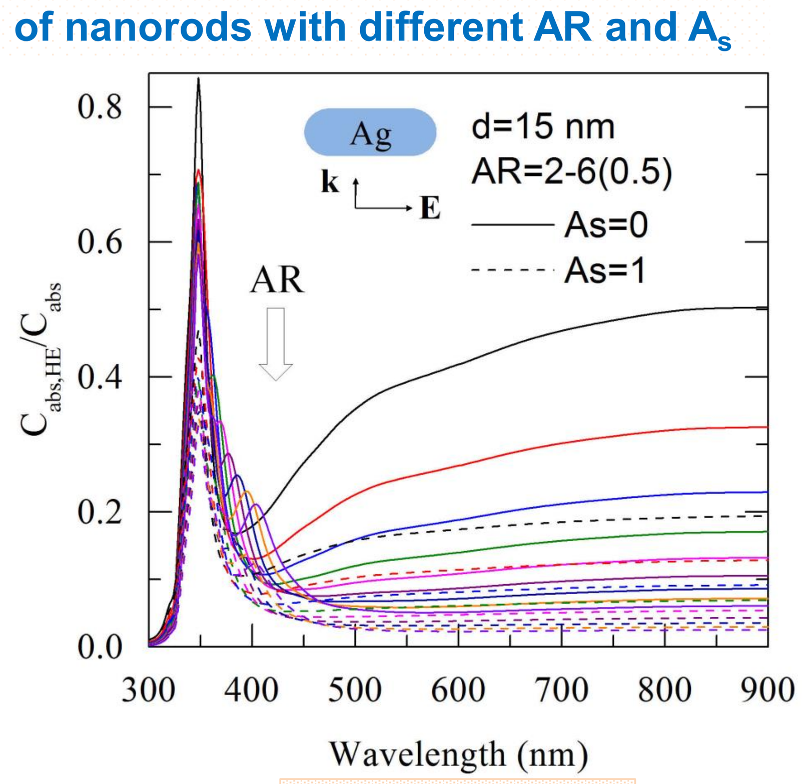

Fig. 7.

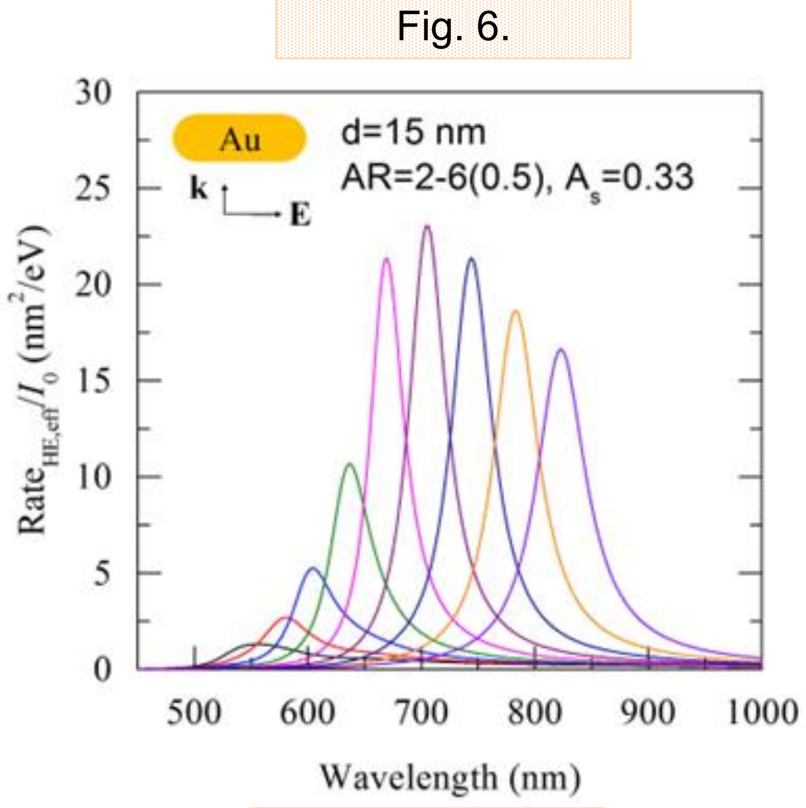

Fig. 10.

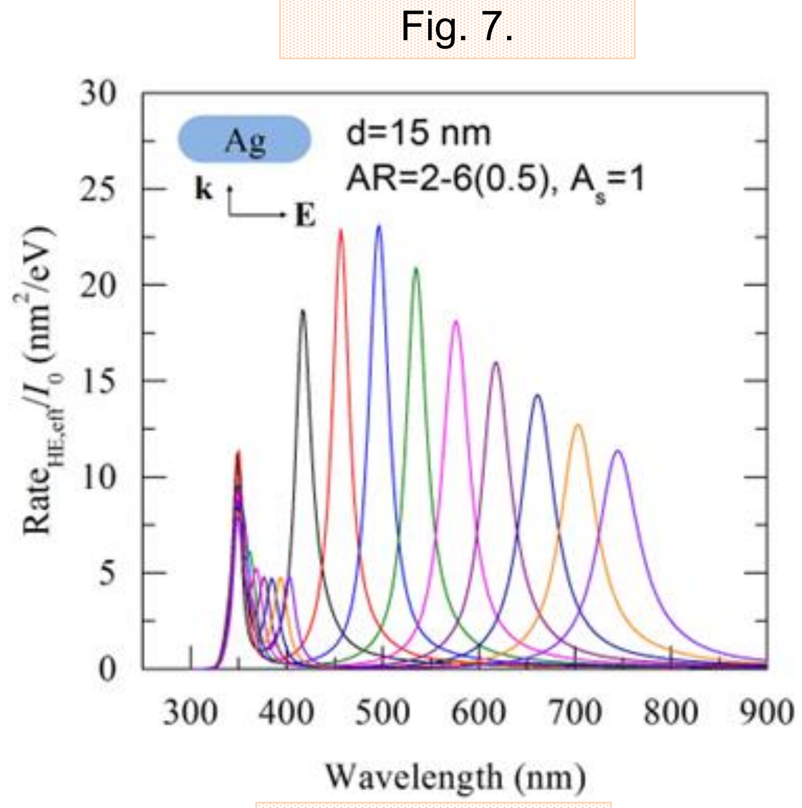

Fig. 11.

From the results in Fig. 2 and 3 it follows that the C_{abs} grows almost proportionally with the AR for both cases of A_s=0 and $A_s \neq 0$. However, taking into account $A_s \neq 0$ reduces the C_{abs} for gold NRs by approximately 20%, and for silver ones by 45%.

The spectra $C_{abs,HE}$ in Figs. 4 and 5 show a different trend. The peaks $C_{abs,HE}$ associated with resonances at different AR values practically do not change in magnitude. A decrease in their magnitude at $A_s \neq 0$ is observed for gold NRs by almost a factor of 2, and for silver NRs - by 4 times. The differences in $C_{abs,HE}/C_{abs}$ for gold and silver NRs in Figs. 6 and 7 for AS=0 are leveled out when taking into account $A_s \neq 0$.

Spectral dependences of $Rate_{HE,eff}/I_0$ value of nanorods with different AR and A_s

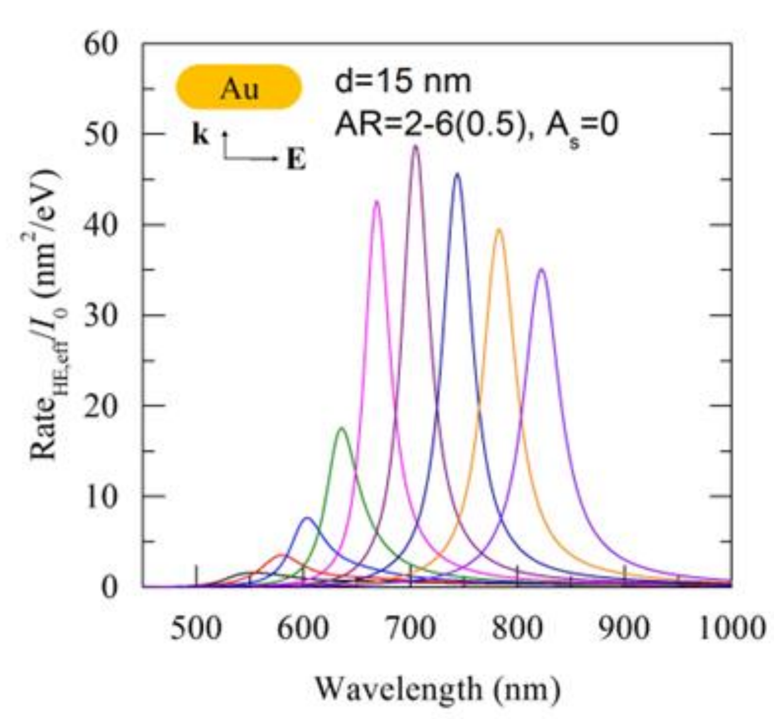

Fig. 8.

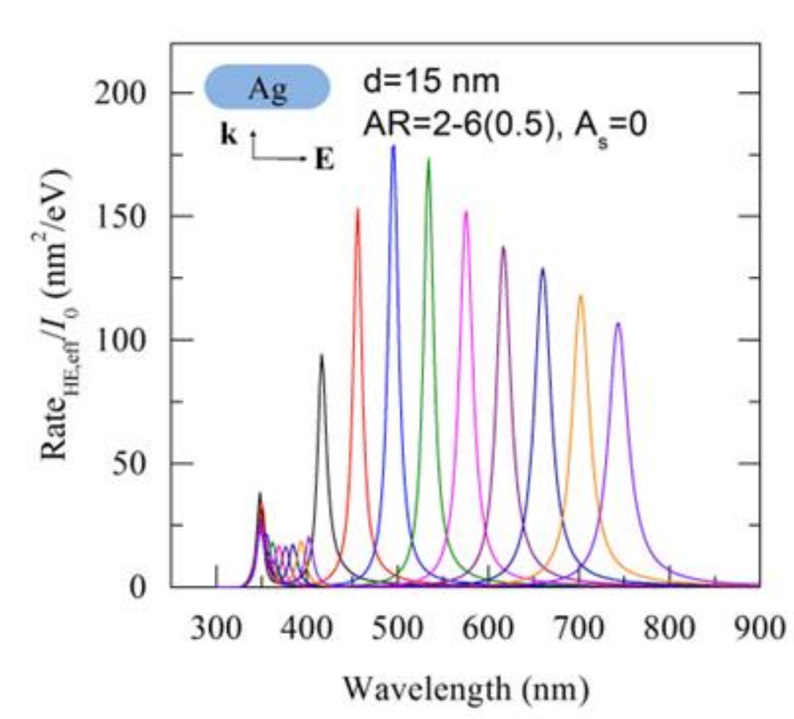

Fig. 9.

A similar trend is revealed by analyzing the results of simulation of $Rate_{HE,eff}/I_0$ in Fig. 8-11. The differences in $Rate_{HE,eff}/I_0$ for gold and silver NRs in Figs. 8, 9 and Figs. 10, 11 for A_s=0 are leveled out when taking into account $A_s \neq 0$. A decrease in their magnitude at As≠0 is observed for gold NRs by a factor of 2, and for silver NRs - by 8 times.

CONCLUSIONS

1. **Hot electrons can be generated in significant quantities only at resonance and in its small vicinity.**
2. **By tuning the nanorods, it is possible to achieve virtually identical hot electron generation power over a fairly wide wavelength range—650-850 nm for gold NRs and 450-750 nm for silver NRs.**
3. **The thermal efficiency of hot electron generation on gold and silver NRs is quantitatively very similar.**
4. **Taking into account the dimensional correction A_s leads to a significant refinement of the modeling results both qualitatively and quantitatively.**

Acknowledgments. This research was done as part of a State Task of the Ministry of Science and Higher Education of the Russian Federation (project No. **25030403156-0**).