Radioactive preionization in space lasers

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Radioactive preionization may have advantages over x-ray or UV preionization when simplicity, power consumption, and weight are at a premium, as in space lasers. Computations show that a few Ci/cm^2 of ^{90}Sr in the laser sidewalls or the electrodes results in a homogeneous electron source strength exceeding 10^{14} cm^{-3} s^{-1}.

Spaced-based high power lasers are contemplated for a variety of missions. Of these, excimer lasers powered by a pulsed electrical discharge are particularly interesting because of the potential for trouble-free long-life operation in relevant wavelength regimes. In these lasers, the avalanche discharge remains homogeneous only if at the beginning of each pulse there is sufficient preionization, typically[1] exceeding $10^6 e/$ cm^3. Such an electron density can be obtained by irradiating the gas with a pulse of electrons, UV light, or x rays of sufficient power and pulse length. Alternatively, the irradiation can be continuous. In this case, the electron density is determined from a balance between electron generation due to irradiation and electron loss mechanisms,[2] mostly electron attachment in excimer lasers.

Of the dc methods, preionization with radioactivity can be advantageous for space-based lasers because it is a passive technique; there are no parts that can fail or wear out. Radioactivity is inexpensive, lightweight, long lived, and carries its own power. The disadvantages of radioactivity include a possible inhomogeneity in the preionization and the radiological danger with the attendant problems.

Experiments on radioactive preionization for discharge lasers performed in the early 1970's at Lockheed, Naval Research Laboratory (NRL), Air Force Weapons Laboratory (AFWL), and Northrop apparently were negative or inconclusive, probably due to insufficient ionization levels that were thought to be adequate at the time. However, a recent experiment[3] at Los Alamos National Laboratory (LANL) was successful in extending the pressure regime for a homogeneous discharge in a nitrogen laser using a 0.3 mCi/cm strip of the alpha emitter ^{241}Am. Conductivity measurements performed during 1980 at Lawrence Livermore National Laboratory (LLNL) on mixtures of hydrogen and radioactive tritium give an electron density on the order of 10^6 e/cm^3, depending on pressure and tritium concentration.[4]

Theoretical evaluation of radioactive preionization in this article indicates that 1–10 Ci/cm^2 ^{90}Sr, in the chemically inert form SrSiO$_3$, fulfills the technical requirements on preionization for space lasers.

The electrical current density from this radioactive source is of the order 50 nA/cm^2; a homogeneous megavolt electron beam with this minute current density would work equally well.

To be suitable for preionizing space lasers the radioactive isotope must satisfy somewhat contradictory requirements. For example, in a beta emitter,[5] lifetime and beta energy are invariably related. Isotope half-life should exceed a typical mission timespan, e.g., 5–10 yr; on the other hand, the range and therefore the energy of the emitted particle should be such that it transfers a large fraction of its energy to the laser gas. For lasers of interest with 5–10-cm-wide cavities using a few atmospheres of neon as a buffer and the isotope in the sidewalls, the range should be of order 1 cm^2/g, suggesting megavolt beta energies. Alternatively, the buffer gas can itself be radioactive, but the chemical kinetics may be incompatible with the available isotopes or the decay products, perhaps resulting in condensation on the optics or the insulators.

Evaluation of the available isotopes in light of these requirements only allows beta emitters, in particular, the solid ^{90}Sr in equilibrium with its radioactive decay product ^{90}Y. ^{90}Sr has a 28-yr half-life, with a 0.54-MeV end-point energy; ^{90}Y is also a beta emitter, with a three-day half-life and 2.26-MeV end-point energy. The end product ^{90}Zr is stable. Few x-rays are emitted and, in addition, a few percent of the decay energy may go into bremsstrahlung; thus, shielding problems are relatively minor. The combination of long lifetime with energetic betas in ^{90}Sr is in part due to the two-step decay with disparate half-lives, and in part to a forbidden decay mode in both nuclei.

^{90}Sr is overabundant and very inexpensive, down to \$1000/10 kCi. It is more expensive in the most suitable form, beads of the chemically inert silicate SrSiO$_3$. This material and the decay products with their silicates are inert solids that can be put in the laser sidewalls without undue swelling from gas buildup or crystal defects.

A simple estimate for a one-dimensional geometry shows that the high but easily obtained activity of 1 Ci/cm^2 corresponds to an electron source strength of $S = 3 \times 10^{13}$ cm^{-3} s^{-1}. Assuming a 100-ns electron removal time (as in a proposed HgBr laser), the corresponding electron density is 2×10^6 cm^{-3}, which already exceeds the 10^6 cm^{-3} requirement commonly quoted. The estimate takes an average electron, with energy about 0.6 MeV, that produces roughly 2000 secondary electrons per centimeter at 30 eV/e along its 10-cm-long path in the gas (here 4 atm neon). Due to isotropic emission and self-absorption, less that half the decay electrons reach the gas; taking only 25% of the electrons and 1 Ci/cm^2 gives 10^{10} cm^{-2} s^{-1} decay electrons into the gas, and the source strength quoted.

The electron source strength needed for preionization of particular laser mixture would change with effective electron removal time[2] for the gas: our value 100 ns is illustrative only.

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Computations in the next section corroborate this estimate. In addition, they show that the hardening of the electron spectrum in the self-absorption of thick radioactive slabs or thick protective covering may lead to good irradiation homogeneity.

Computations with the general 3-D Monte Carlo code *SANDYL*[6] were done in an almost one-dimensional geometry. A 1-m-radius thin disc of $^{90}SrSiO_3$, separated from the laser cavity by a thin Al foil, is backed by a 0.5-cm-thick graphite electron stopper. The laser gas is assumed to be neon at 1 and 4 atm pressure.

Electron emission is isotropic with energy spectrum as in Fig. 1. This spectrum applies to thin samples: the self-absorption modifies the energy spectrum for strongly radioactive and therefore thick slabs. The present computation treats self-absorption properly by specifying that emission occurs homogeneously throughout the $SrSiO_3$ slab. Ten-kCi $^{90}SrSiO_3$ is about 1 grammolecule, 166 g, and about 50 cm^3; hence, a 1-Ci/cm^2 slab is 0.005 cm thick, which equals the range of a 40-keV electron. A 10-Ci/cm^2 slab, 0.05 cm, corresponds to the range of a 175-keV electron. In this case, the low-energy electrons from the ^{90}Sr decay are strongly affected, but most of the high-energy electrons from the ^{90}Y decay get out of the radioactive slab.

Figure 2 gives the secondary electron source strength versus depth in 1 atm of neon per Ci/cm^2 activity, for the ^{90}Sr with a 1-mil-thick aluminum foil between radioactive source and laser gas. The source strength is given in units 10^{14} cm^{-3} s^{-1}, assuming 30 eV per secondary electron. When the electron attachment time is 100 ns (typical for interesting laser gases), the electron density is estimated at 10^7 e/cm^{-3}.

The secondary electron source for a 1-Ci/cm^2 activity, marked 1 in Fig. 2, is rather inhomogeneous, i.e., three times higher close to the emitter than on the opposite sides. Higher activities from thicker slabs give much better homogeneity: with 10 Ci/cm^2 the source strength close to the emitter is only twice that at the opposite sides. Putting the same activity in the second laser sidewall gives much better homogeneity, especially in the case of 10 Ci/cm^2 (curves marked $2\times$...).

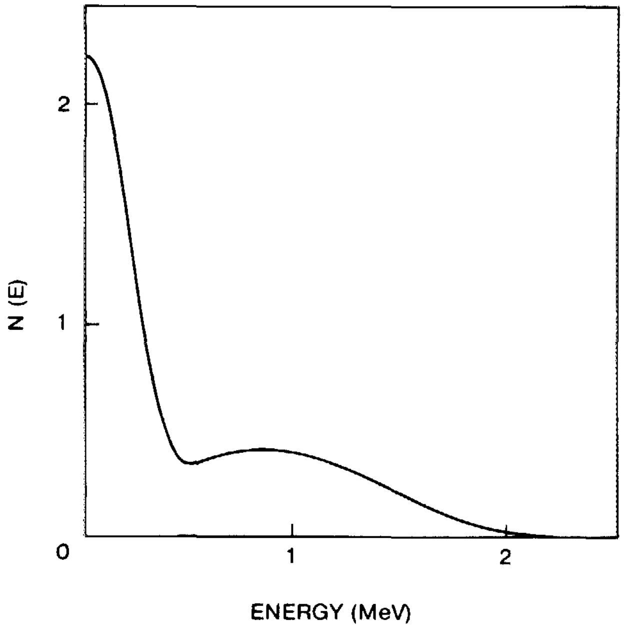

FIG. 1. Energy spectrum for electrons from $^{90}Sr/^{90}Y$.

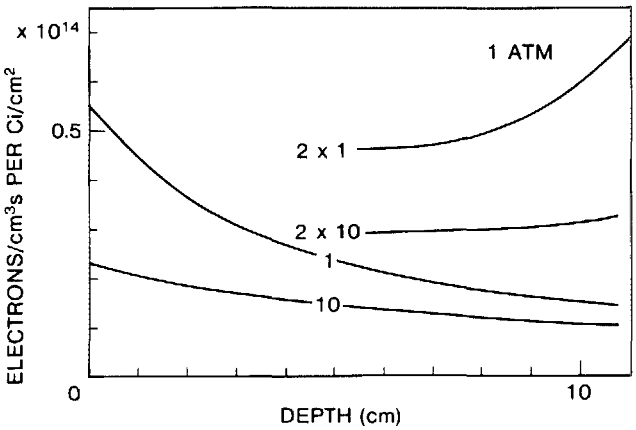

FIG. 2. Secondary source strength per Ci/cm^2 as function of depth into 1 atm neon. Curve marked 1 corresponds to 1 Ci/cm^2 or a 0.005 cm thick slab of $SrSiO_3$; Curve 10 corresponds to 10 Ci/cm^2 (0.005 cm thick). Curves 2×1 and 2×10 are for 1 and 10 Ci/cm^2 in each sidewall.

For thick slabs, the homogeneity improves because the electrons emanating from a thick, active region emerge perpendicularly. The electrons emitted under a large angle with the normal, especially those from the back of the radioactive slab, can lose all their energy before they reach the laser gas. This effect is most important for the 0.5-MeV electrons from the ^{90}Sr. Relatively thin slabs, however, emit more isotropically, resulting in enhanced irradiation close to the slab.

The secondary electron source strength is somewhat lower than estimated, because a fair fraction (about 20% for 1 Ci/cm^2, compared to about 60% for 10 Ci/cm^2) of the electrons are self-absorbed. Hence, few electrons, 25% and 15%, respectively, make it into the gas, with the remainder going into the carbon stopper and about 1% into the aluminum foil.

Two 10-Ci/cm^2 radioactive preionizers, one in each sidewall, give an interesting secondary electron source strength: $S = 1.5\times10^{14}$ cm^{-3} s^{-1}, with sufficient homogeneity in this rather tenuous gas. Figure 3 shows the secon-

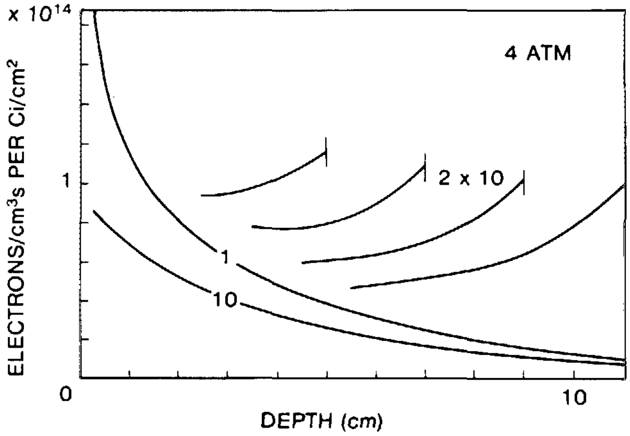

FIG. 3. Secondary electron source strength per Ci/cm^2 as function of depth into 4 atm neon. Curve marked 1 corresponds to 1 Ci/cm^2, curve 10 to 10 Ci/cm^2. The four curves marked 2×10 give the source strength for 10 Ci/cm^2 in two sidewalls separated as shown.

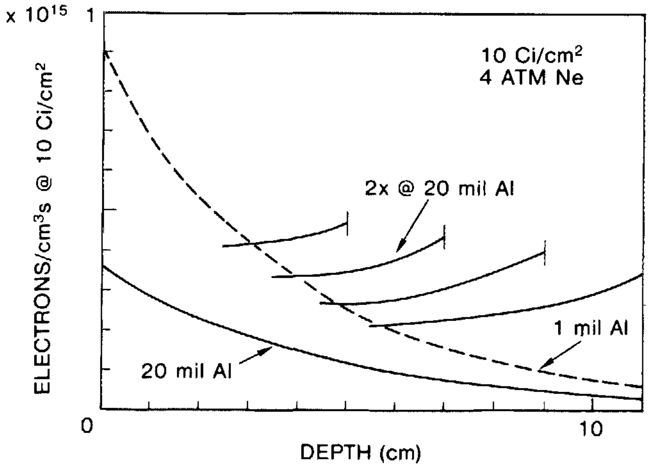

FIG. 4. Secondary electron source strength in 4 atm neon for 10 Ci/cm^2 behind 1- and 20-mil aluminum foils. The four curves marked 2 × ... give the source strength for two radioactive electrodes as shown.

dary electron source strength for 4 atm neon; the source strength at the radiating edge is of course four times larger due to the fourfold pressure, and the homogeneity is worse.

To reach acceptable homogeneity, the activity must be put in both sidewalls, and these should be rather close; the curves marked 2×10 in Fig. 3 show the source strength (per Ci/cm^2) versus position for 10 Ci/cm^2 in both walls, parameterized by the cavity width as shown. For a 7-cm-wide cavity, the source strength at the minimum exceeds 8×10^{14} e/cm^3 s, which is ample for preionization: this minimum is only 20% lower than the maximum $S = 10^{15}$ e/cm^3 s close to the sidewalls.

Separating the radioactivity from the laser gas with a thin aluminum foil is appropriate if the source forms the laser cavity wall. Alternatively, the radioactivity can be put in the electrodes to alleviate any problems due to inhomogeneous irradiation. The electrode should be reasonably solid; it may intercept part of the primary electrons before they reach the gas, and it decreases the average electron energy by about 250 keV.

Figure 4 gives the secondary electron source strength in the laser gas for 10-Ci/cm^2 activity behind a 20-mil (0.05-cm) aluminum electrode. Compared to the 1-mil case (dashed line, taken from Fig. 3) the source strength is about halved; still, the source exceeds 3×10^{14} e/cm^3 s at the minimum between identical electrodes, each with 10 Ci/cm^2 embedded. This source strength would correspond to 3×10^7 e/cm^3 for a typical laser gas.

The secondary electron source strength due to the activity from ^{90}SrSiO$_3$ exceeds 10^{15} cm^{-3} s^{-1}, sufficiently high to give a steady-state secondary electron density more than 10^6 e/cm^3 for typical laser gases. The computed preionization homogeneity is acceptable if the sources can be put in opposing sidewalls or in the electrodes.

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