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RESEARCH ARTICLE

HOME BUILT LASING ACTION: A REVIEW ON NITROGEN LASER

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ABSTRACT

Laser is an acronym which stands for light amplification by stimulated emission of radiation. It is widely used in medicine, agriculture, military, security, laboratories and research activities. From different types of lasers; gas laser is commonly used of which nitrogen laser is emerging. Nitrogen molecules are the most abundant molecules in the earth's atmosphere, constituting 78.08%. Electron collisions with molecular nitrogen continue to receive interest due to their importance in gaseous discharge processes, such as those involved in nitrogen lasers. Nitrogen lasers are capable of producing very high power short pulses of ultraviolet light at a wavelength of 337.1nm. They have a wide range of applications in dye laser pumping, lidar (remote sensing), fast speed photography, atomic and lifetime spectroscopy, medical and biological research, etc. Compared to other gas lasers, nitrogen lasers are very cheap and easy to construct. Sometimes call us “home built lasers" for multiple comparative advantages.

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INTRODUCTION

Laser is an acronym which stands for light amplification by stimulated emission of radiation. It is widely used in medicine, agriculture, military, security, laboratories and research activities. From different types of lasers; gas laser is commonly used of which nitrogen laser is emerging. The milestones in the history of lasers dates back 100 years when Einstein came up with the idea of stimulated emissions, which became a platform for the Nobel prize winner T. H. Maiman in inventing the first ever known laser in 1960. The first gas laser was developed by A. Javan, W. Benneth and D. Harriott of Bell laboratories in 1961 using a mixture of helium and neon gases before Heard demonstrated the action of the first nitrogen laser in 1963 (Mark Csele, 2004). Although the average power of this laser was very low, it captured attention to develop new design methodologies to improve the peak power output. Research continued until a transverse electrical discharge at atmospheric pressure (TEA) nitrogen laser developed to have capability of producing megawatt powers using molecular nitrogen at atmospheric conditions. This appeared at a time when it was needed in ultraviolet laser development, which led to excimer lasers which are now of great use on large scale (Mark Csele, 2004; Montaser Foad *et al*., 1984; Gerry, 1957; Heard, 1963).

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Principle of laser action

Having the principle of laser i.e. its monochromaticity, directionality, coherence, brightness, focusing of laser beam the mechanism of laser action involves three processes: photon absorption, spontaneous emission and stimulated emission. In the description of these processes, we consider a simple two level {energy system represented in Figure 1.1, where E_1 and E_2 are the lower and higher energy levels with populations N_1 and N_2, respectively. Normally, atoms or molecules depending on the laser material undergo repetitive jumps from one level to the other by either the pump source or the emission of photons (Montaser Foad *et al*., 1984; Gerry, 1957; Heard, 1963)

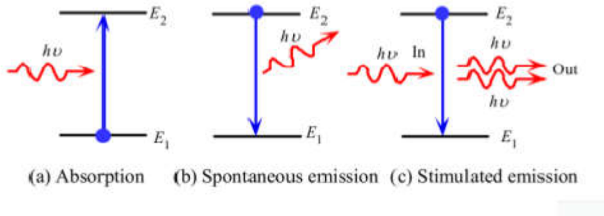

Figure 1.1. Energy conversion processes involved in laser action (Montaser Foad *et al*., 1984)

Photon absorption: When incident radiation is absorbed by the matter the atoms may jump from the lower level to the upper level, with a discrete amount of energy given by $h\nu = E_2 - E_1$, as shown in Figure 1.1a. Due to the energy transfer from

E_1 to E_2, there is absorption of photons, with the absorption rate given by

$$\frac{dN_1}{dt} = -\frac{dN_2}{dt} = -\beta_{12} N_{1\rho(\nu)} \qquad 1.1$$

Where $\rho(\upsilon)$ *is the spectral energy density (intensity) at a frequency* υ*, and* β_{12} *is Einstein's coefficient of absorption. In the absorption process, a photon is annihilated* (Heard, 1963).

Spontaneous emission

The excited atoms in the upper level are unstable, thus they decay to the lower level by releasing some of their excess energy in the form of photons. The amount of excess energy is given by $h\upsilon = E_2 - E_1$, as shown in Figure 1.1b. Spontaneous emission processes are random and isotropic in nature, thus occur without any external influence. The probability of the process to occur is defined in terms of the decay rate of the upper level population and the increase rate of the lower level population

$$\frac{dN_2}{dt} = -\frac{dN_1}{dt} = -A_{12} N_2 \qquad 1.2$$

where A_{12} *is Einstein's coefficient which determines the probability of emission of a photon, the negative sign signifies the decreasing population of atoms in the upper level (Montaser Foad et al., 1984; Gerry, 1957; Heard, 1963).*

Stimulated emission: The atoms in the upper level can be brought to the lower level through an external influence. When a stimulating photon with exactly the same energy as the difference in energy between the upper and lower levels, in the same direction and polarization is made to strike the excitable laser material, the atom decays to the lower level and emits a photon. Both the emitted photon and the stimulating photon have an energy given by $h\upsilon = E_2 - E_1$, as shown in figure 1.1c, with the transition rate given by

$$\frac{dN_2}{dt} = -\frac{dN_1}{dt} = -\beta_{21} N_{2\rho(\upsilon)} \qquad 1.3$$

where B_{21} *is Einstein's coefficient for stimulated emission, basically an intrinsic property of the system (Heard, 1963).*

At equilibrium:

Rate of absorption = Rate of spontaneous emission + Rate of stimulated emission

$$\left(\frac{dN_2}{dt}\right)_{stimulated} = -\beta_{21}\rho(\upsilon) N_{2\rho(\upsilon)}[N_2 - N_1] \qquad 1.4$$

Now, at steady state $N_2 = 0$. So, the rate stimulated emission is negative or absorption is greater this means that there is no stimulated emission. To have $N_2 > N_1$ we should have negative temperature.

$$\frac{N_2}{N_1} = \exp\left(\frac{E_2 - E_1}{\kappa T}\right) = \exp\left(\frac{-h\nu}{\kappa T}\right) \qquad 1.5$$

Where N_2 *and* N_1 *are the number of atoms in the excited state and the ground state respectively, k is Boltzmann's constant, and T is the absolute temperature of the material.*

Under equilibrium conditions, the system acts as an absorber at a frequency υ, since $N_2 < N_1$. However, if the inversion condition is achieved $N_2 > N_1$, then the system acts as an amplifier. This is defined as population inversion (Elton *et al*., 1972).

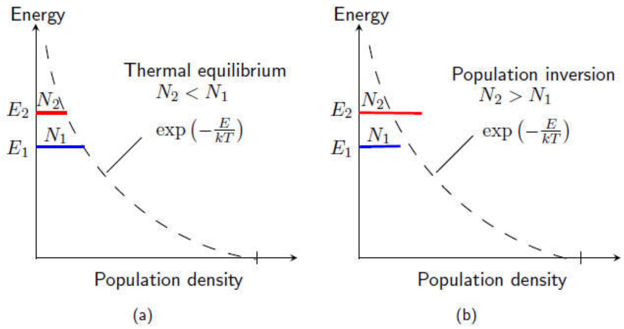

Figure 1.2. Population distribution between levels 1 and 2 for thermal equilibrium and population inversion conditions (Silfvast, 2004)

The pulsed molecular nitrogen laser is a gas discharge laser that produces ultra violet laser output at 337.1 nm. This laser operates on the ($C^3_{\pi u} \longrightarrow B^3_{\pi g}$) vibronic system, which involves a change in both electronic and vibration energy level (Mark Csele, 2004; Montaser Foad *et al*., 1984; Gerry, 1957; Heard, 1963). A pulsed nitrogen laser has been constructed at relatively low cost. This design incorporates V-shape electrodes to ensure even transverse discharge at low pressure closed system and produces super radiant emission at 337.1 nm. Our nitrogen laser was constructed for spectroscopy studies and oil spill detection (Silfvast, 2004).

1.Nitrogen Laser

1.1 Concept of Nitrogen Laser

Nitrogen (N_2) lasers are convenient and economical sources of short, nanosecond, ultraviolet (337.1 nm) pulses. All are based on a fast electrical discharge through N_2 gas. Traditional designs required vacuum pumps and flowing gas. Smaller sealed tubes, a more recent variant, are much more convenient but lack the energy of the more cumbersome older systems. They also rely on the inexpensive but limited spark gap switch. Our design represents an advance in laser technology. The sealed tube with the thyratron switch provides the high energy of the conventional models, yet adds all the convenience and portability of the stand alone sealed models. N_2 lasers have long been a favored pump for low energy tunable dye lasers. The short pulse duration is ideally suited to dye excitation. The short UV wavelength allows generation of tunable output from 350 nm through the visible and NIR, without any complicated frequency conversion schemes. The high peak power of the N_2 laser translates into a high peak power dye laser, adequate power for many non-linear optical phenomena, especially on the micro spatial scale (Elton *et al*., 1972; Lee *et al*., 1985;

Gholap *et al*., 1997). The short pulse duration is a major advantage of the nitrogen laser. The pulse is completely over in nanoseconds; there is no long trailing edge. We use this property ourselves to test detector response. You can use it as the well defined "starting gun" for a whole host of applications. The UV pulse can create micro plasma for time-of-flight studies, or a well defined pulse of photoelectrons for condensed matter studies. You can use it as an excitation source for a range of lifetime measuring techniques and for many excite and probe kinetic studies (Gholap *et al*., 1997; Orazio Svelto, 4th edition; Iwasaki and Jitsuno, 1982; Richter *et al*., 1976; Chang, 1985).

The brightness of the N_2 laser also gives it an advantage over conventional lamp sources. The basic laser has relatively poor spatial coherence compared with our HeNe lasers, but you can still focus it efficiently to extremely high peak power densities. It is well suited for coupling to fiber optics and for use in micro spectrometry where high energy is often a liability. In short, N_2 lasers are an economical solution to a wide range of problems. Oriel now brings you this versatile source in a small, convenient, and reliable package.

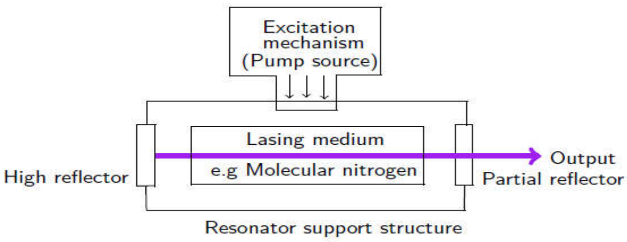

Figure 2.1. Schematic layout of the laser (Farooq Kyeyune, 2011)

Pumping mechanism for a nitrogen laser

To create population inversion in laser medium there are different pumping schemes like, electrical, chemical and gas dynamics pumping schemes. To excite the nitrogen laser molecule mostly we use electrical pumping (Svelto, 2009; Kasap, 1999; Mark Csele, 2004; Gunandjar at Radioactive Waste Technology Centre, National Nuclear Energy Agency of Indonesia (BATAN) Kawasan Puspiptek Serpong, Tangerang, Banten-Indonesia, 15310) A nitrogen molecule like any other diatomic molecule possesses vibronic energy levels that constitute both vibrational and electronic states. These energy states are mainly separated by the change in electron energy of the atoms, and a small contribution resulting from the vibrations within the nitrogen molecules themselves. The laser action therefore involves a series of the transitions, resulting from the changes in vibrational and electronic states of the nitrogen molecules, which are nearly spaced to favour the emission of ultraviolet radiation at 337.1 nm (Elton *et al*., 1972). The pumping mechanism in a nitrogen laser, involves collision of high energy electrons with the gas molecules in a laser tube through electron impact excitation. The accelerated electrons in the laser tube strike the nitrogen molecules, thus exciting them to a higher electronic energy state. Figure 2.4 shows the energy level scheme for a nitrogen laser, with each level showing a series of vibrational energy level, which depends on the inter nuclear separation of the molecule. The laser normally starts when the nitrogen molecules become excited by an electric discharge in the lasing tube from the electronic ground state, labeled $X^1\sum^+$ energy band to the upper lasing level, labeled C_u^3 energy band. The molecules at the upper lasing level are unstable, thus they decay to the lower lasing level, labeled as $B^3\pi_u$ energy band, by emitting photons of ultraviolet radiation at 337.1 nm. This corresponds to only energy levels with the lowest vibration state, for which v= 0, and v = 1 corresponding to the upper vibrational state. However, other transition states are also possible. For example in a 1-0 state, where in this case the lower lasing level involved in the vibration state is at v = 1 and the upper lasing level is the same as the lowest, at v = 0 (Silfvast, 2004). This result into a shorter jump during the transition state than before, thus an output with a lower energy at a wavelength of 358 nm is given off as shown in Figure 2.2. When a molecule emits a photon as it falls to the lower lasing level, it then decays to a metastable state where it stays. Thus a nitrogen laser is effectively a three-level laser. The biggest problem with a nitrogen laser is the lifetime of the upper lasing level, which is their greatest barrier in the laser development (Atezhev *et al*., 2004; Solomon Zerihun, 2013; Silfvast, 2004; Seki *et al*., 1995; Kau *et al*., 2004; Rosa *et al*., 1997).

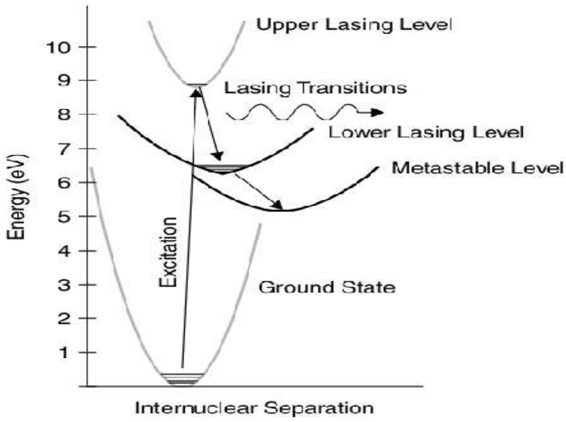

Figure 2.2. Energy level of molecular nitrogen laser (Design and Fabrication of Prototype Transversely Excited Atmospheric (TEA) Nitrogen Laser, Mukhtar Hussain, 2012)

The upper lasing level has a lifetime that is pressure dependent according to

$$t = \frac{36}{1 + \frac{58}{P}} \qquad 2.1$$

where t is the upper lasing level lifetime in nanoseconds and p is the pressure in torr.

The transition lifetime of the gas molecules from the upper lasing level to the lower lasing level is very short (≤ 40ns) as compared to lifetime for the transition between the lower lasing level and the metastable state (about 10 μs) (Silfvast, 2004). Thus the population of the gas molecules at the lower level exceeds that at the upper lasing level. This means that the lasing process will terminate, since the condition for lasing to take place is violated. Creating a population inversion at the upper lasing level in this case, is only possible if the pump power from the source is sufficient to have the nitrogen molecules in the upper lasing level as quick as possible. Gas lasers in general, are pumped directly by electron impact excitation. The gas molecules are excited from the ground level to the upper level through collisions with the electrons accelerated by the electric field set-up between the electrodes of the discharge chamber (Experimental optimization of a nitrogen laser A. VÁZQUEZMARTÍNEZ AND V. ABOITES Laser Laboratory, 1993; Kamal H. Latif and Wissam H. Mahdi, 2009; Modeling of Nitrogen Laser Melak Gedefe, 2011; The Application of Nitrogen Laser on Extraction of Uranium in The Long Life of High Level Radioactive Liquid Waste Using TBP-Kerosene Solvent, 2012).

1.2. Nitrogen laser structure

The basic requirement for a practical nitrogen laser is to supply a massive electrical current (i.e., a huge quantity of electrons) with a fast rise time and short pulse length to excite the gas. To achieve this, most nitrogen lasers use an electrical configuration called a Blumlein configuration, which generates a massive over voltage of the laser channel (and subsequent large current through the lasing gas) with a rise time of nanoseconds (Atezhev *et al*., 2004; Kau *et al*., 2004). A Blumlein configuration is shown schematically in Figure 2.3, where we find two capacitors essentially in parallel separated by the laser channel itself. Both capacitors charge simultaneously through the charging inductor (which offers little electrical resistance to the charging current) until the spark gap fires when the breakdown voltage is reached (typically, about 10 kV for a small laser). In simplest form, a nitrogen laser may operate as a relaxation oscillator, repeatedly charging and firing; the use of triggered spark gaps or thyratrons allows the laser to be triggered as required. The gap now conducts essentially short-circuiting C_1 and draining charge from it, making the top terminal of C_1 negative. A massive voltage difference appears quite suddenly across the laser gap since the left side of the tube is now negative and the right side still positive. Charge from C_1 flows across the laser channel as a pulse of very high electrical current, in many cases thousands of amperes. The electrical dynamics of the laser are not as simple as a discharge, since the laser tube has long transverse electrodes over which the high current must be distributed. With a short discharge time necessitated by the short upper lasing level lifetime, the laser is best excited by a traveling electrical wave which starts at the rear of the laser and moves forward at the speed of light exciting nitrogen molecules as it progresses. To accomplish this, capacitors are fabricated as long, distributed capacitances parallel to the laser tube. The initiating spark gap is placed at the rear of one capacitor so that the electrical pulse begins at the rear of the laser first and travels toward the front of the laser. In many cases it is possible to design the laser as a transmission line for efficient transfer of electrical energy into the lasing volume. In this particular design, common for small laboratory-type nitrogen lasers, the capacitors are fabricated on an epoxy glass substrate (Razhev and Churkin, 2007; Fitzsimmons, 1976; Silfvast, 2004; Design and Fabrication of Prototype Transversely Excited Atmospheric (TEA) Nitrogen Laser, Mukhtar Hussain, 2012).

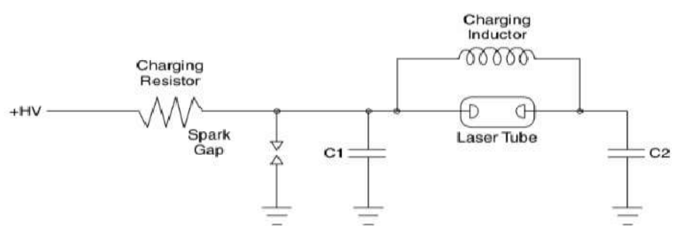

Figure 2.3. Electrical schematic of a Blumlein laser (Modeling of Nitrogen Laser Melak Gedefe)

Nitrogen Gas Laser is appropriate home built lasers because of multiple advantages. The first advantage is the nitrogen gas availablibility in abundance within the atmosphere. The second is its economical advantage that cylinders can be purchased locally at affordable cost and vacuum system is not essential which reduces additional cost. It works at atmospheric pressure as well as low pressures. Another advantage is, it does not require noble gas which is usually essential in other gas lasers. Nitrogen gas laser also has another advantage. It can operate in super radiance mode with high gain so that mirrors are not required. When power source is considered, power supply units from television or computer monitors or other appliances can be used. Comparatively, it can be operated in self triggered as well as triggered mode. Another most important feature of nitrogen gas laser is its construction. It is very easy to construct. However, mylar dielectric may not be easily available that can be purchased from potential suppliers or retailers (Mark Csele, Fundamentals of light sources and lasers, John Wiley 2004, Kau *et al*., 2004; The Application of Nitrogen Laser on Extraction of Uranium in The Long Life of High Level Radioactive Liquid Waste Using TBP-Kerosene Solvent, 2012; Design and Fabrication of Prototype Transversely Excited Atmospheric (TEA) Nitrogen Laser, Mukhtar Hussain, 2012).

Table 2.1. Spectroscopic properties of UV laser transition and gas mixture composition in nitrogen and KrF Lasers (34) Properties

Properties		
Laser Type	N_2	(KrF)*
Laser wave length (nm)	337.1	48
Cross section (10^{-14} cm^2)	40	0.05
Upper state life time (ns)	40	10
Lowe state life time (ns)	10 μs	
Transition line width (THz)	0.25	3
Partial Pressure of gas mixture (mbr)	40(N_2) 960(He)	120(Kr) 6(F_2)
		2400(He)

2. Review of different Result Analysis of Nitrogen Laser

As long as nitrogen lasers have been in the field, theoretical and experimental investigations on various parameters and electronic discharge circuit designs continue in order to improve their efficiencies. Thus, following the previous work done in (Lee *et al*., 1985; Gholap *et al*., 1997; Orazio Svelto, 4th edition; Iwasaki and Jitsuno, 1982; Richter *et al*., 1976; Chang, 1985; Farooq Kyeyune, 2011; Svelto, 2009; Kasap,1999; Mark Csele, 2004; Gunandjar at Radioactive Waste Technology Centre, National Nuclear Energy Agency of Indonesia (BATAN) Kawasan Puspiptek Serpong, Tangerang, Banten-Indonesia, 15310; Atezhev *et al*., 2004), it has been shown that nitrogen lasers operate efficiently, depending on a fast discharge circuit to provide a high voltage across the laser tube, anterior to the gas breakdown which is gas condition (flow and pressure), the charging voltage, the electrode profiles, the inter electrode spacing, the capacitance relation of the two capacitance and circuit designing which more associated with Blumlein circuit. If we look at some of the works, the research which is conducted by A. Vazquezmartinez and V.Aboites they found that 0.8 % efficient nitrogen laser in that time. Now starting from and regard to design like by Kamal H. Latif, Wissam H. Mahdi they construct V-Shape

Electrodes Nitrogen Laser and they found best result by applying voltage 10 KV, gas pressure 60 mbar, electrode spacing 1 cm, and repetition rate 1 PPs, no gas flow and E/P ratio 222 V / (cm.torr). And similar modeling by Melak Gedefe unpublished paper which is done 2011 was done but on his was done by another different researchers and no new thing was done. By may self in 2013 I did a computational experiment on analysis of two channel sequential nitrogen laser circuit which is an additional another channel than common Blumlien circuit and the result what I found was appreciable that it can absorb more power for creation of better lasing action (Analysis of two channel sequential nitrogen laser, Solomon Zerihun). Regards to application of nitrogen laser different scholars put different suggestions on application of nitrogen lasers like The Application of Nitrogen Laser on extraction of uranium in the long life of high Level radioactive liquid waste using TBP-Kerosene solvent (Gunandjar at Radioactive Waste Technology Centre, National Nuclear Energy Agency of Indonesia (BATAN) Kawasan Puspiptek Serpong, Tangerang, Banten-Indonesia, 15310). Based on the work of Kamal H. Latif, Wissam H. Mahdi on their work of Construction of V-Shape Electrodes they come to the conclusion of one of the most important parts of the N2 laser system is the shape of the electrodes. The V-shape electrodes is a good choice because of the high current density produced inside the laser channel can be acted as pre ionization then fast rise time of voltage and current pulse. The discharge parameters have been studied experimentally and concluded that: The peak laser power increases with applied voltage until reach certain value, the output will decrease. There is an optimum value of gas pressure gives the maximum peak laser power. The optimum value of the E/P ratio has been measured by determining the maximum value of peak laser power, and then dropping vertically on the X-axis. The output laser takes a somewhat saturated value when the capacitance of storage–side capacitor C_1 is in excess of that of switch side capacitor C_2; ($C_2 \leq C_1$). The output laser decreases when the capacitance of switch side capacitor C2 in excess that of storage –side capacitor C_1; ($C_2 \geq C_1$). Provided that $C_1 = C_2 = C_o$, although the laser output increase with Co (The Application of Nitrogen Laser on Extraction of Uranium in The Long Life of High Level Radioactive Liquid Waste Using TBP-Kerosene Solvent, 2012).

3. Conclusion

Light amplification by stimulated emission of radiation (laser) is widely used in medicine, agriculture, military, security, laboratories and research activities. From different types of lasers; gas laser is commonly used of which nitrogen laser is emerging. In the frame of the present work, a detailed review of the principles behind laser action is summarized. It provides a background to understanding of the necessary conditions for lasing to take place, the population inversion. Unlike other gas lasers, nitrogen lasers have a shorter transition lifetime for the upper lasing level than the lower lasing level. Thus to create a higher population of the gas molecules at the upper. Lasing level requires sufficient power to excite the gas molecules to the upper level as fast as possible. Beside of that in terms of its economical advantage and availability of materials nitrogen laser is preferable other than other gas lasers. It is easy to construct and materials needed to construct the laser circuit is available like power supply from any old TV or computer monitors, source is from atmosphere which is nitrogen gas, no need of noble just like other gas lasers, and it can be operate in self triggered as well as triggered mode and because of this one we call sometimes nitrogen laser is a home built laser.

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