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PICOSECOND LASER PULSE OPTICAL DENSITY OF THREE 1060-NM FILTERS

John Taboada, Ph.D.

December 1980

Interim Report for Period September 1977 - January 1978

Approved for public release; distribution unlimited.

USAF SCHOOL OF AEROSPACE MEDICINE
Aerospace Medical Division (AFSC)
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This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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Under a U.S. Navy funded research program, three basic types of 1060-nm optical filters were investigated for dynamic response to intense picosecond laser pulses. These included a dyed glass plate (Schott KG-3), a polymethyl methacrylate plate (PMMA) developed for the Air Force for 1060-nm-specific visors, and a dielectric-coated laser cavity mirror manufactured by Korad Corporation. These filters were selected for their high visual transmittance.

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PICOSECOND LASER PULSE OPTICAL DENSITY OF THREE 1060-NM FILTERS

INTRODUCTION

The neodymium glass or YAG laser emitting in the near-infrared at λ = 1060 nm is a very important component of many present and future military systems. This laser can be mode locked to generate picosecond pulses of light having very high intensities. To protect military personnel and sensitive optical detection equipment from damage, adequate filter materials must be available. The filters must specifically be able to maintain their optical properties to very high intensities where in some cases nonlinear effects have been observed.

Under a U.S. Navy funded research program, three basic types of 1060-nm optical filters were investigated for dynamic response to intense picosecond laser pulses. These included a dyed glass plate (Schott KG-3), a polymethyl methacrylate plate (PMMA) developed for the Air Force for 1060-nm-specific visors, and a dielectric-coated laser cavity mirror manufactured by Korad Corporation. These filters were selected for their high visual transmittance. Note the respective spectrophotometric curves in Figures 1-6.

Dynamic absorption effects in filters occur with high-intensity irradiation. These effects are observed as departures from Beer's law of absorption: $I = I_0 \exp(-\alpha x)$, where I_0 is the incident intensity and I, the transmitted intensity through a filter of thickness (x) with extinction coefficient α. Two primary processes can contribute; viz, (a) saturation [1], and (b) self-induced transparency (SIT) [2]. In the saturation process, the irradiating field excites ground-state absorbing molecules into an upper energy level at such a rate that equal populations exist in the two states. When this occurs, radiation absorption is reduced, theoretically to zero. Saturation does not depend on pulse length or the coherence of the incident beam. The SIT process occurs only in coherent beams and depends not only on the intensity but on the pulse duration as well. SIT requires that the phase information in a molecule excited by the front end of a laser pulse be retained long enough for the trailing end to stimulate coherent reemission. In solids, the phase information is carried away by lattice vibrations in the period of one oscillation which can be in the picosecond-pulse time frame.

The objective of the experiments reported here was to investigate the possibility that the above-mentioned materials would show dynamic absorption effects. This required a picosecond laser pulse system and a special optical arrangement for measuring optical density as a function of pulse intensity.

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1. Armstrong, J. A. Saturable optical absorption in phthalocynine dyes. J Appl Phys 36:471-473 (1965).
2. McCall, S. L., and E. L. Hahn. Self-induced transparency. Phys Rev 183: 457-483 (1969).

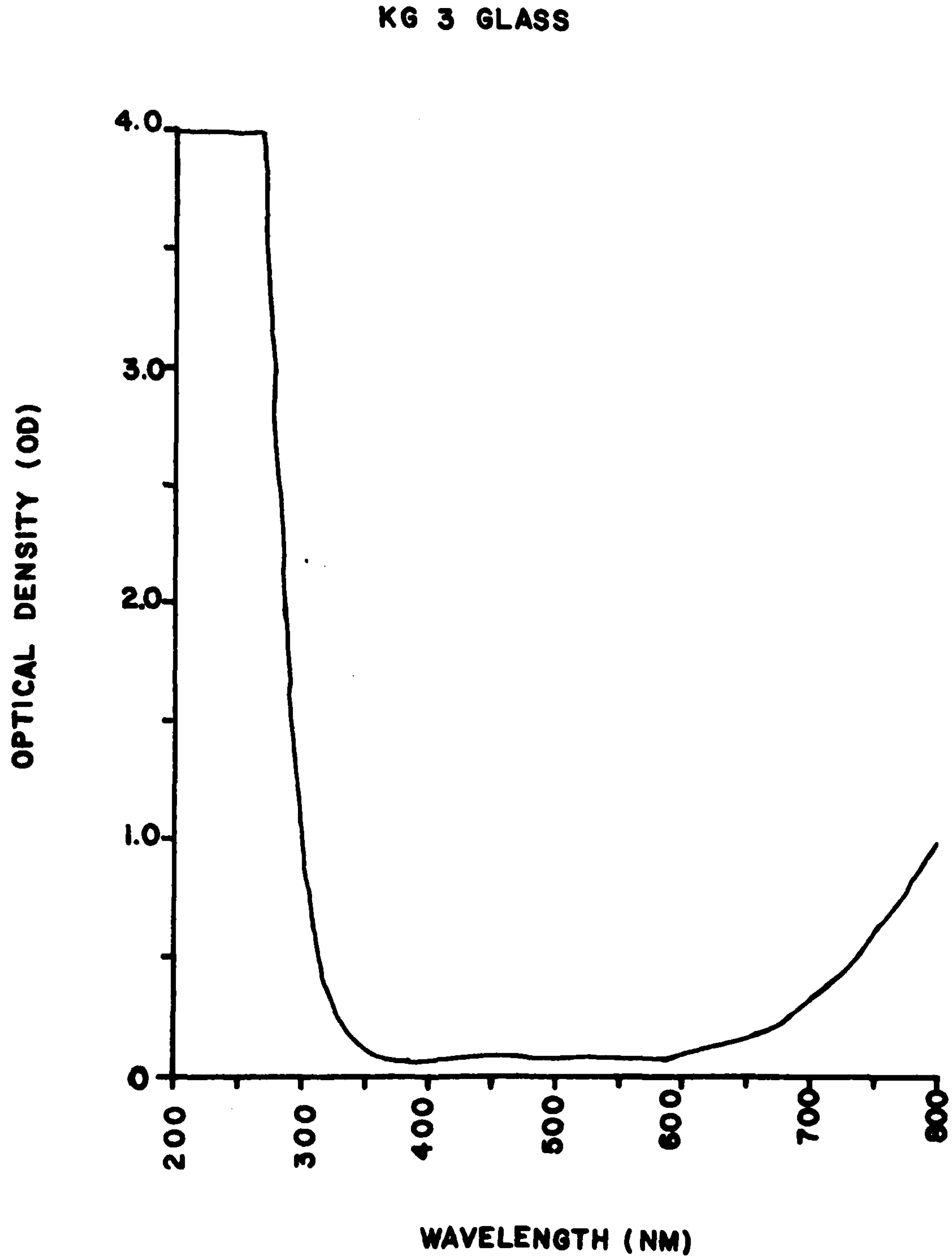

Figure 1. Optical density of KG-3 glass in the visible spectrum.

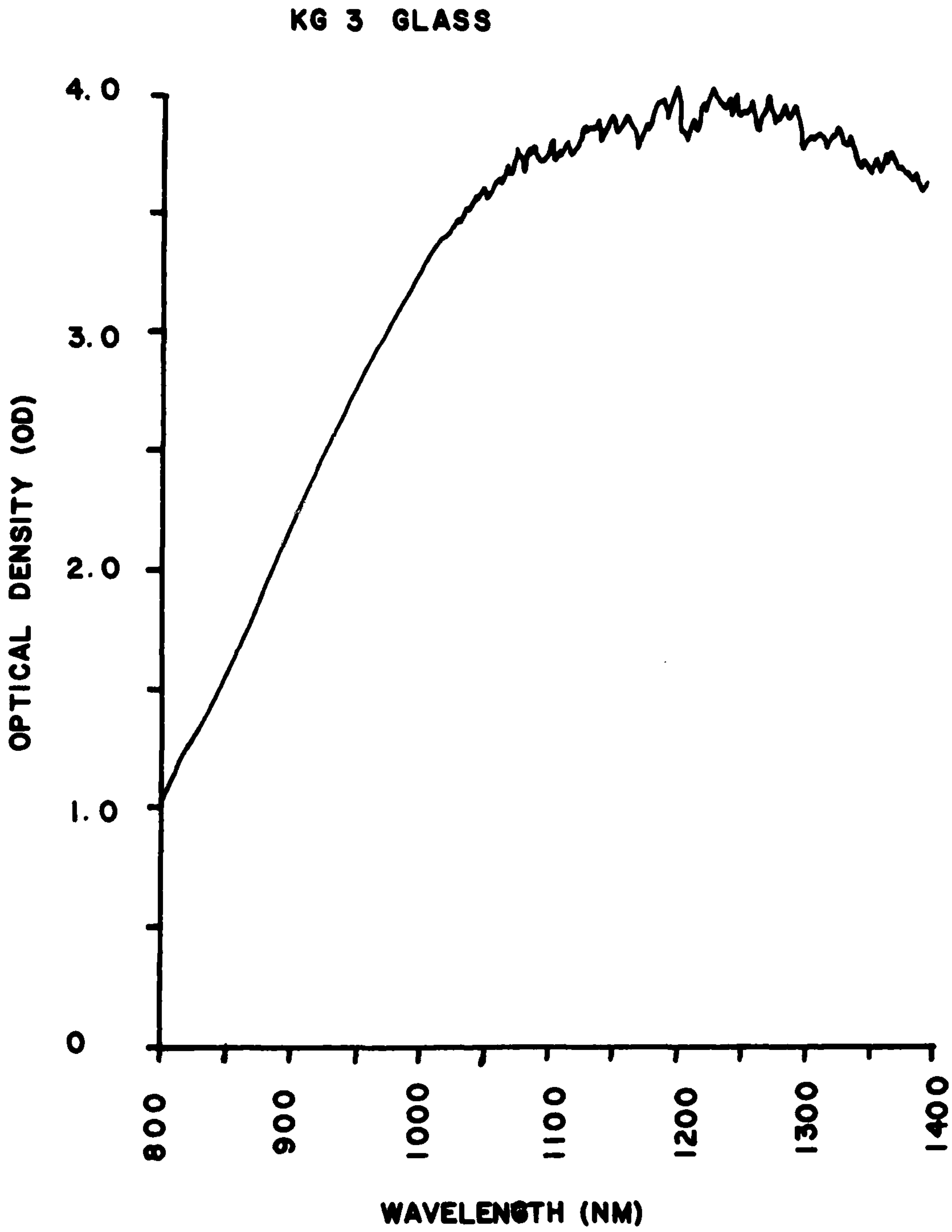

Figure 2. Optical density of KG-3 glass in the near-IR.

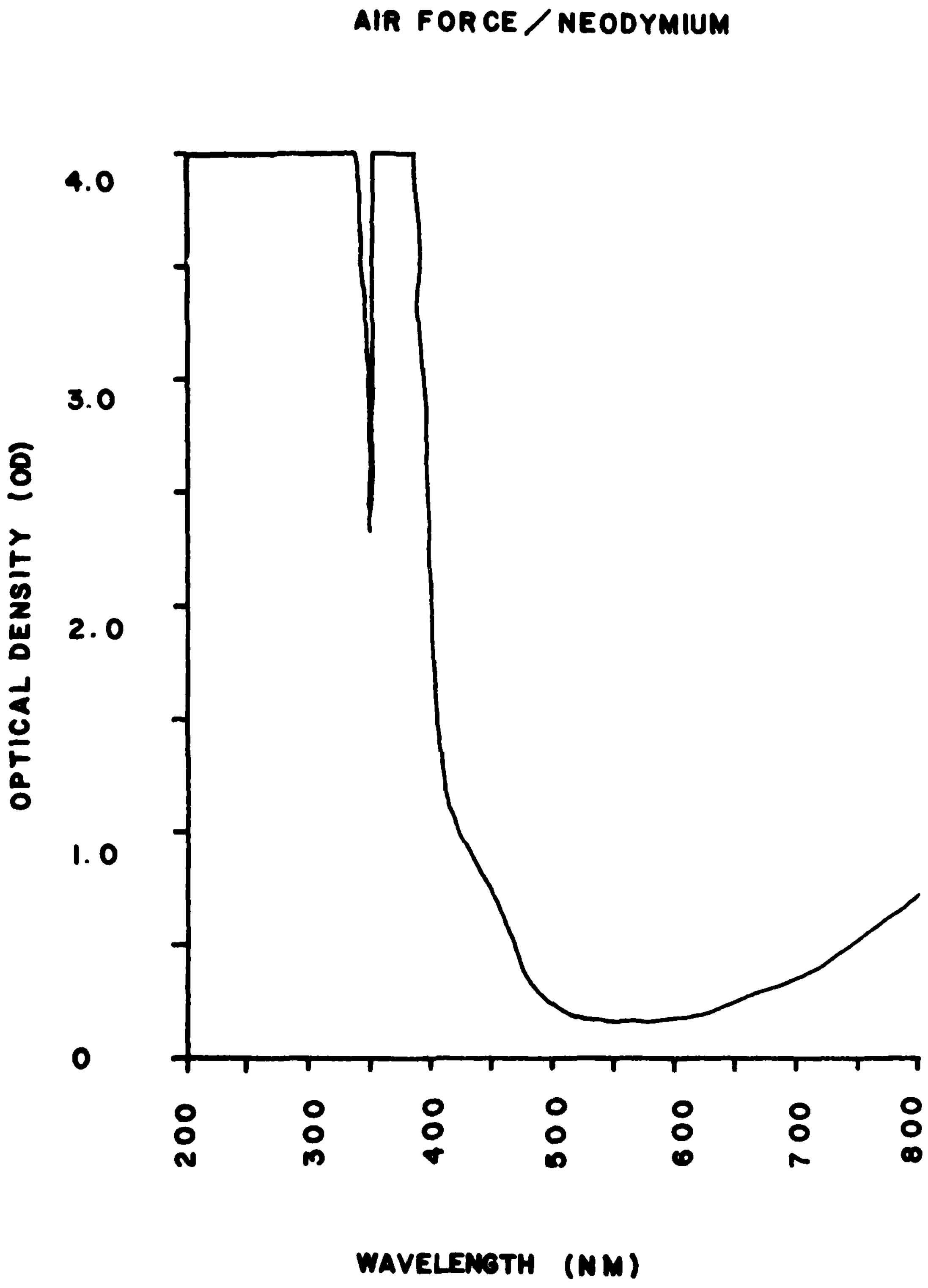

Figure 3. Optical density of Air Force neodymium laser visor material in the visible spectrum.

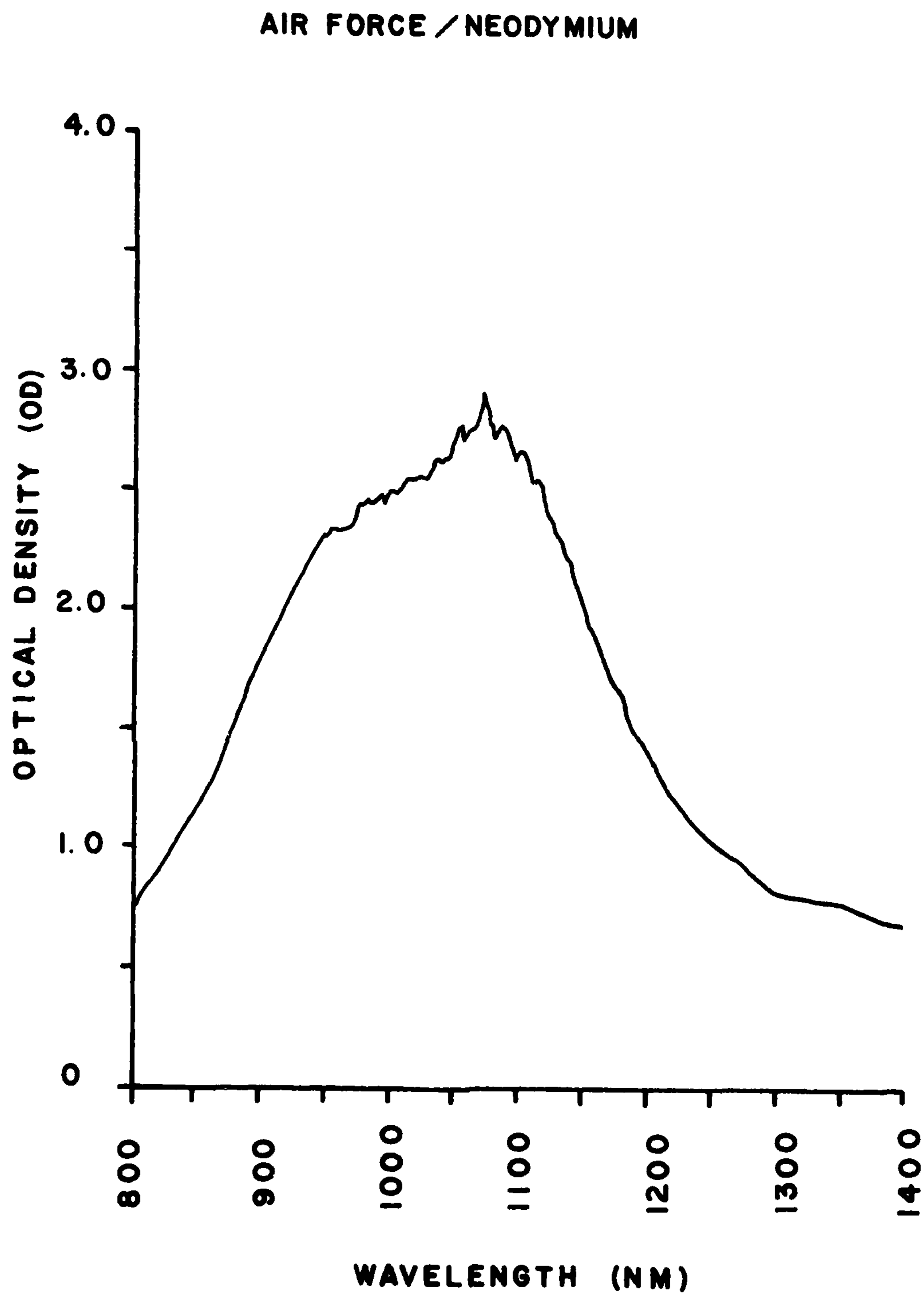

Figure 4. Optical density of Air Force neodymium laser visor material in the near-IR.

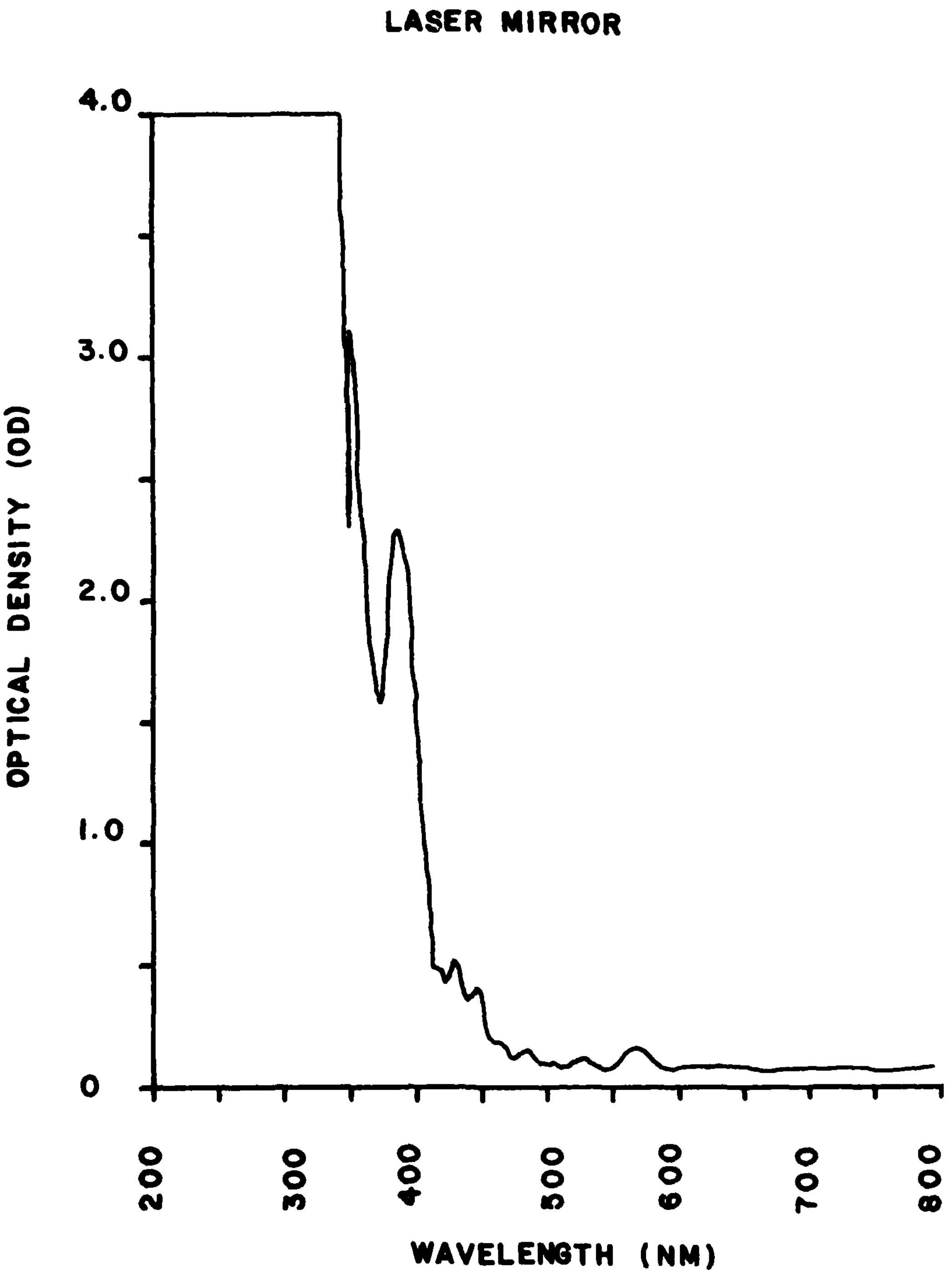

Figure 5. Optical density of a laser cavity mirror in the visible spectrum.

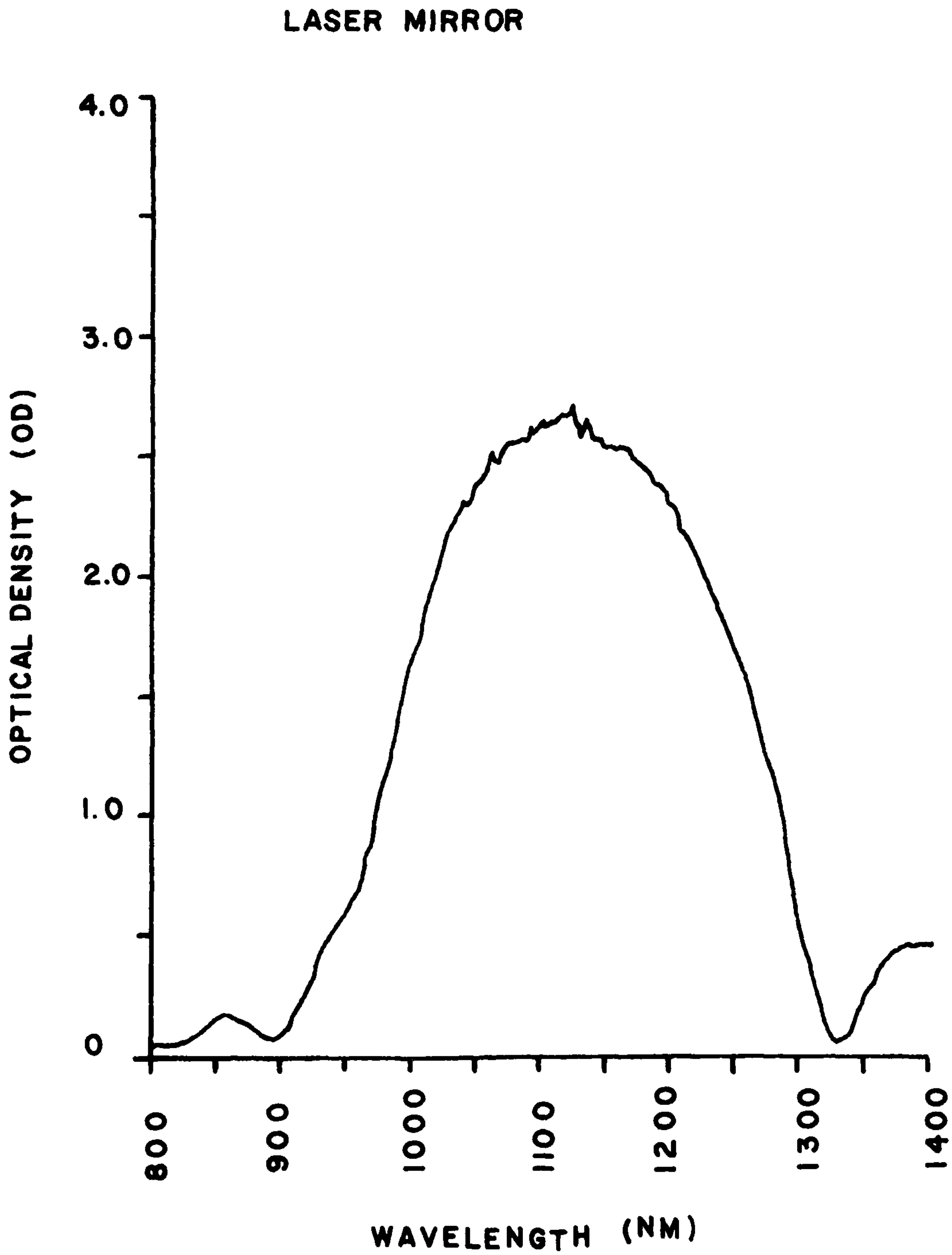

Figure 6. Optical density of a laser cavity mirror in the near-IR.

EXPERIMENTAL METHODS

A schematic diagram of the experimental apparatus is shown in Figure 7. A carefully controlled, simultaneously Q-switched and mode-locked Nd-glass laser (MLL) generates a short train of 6-psec pulses separated by 7 nsec [3]. A single pulse is extracted from this train by an electro-optic switch subsystem (EOS) consisting of a pair of Glan polarizers, a Pockel's cell, and a laser-triggered spark gap. Small fractions of the single-pulse beam are partitioned into two channels by a prism (P): (1) a long fiber optic delay line (FODL) and (2) an energy calibration reference channel consisting of a microcalorimeter (MC), a Kiethley 180 nanovoltmeter, and an X-Y recorder. The pulse duration is monitored by a two-photon-fluorescence on-line system (TPF) developed in-house [4,5]. The beam is passed through filter stack FS2, the sample (S), filter stack FS1, and into a second, short fiber optic line (FOL). The light signals from both fiber optic lines are coupled into a photomultiplier tube (PMT) and read out through a storage oscilloscope (OS).

The display on the oscilloscope is sketched in the inset of Figure 7. Since the laser pulses are much shorter in duration than the response time of the PMT optical detection system, the display shows peaks scaling with total energy in the pulses transmitted through the sample and the delayed reference channel through the fiber optic delay line (FODL). Filter stacks FS1, FS2, and FS3 are adjusted in a manner previously described for the measurement of optical density using a pulsed laser source [6]. With filter stack FS1 unoccupied and the sample in place, the optical density is given by

$$OD = f_r - \log_{10}(A_p/A_r), \tag{1}$$

where f_r is the initial value of filters removed from filter stack FS2, and A_p and A_r are the relative amplitudes of the light transmitted through the sample (probe) and the reference channels, respectively. With this optical bridge device in near-balanced condition, the energy incident on the sample is then increased directly by transferring (one-for-one) filters from FS2 to FS1. As the energy is increased, the optical density is closely monitored through measurements of the ratio A_p/A_r.

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3. Taboada, J., and R. W. Ebbers. Ocular tissue damage due to ultrashort 1060-nm light pulses from a mode-locked Nd:glass laser. Appl Opt 14:1759-1761 (1975).
4. Taboada, J., and D. D. Venable. Picosecond laser pulse duration measurements with a low light level electro-optic two-photon fluorescense technique. J Appl Phys 49:5669-5671 (1978).
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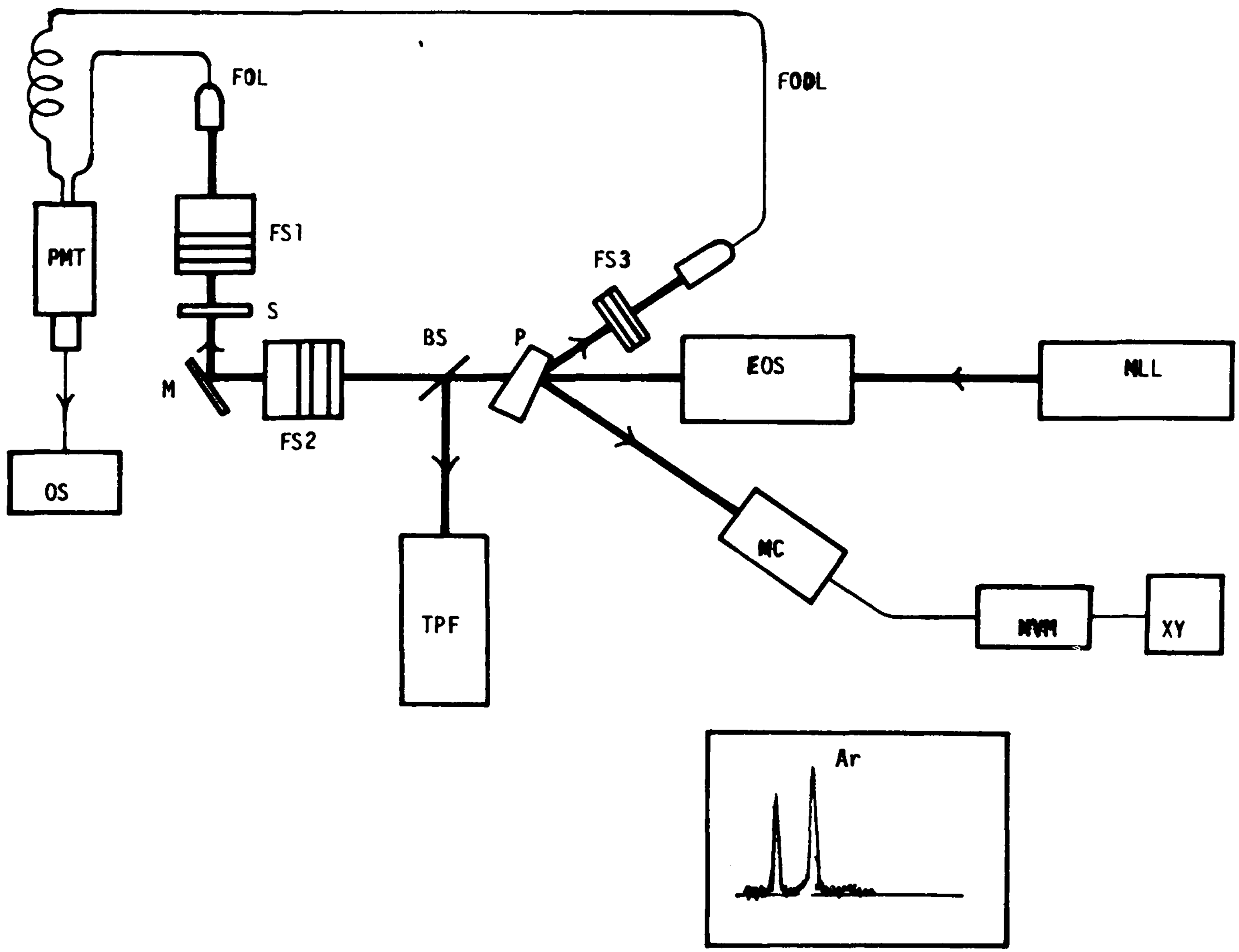

Figure 7. Apparatus for the measurement of picosecond laser pulse optical density: BS--beam splitter, EOS--electro-optic pulse selector, FODL--fiber optic delay line, FOL--fiber optic line, FS1-3--filter stacks, M--mirror, MC--microcalorimeter, MLL--mode-locked Nd-glass laser system, NVM--nanovoltmeter, OS--oscilloscope, P--prism, PMT--photomultiplier tube, S--filter sample, TPF--two-photon-fluorescence pulse duration measurement apparatus, XY--xy chart recorder. In the inset: A_p--probe pulse transmitted through sample, A_r--reference pulse delayed by about 50 nsec.

RESULTS AND DISCUSSION

The relatively low intensity spectrophotometric curves for the various filters are shown in Figures 1-6. Note the wide transmission band in the visible and the optical densities at 1060 nm: the (1) KG-3, OD = 3.61; (2) Air Force/Nd, OD = 2.74; (3) Laser mirror, OD = 2.42. Figures 8-10 show the optical density as a function of energy in the pulse incident on the sample. From a measurement of the beam spot (0.40 cm, 1/e point) and the mean of the pulse duration (6 psec), a factor of 1.33×10^{12} should be used to multiply the energy on the sample to obtain the peak irradiance in watts/cm^2. The peak irradiance for all samples was varied in the range from 10 kW/cm^2 to 10 GW/cm^2 and is plotted for discrete filter changes in Figures 8-10. KG-3 glass remains fairly constant in optical density, varying from 3.45 at 2×10^4 W/cm^2 to slightly above 3.5 at 6×10^9 W/cm^2. The optical density is comparable to that observed on the spectrophotometric measurements, 3.61; thus there does not appear to be any nonlinear transmission effects. The Air Force neodymium visor also showed similar independence from irradiance (Fig. 9). It, however, showed a high-intensity optical density of about 3.0, slightly higher than a value of 2.74 at low irradiation. The laser mirror also had a relatively constant optical density of about 2.5 compared to 2.42 at low intensities.

In a study of multiple-pulse effects, two pulses were allowed to be incident on the sample. This was accomplished by adjusting the laser-triggered spark gap to allow an 18-nsec window in the electro-optic selector system. The time resolution of the system was sufficient to permit the optical density measurements using the second pulse in the pulse pairs which were separated by 7 nsec. The optical density of the laser mirror (Fig. 11), as expected, remained about the same as previous measurements, with a value of 2.6 OD. KG-3 glass (Fig. 12), however, showed an increased optical density to a value of about 3.8 at about 2.6×10^4 W/cm^2 and decreased slightly with increasing irradiance to a value of approximately 3.6 at 1.0×10^{10} W/cm^2. In contrast, the Air Force Nd-visor material (Fig. 13) showed a slight decrease from the single pulse optical density of 3.0 to a value of approximately 2.6.

The results presented here show that the three filter materials investigated do not exhibit very strong optical density variations with irradiance increased to levels as high as 10^{10} W/cm^2. There may be a two-pulse effect in the absorption filters, but it does not vary significantly with the peak irradiance. It would be of interest to investigate what are the absorption processes in KG-3 that account for such low nonlinearities in transmittance. Similar materials could be derived for filter applications at other wavelengths.

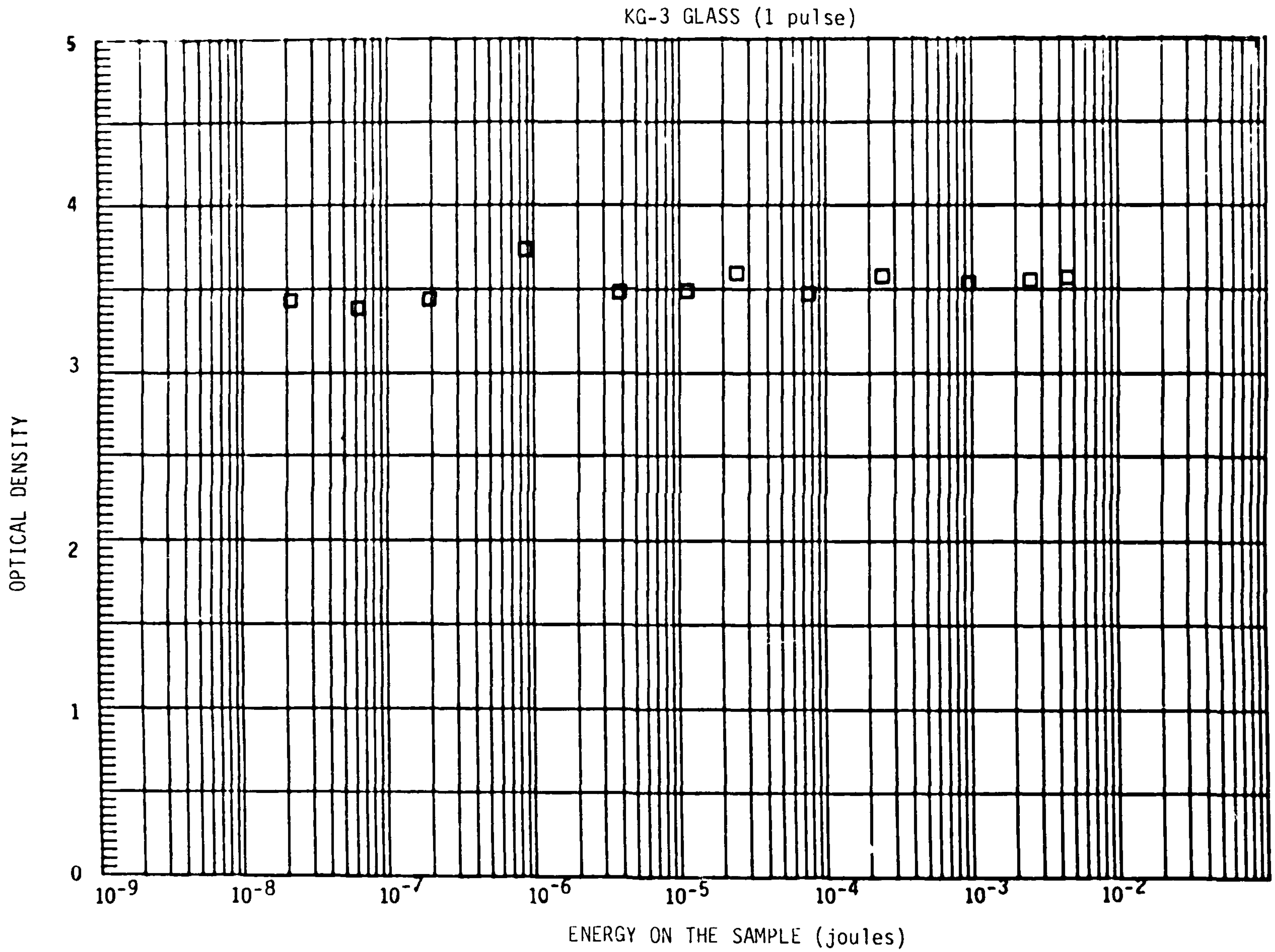

Figure 8. Optical density of KG-3 glass vs energy in single picosecond pulse incident on sample.

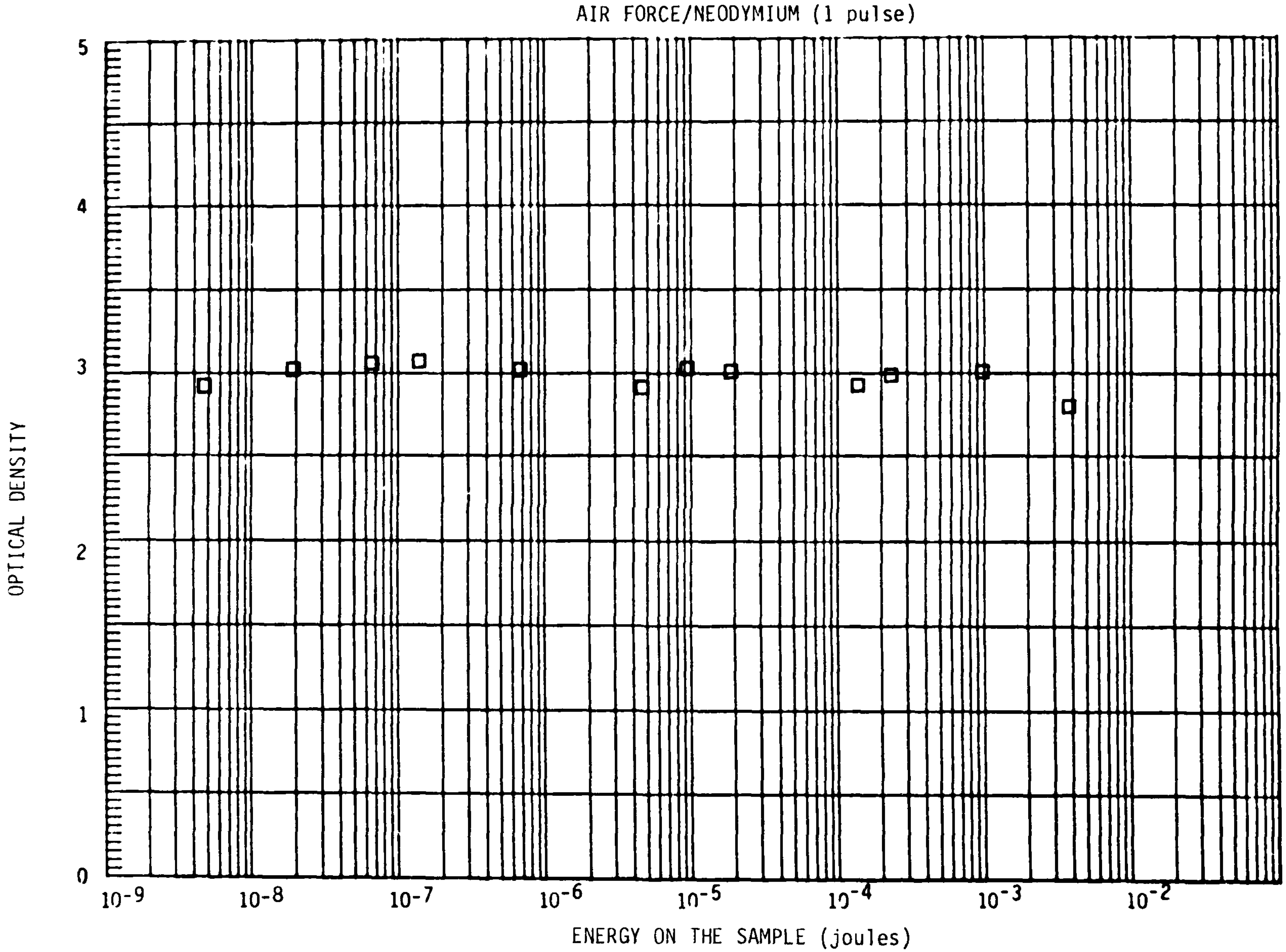

Figure 9. Optical density of Air Force neodymium laser filter vs energy in single picosecond pulse incident on sample.

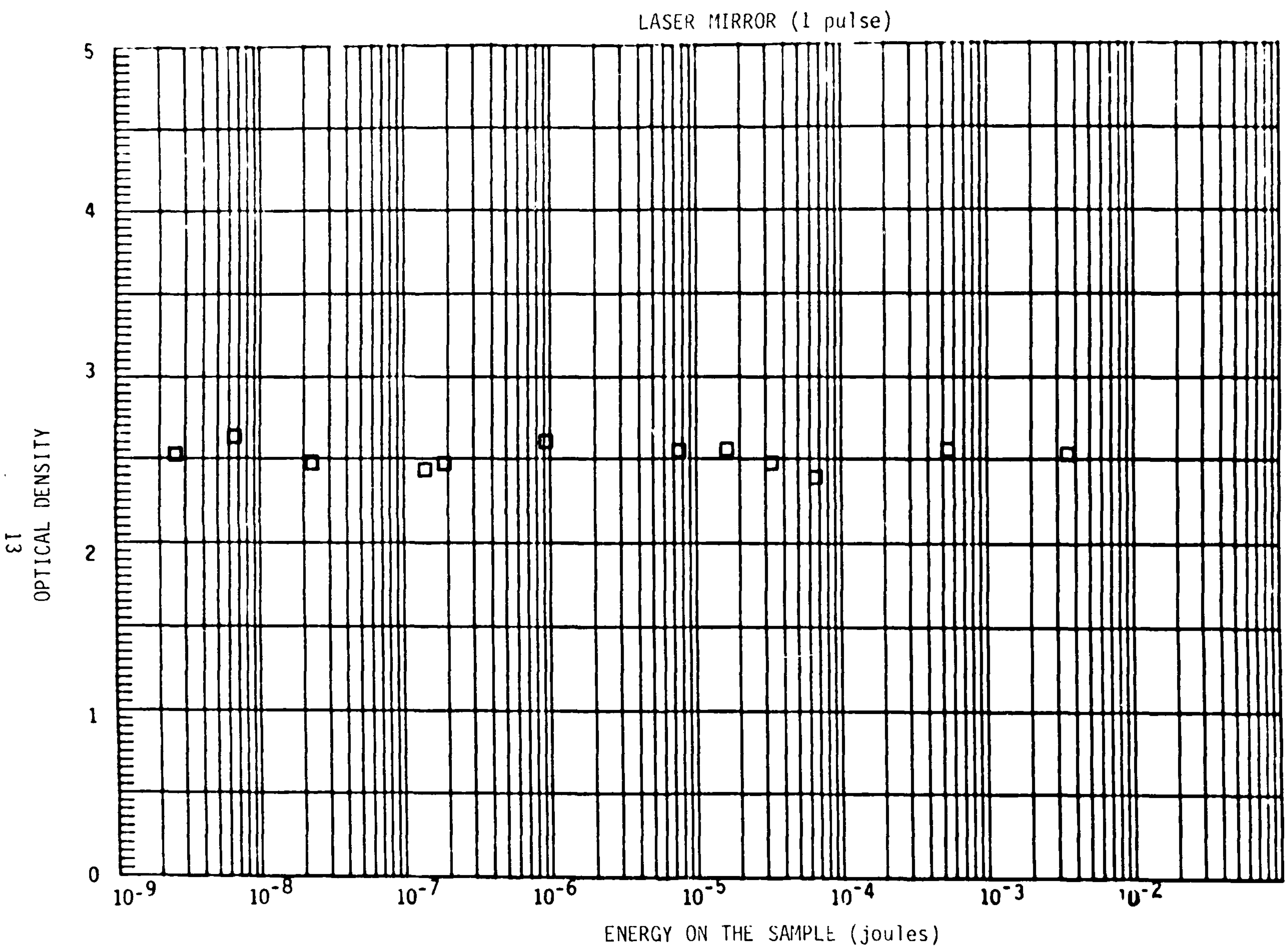

Figure 10. Optical density of laser cavity mirror vs energy in single picosecond pulse incident on sample.

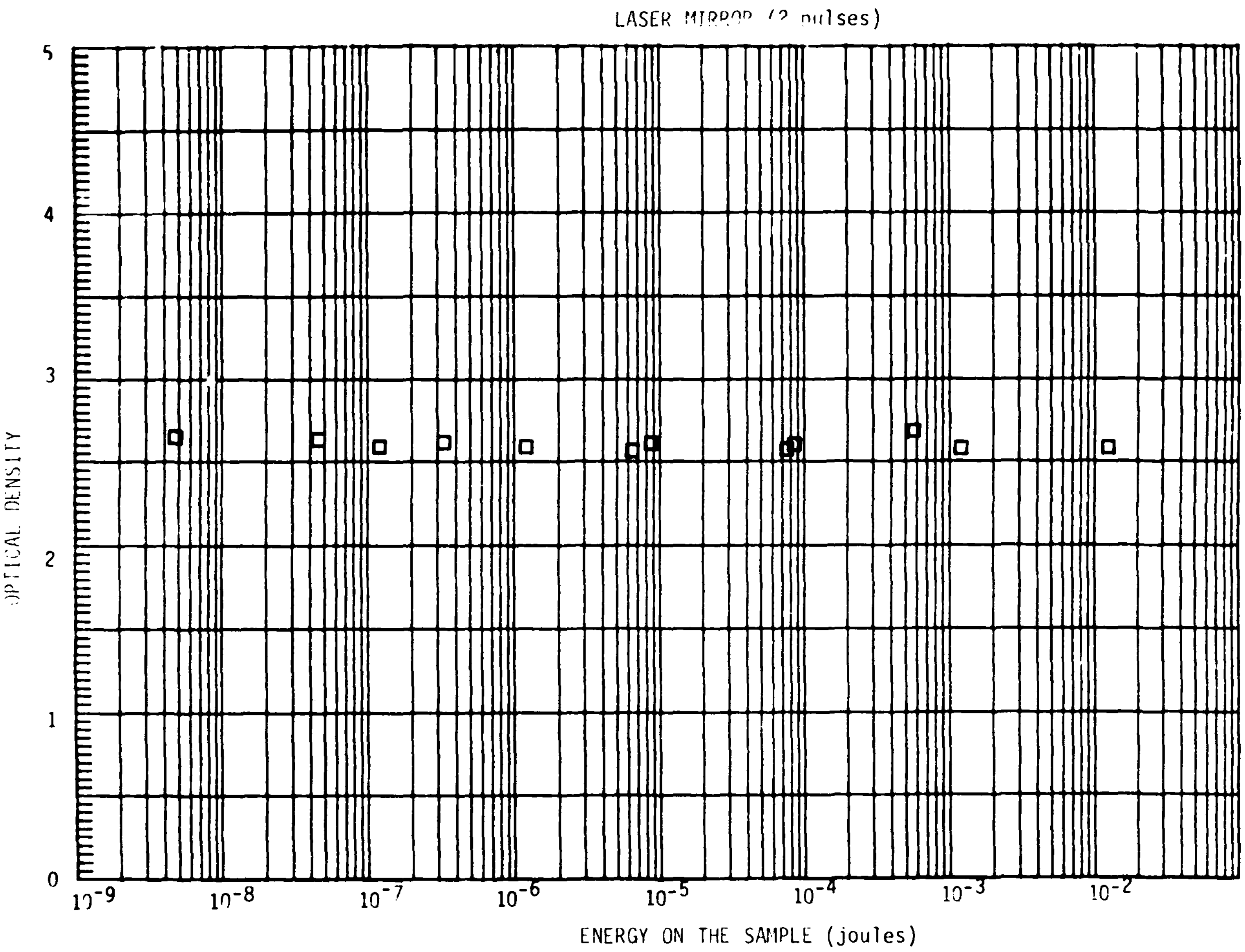

Figure 11. Optical density of laser cavity mirror vs energy in double picosecond pulse incident on sample.

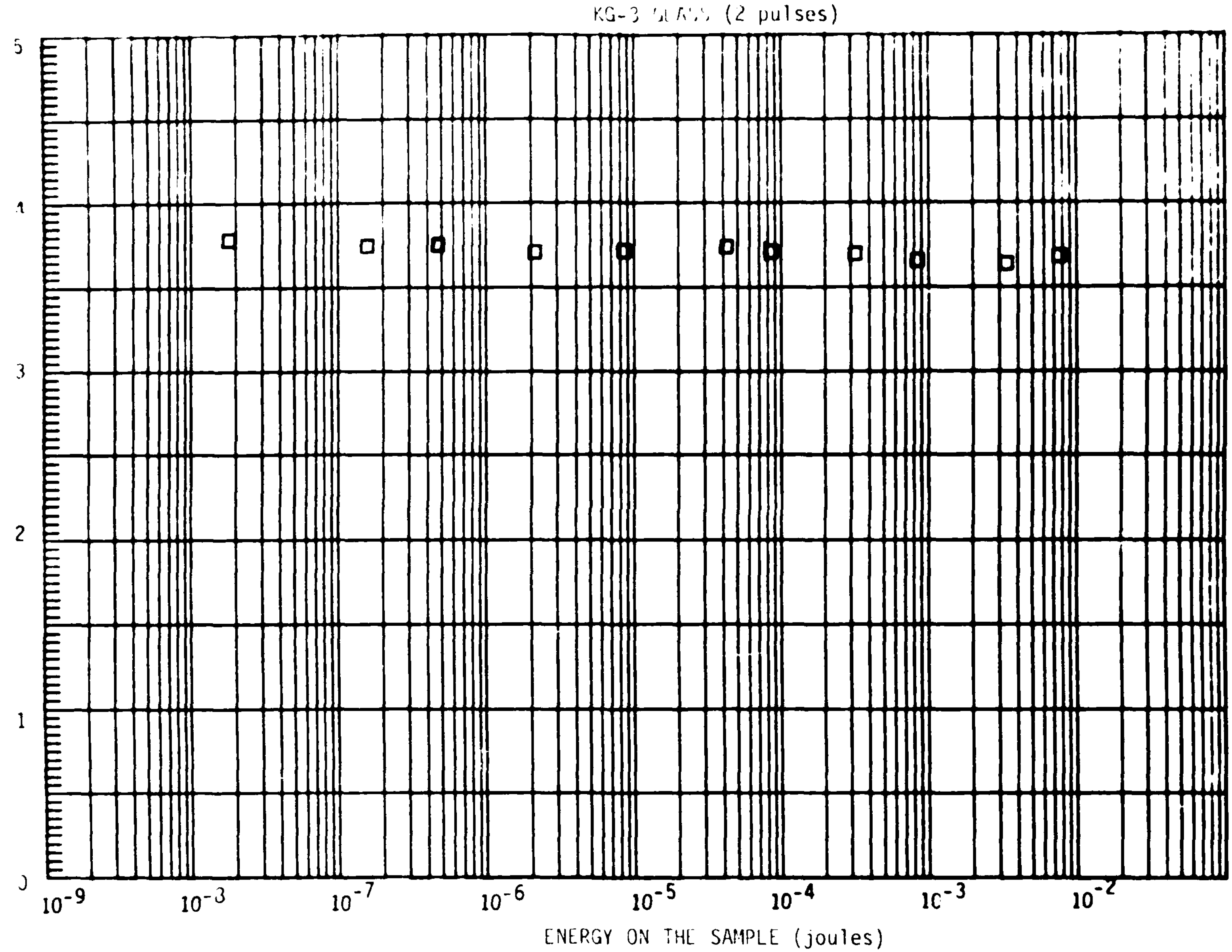

Figure 12. Optical density of KG-3 glass vs energy in double picosecond pulse incident on sample.

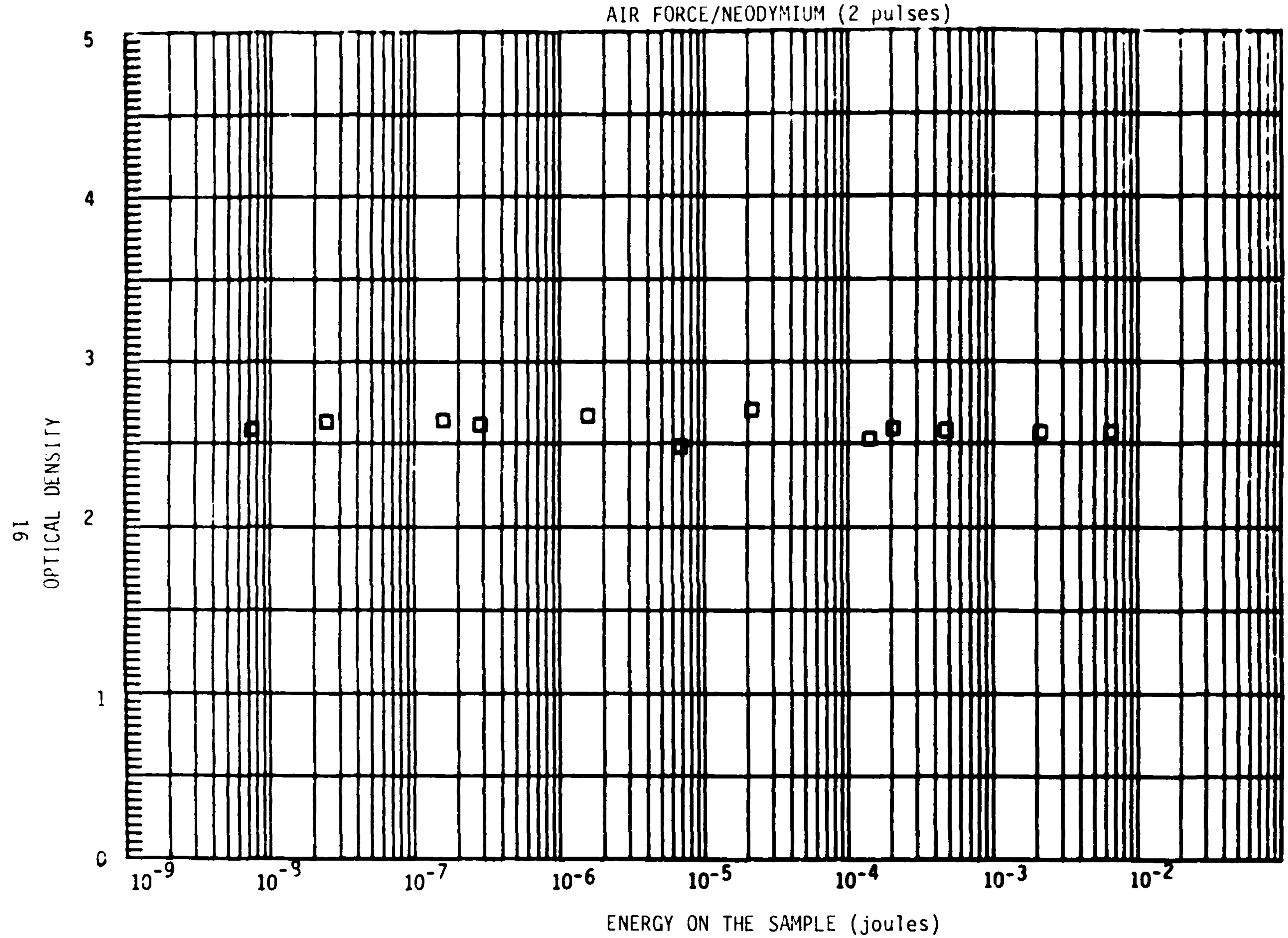

Figure 13. Optical density of Air Force neodymium laser filter vs energy in double picosecond pulse incident on sample.