LA-UR-92- 92-754

LA-UR--92-754

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SUBMITTED TO: Nuclear Instruments and Methods in Physics Research, proceedings of 1991 FEL Conference

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THE LOS ALAMOS POP PROJECT: FEL OSCILLATOR EXPERIMENTS IN THE ULTRAVIOLET AND BEYOND*

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The Los Alamos POP Project will include a series of proof-of-principle FEL oscillator experiments in 1992 designed to extend FEL operation into the ultraviolet (UV) and vacuum ultraviolet (VUV). With beam energy extended to 50 MeV, enhanced beam brightness with a photoinjector, and appropriate UV and VUV resonator optics, the Los Alamos FEL oscillator should have sufficient single-pass gain (20-30%) to reach below 200 nm. The first goal will be lasing at 250 nm utilizing a permanent-magnet undulator with 5-mm period or alternatively on the third harmonic with a 1-cm period. To operate at VUV wavelengths of 200 and 150 nm (third harmonic), pulsed electromagnetic microwigglers with periods of 5.7- and 4.3 mm will be employed.

1. Introduction

The demand for free-electron lasers (FELs) for scientific research and industrial processing will dramatically increase when the operating wavelength is extended into the VUV (100-200 nm) and XUV (10-100 nm) regions [1-5]. Up to this time, the shortest operating wavelength for any FEL oscillator is 240 nm using a storage ring [6], and at least two other storage-ring facilities are being constructed especially to reach below 100 nm [7,8]. With the recent development of the laser photoinjector [9], rf-linacs are producing even brighter electron beams which may enable FELs eventually to operate down to 10 nm. Additional advances include high-precision magnetic wigglers [10] and multifacet resonator mirrors with useful reflectance down to 40 nm [11]. These developments increase the credibility of user facility proposals involving rf linacs [12-14].

*This work was supported by Los Alamos Exploratory Research and Development under the auspices of the U. S. Department of Energy.

For an intermediate FEL extension into the VUV, Los Alamos scientists have designed a set of proof-of-principle (POP) FEL experiments using the existing APEX FEL oscillator. Over the last decade, this FEL has operated in the infrared from 3 to 45 μm [15-17]. To operate in the UV and VUV regions between 250 and 150 nm, the rf linac energy will be raised above its nominal 40-MeV design point (to 50 MeV) while using very short-period (≤0.5 cm) wigglers. The demonstrated capability of the laser photoinjector to produce a low emittance beam (30π mm-mr, normalized, 90% of electrons) with ≥100 A peak current [18] will be essential to the success of these experiments.

The first goal will be lasing at 250 nm utilizing a permanent-magnet undulator with 5-mm period (two-magnets per period), or alternatively on the third harmonic with a 1-cm period. The feasibility of lasing on the third harmonic[redacted] was demonstrated previously at 4 μm with the Los Alamos FEL [19]. To operate at VUV wavelengths of 200 and 150 nm (third harmonic), pulsed electromagnetic (PEM) microwigglers [20,21] with periods of 5.7- and 4.3 mm will be employed. (Evaluation of the practical utility of PEM wigglers will be one of the primary objectives of this project.) At 50 MeV, the electron beam brightness attainable wit a photoinjector should result in sufficient single-pass gain (20-30%).

2. Experimental apparatus and optical components

The APEX FEL shown in Fig. 1 is based on a room-temperature, standing wave, 1.3-GHz rf linac. During 1992, this FEL is scheduled to be used for experiments alternately at ~3-μm in the infrared as well as in the UV/VUV. Thus, provisions are being made to have the respective resonator mirrors and magnetic undulators interchangeable and realigned in about one day. With the linac operated at 50 MeV, Table 1 lists the operating parameters for 250, 200, and 150 nm needed to obtain respective single-pass optical gains of 33%, 33%, and 20% as computed with the 3-D code FELEX [22]. Uniform-period undulator/wigglers are necessary to maximize the gain, with the output power magnitude being a lesser priority. The parameters will be proportionately adjusted if the electron beam energy is less than 50 MeV. However, the normalized beam emittance must be close to that specified in Table 1.

Multilayer dielectric mirrors with the cited reflectances are commercially produced for 193-nm and 248-nm excimer lasers by a number of coating companies using oxide layers such as Al_2O_3 and SiO_2. For shorter wavelengths, fluoride multilayers are used by at least one commercial coater to produce 92-96% reflectance down to 146 nm [23].

A description of R. Warren's design of the slotted-tube, pulsed-electromagnet microwiggler is given in Ref. 21. Substantial effort is being given to providing a flat-top current pulse to the wiggler, since this determines the time-dependence of the wiggler magnetic field. Deviations from constant field during the 50-μs electron macropulse will cause an undesirable variation of the FEL wavelength.

3. Expected results

The predicted optical performance of the Los Alamos APEX FEL at 250, 200, and 150 nm is summarized in Table 2. Sideband emission, to the extent it occurs at our relatively low gains, will augment the output energies and average powers. This was not included in the simulations. Predictions of single-pass gain versus internal peak power at the exit mirror, also obtained from FELEX simulations, are presented in Figs. 2 to 4. The predicted output powers listed in Table 2 were calculated from these curves at the intersection with the total loss lines. Megawatt peak powers are predicted at 250 and 200 nm, but the power at 150 nm is expected to be substantially less due to lower gain and higher mirror losses.

4. Summary

The primary objective of the Los Alamos UV/VUV POP project is to extend the operating range of FELs below 200 nm. With the moderate electron energy available from the APEX-FEL rf linac (40-50 MeV), attainment of adequate small-signal gain (20-30%) on the third harmonic will require high-field, pulsed- electromagnet wigglers with periods of 4-6 mm and peak wiggler parameters of ~1.4. The bright electron beam available from the photoinjector will be essential at such low electron energies. Future upgrades of the linac energy to ≥60 MeV are expected to provide a large gain enhancement for the 150-250-nm range and permit lasing at wavelengths near 120 nm.

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Table 1
FEL design parameters

Wavelength:	250 nm	200 nm	150 nm
Electron beam			
Energy, MeV	52	50	50
Energy spread, %	0.2	0.3	0.3
Peak current, A	100	130	130
Micropulse FWHM, ps	10	10	10
Micropulse rep. rate, MHz	21.7	21.7	21.7
Charge/μpulse, nC	1	1	1
Emittance, mm-mrad (normalized, 90%)	30π	30π	30π
Macropulse duration, μs	50	50	50
Macropulse rep. rate, Hz	1	1	1
Wiggler			
Type	PM, 2 blk/per.	PEM	PEM
Period, mm	5.0	5.7	4.3
Gap, mm	1	2	2
Peak field, Tesla	0.6	2.6	3.5
K, peak	0.3	1.4	1.4
No. Periods	200	75	75
Length, cm	100	43	32
Magnet focus planes	1	2	2
Optical Resonator			
Length, m	6.9	6.9	6.9
Mirror reflectance, %	99	97.5	94

Table 2

Predicted optical performance of the Los Alamos APEX FEL in the UV and VUV

Wavelength:	**250 nm**	**200 nm**	**150 nm**
Optical harmonic	1	3	3
Small-signal gain, %	33	33	20
Internal peak power, MW incident on exit mirror	480	170	8
Output coupling, % per mirror (1-R-A)	1	2	1
Peak output power, MW	4.8	3.4	0.095
Output energy, mJ 50-µs macropulse	50	35	1
Average power, W 50-µs macropulse	1000	700	20
Average power, mW @ 1-Hz data acquisition rate	50	35	1

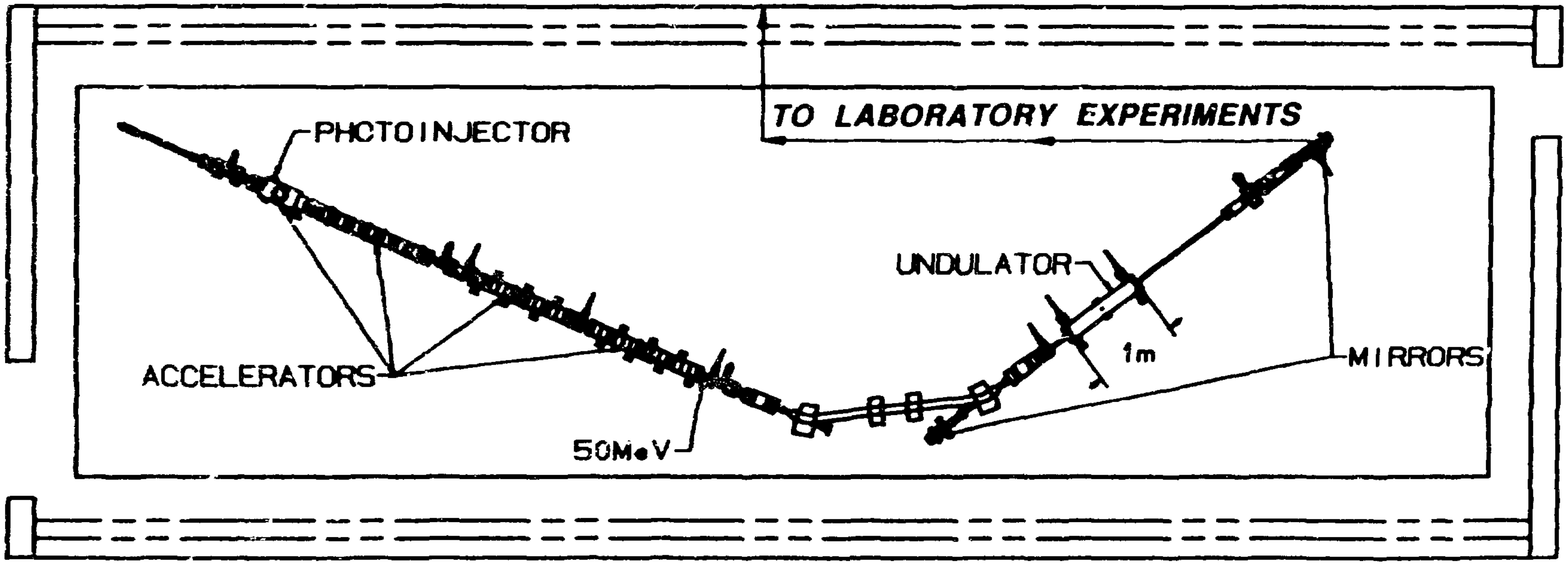
Figure Captions

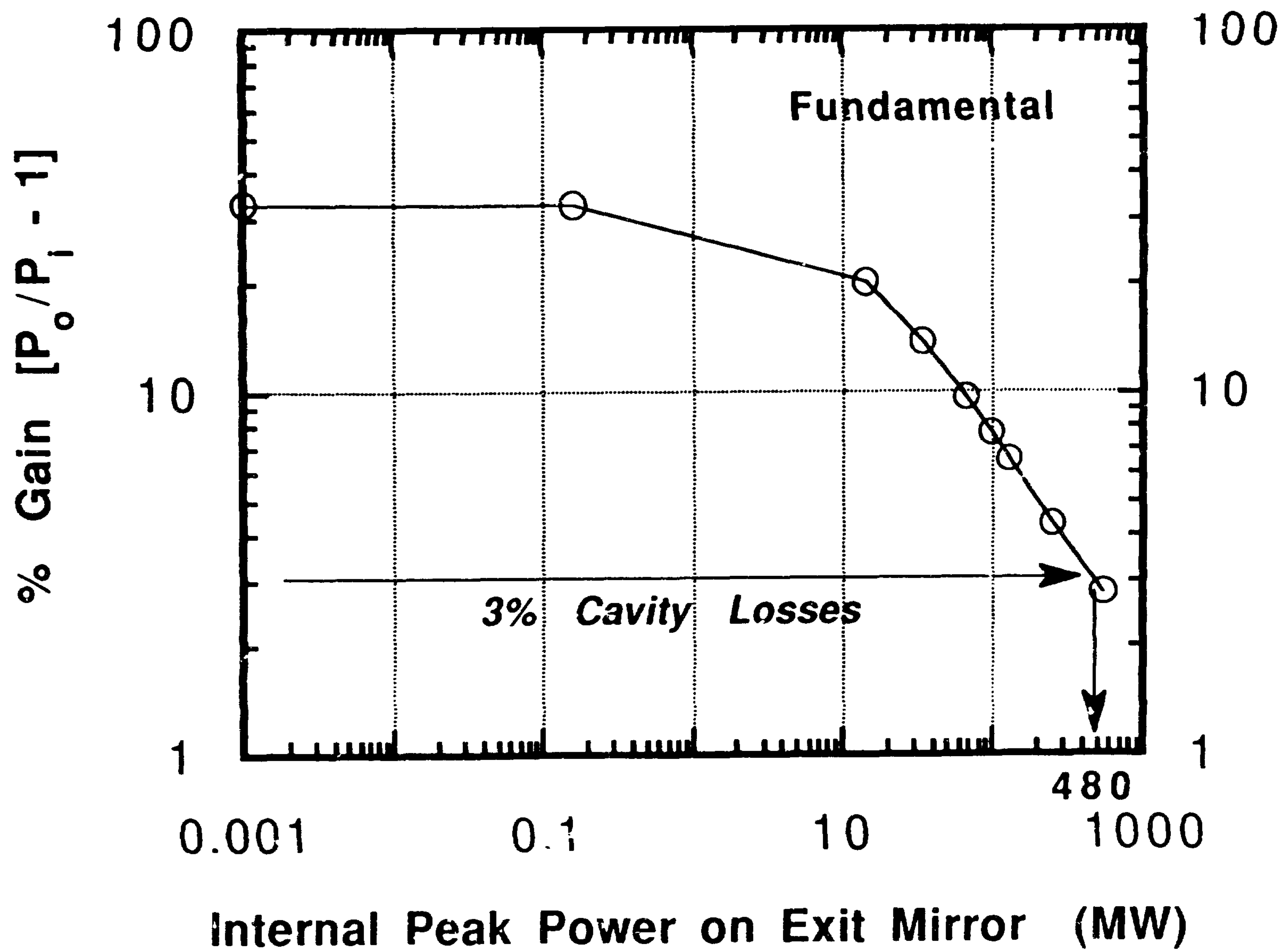
Figure 1. Schematic of the Los Alamos APEX FEL. At wavelengths below 200 nm, it will be necessary to transport the output optical beam within a tube free of oxygen.

Figure 2. FEL optical gain at the fundamental harmonic at 250 nm as a function of internal peak power incident on the exit resonator mirror for APEX FEL design parameters given in Table 1. The 3% cavity losses determine the internal power at saturation.

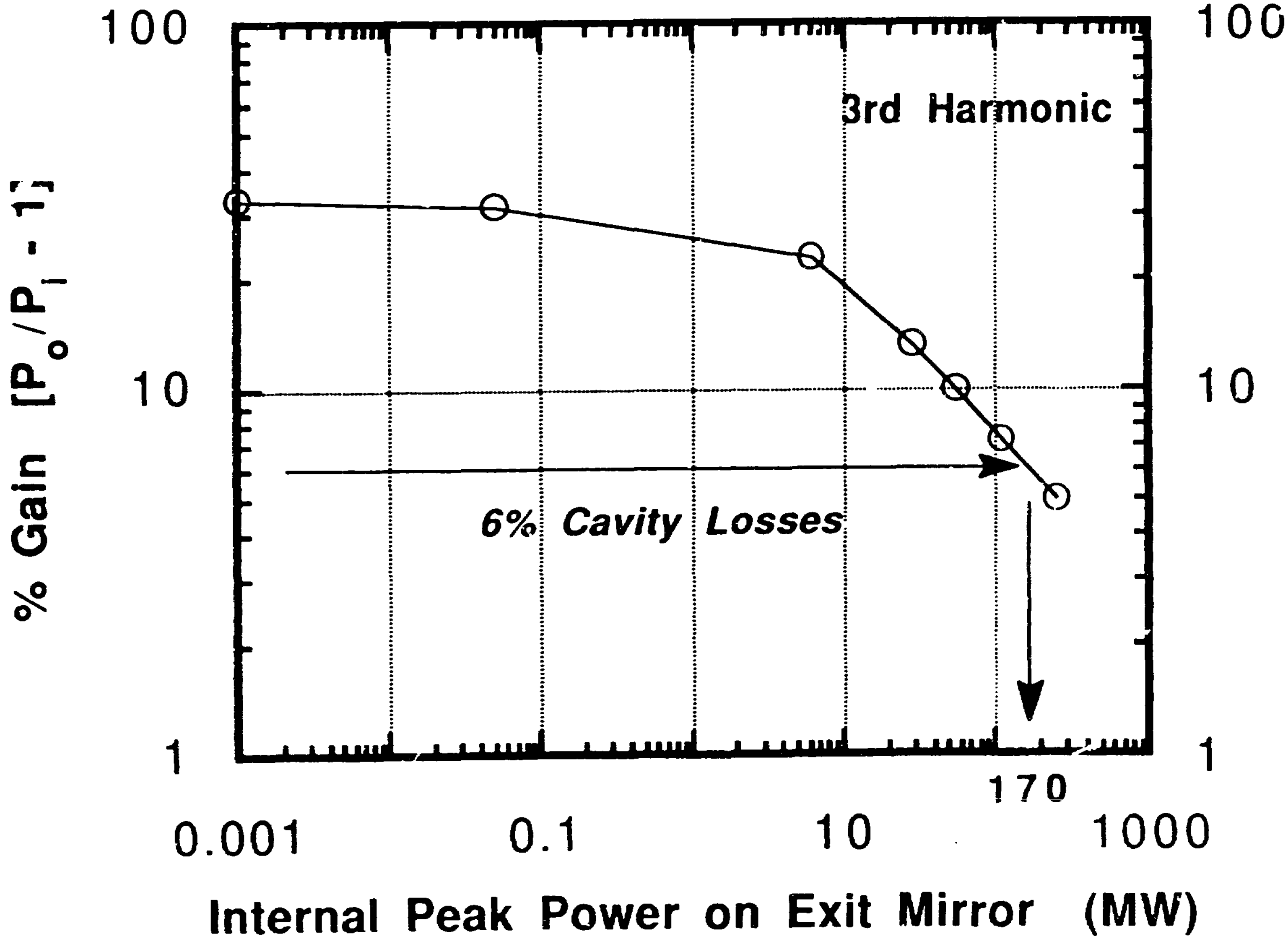
Figure 3. Same as Fig. 2, except 200-nm wavelength FEL oscillator.

Figure 4. Same as Fig. 2, except 150-nm wavelength FEL oscillator.

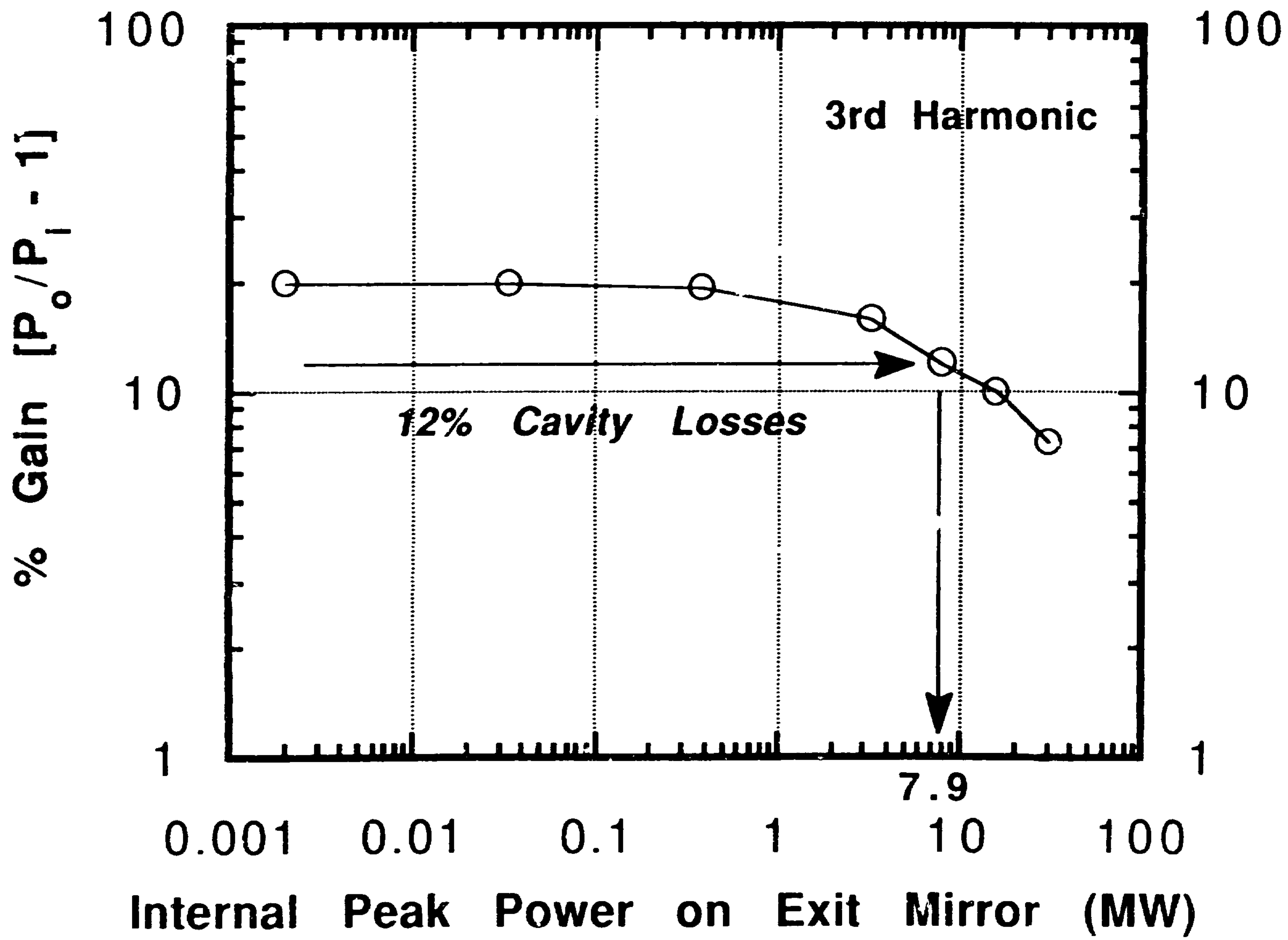

TO LABORATORY EXPERIMENTS
PHCTOINJECTOR
UNDULATOR
1m
MIRRORS
ACCELERATORS
50MeV



100
10
1
100
10
1
Fundamental
3% Cavity Losses
480
0.001
0.1
10
1000
% Gain [P_o/P_i - 1]
Internal Peak Power on Exit Mirror (MW)



100
10
1
100
10
1
3rd Harmonic
6% Cavity Losses
% Gain [P_o/P_i - 1]
170
0.001
0.1
10
1000
Internal Peak Power on Exit Mirror (MW)


100
10
1
100
10
1
3rd Harmonic
12% Cavity Losses
7.9
0.001
0.01
0.1
1
10
100
Internal Peak Power on Exit Mirror (MW)
% Gain [Po/Pi - 1]