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LASERS FOR AP-MINE NEUTRALISATION

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According to UN estimations there are about 80–115 million landmines activated worldwide. The most common explosive in these mines is trinitrotoluene (TNT). In this paper the potential of some most promising lasers for mine neutralisation based on spectroscopic measurements is investigated. We have studied the interaction between ArF, KrF and Nd:YAG laser beams and a bare solid sample of approximately 25 mg TNT. With the pulsed ArF radiation ablation of the TNT without any deflagration has been achieved. With the KrF excimer radiation the TNT started melting and burning. Experiments with a Nd:YAG solid-state laser operating in cw emission have shown the desired burning process of the irradiated sample even after stopping the exposure. Further experiments have shown the influence of the mine case material.

INTRODUCTION

In approximately 70 countries of the world [1] landmines have become a problem and a daily threat. Mines and other unexploded ordnance (UXO) that are mostly triggered accidentally are killing or injuring more than 2000 civilians per month worldwide. There exist a broad range of different types of antipersonnel-mines (AP-mines) [2] but mostly trinitrotoluene (TNT) is used as explosive charge. TNT has some specific properties that made it a nearly ideal explosive for this application. The most desired properties are its strength and brisance, its low melting point of 80.8 °C that makes it easy to cast into different forms. Its chemical stability and its relatively high impact insensitivity are also very desired. The strength of TNT is about a factor of 0.6 the one of dynamite or nitro-glycerine but the impact sensitivity is around 15 and 75 times lower, respectively [3].

There exist different ways to clear detected mines. For military purposes the duration of the mine clearance is much more important than a total clearance and a destroyed environment is accepted. In contrast to that in humanitarian demining a nearly total mine clearance is aspired. After the clearance the land should in general be useful for agriculture. Neutralisation of mines is normally a very delicate and dangerous operation, whereby the deminers are forced to be in immediate contact with the mines. Lasers offer the potential advantage that neutralisation from a safe distance is possible and nearly independent of

the mines triggering mode. The possibility of low order neutralisation of mines, that means that the explosive used in mines does not detonate but only deflagrate, is another advantage.

In this paper the interaction between the emission of some promising lasers based on spectroscopic measurements, TNT and some case materials is investigated.

SPECTROSCOPY

Fig. 1 shows the solid TNT transmission spectrum in the IR range from 4400 cm^{-1} (2.3 μm) to 450 cm^{-1} (22.2 μm).

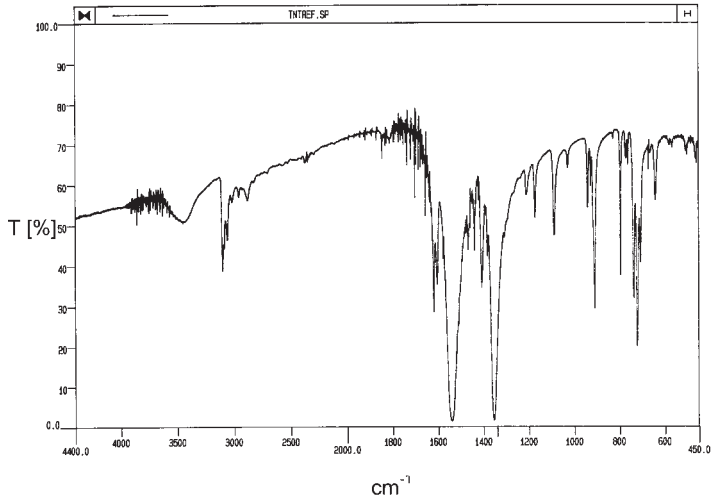

Figure 1: Transmission spectrum of solid TNT with KBr pressed into tablets.

The spectrum shows some typical absorption regimes: an aromatic substance is characterized by the absorptions around 3000 cm^{-1}, 1450 cm^{-1} and 700 cm^{-1} [4, 5]. The most intense lines around 1530 cm^{-1} and 1350 cm^{-1} are given by C-NO_2 asymmetric stretching vibrations and C-NO_2 symmetric stretching vibrations, respectively. Unfortunately at these wavelengths there exist no suitable, powerful laser sources.

Beneath 2.3 μm it is not possible to measure the absorption of solid TNT pressed into KBr wafers, therefore 0.1 g of solid TNT is dissolved in 25 ml of three different solvents, namely acetone, toluene or benzene, respectively. TNT is essentially transparent from 4400 cm^{-1} throughout the visible range. Figure 2 shows the absorption of pure toluene and the one of TNT dissolved in toluene in the UV region.

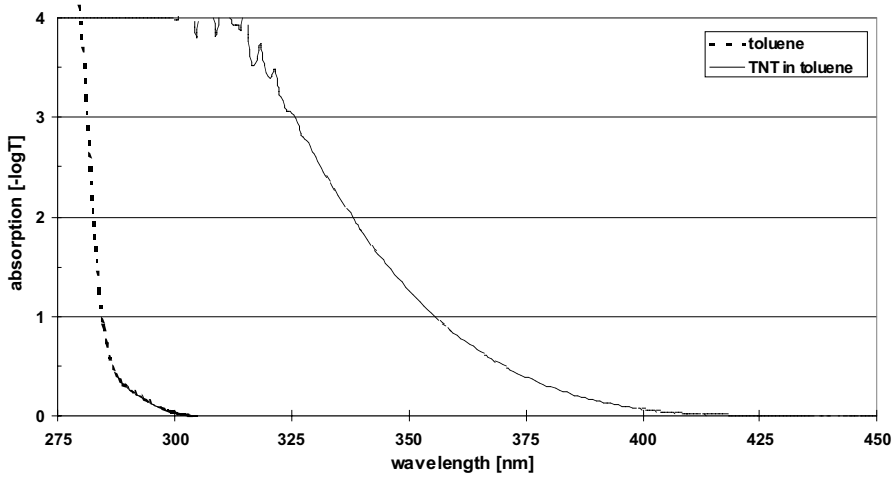

Figure 2: Absorption spectra of toluene and TNT dissolved in toluene.

Toluene absorbs at wavelengths shorter than 300 nm. It is clearly visible, that there is absorption already at wavelengths shorter than 400 nm if TNT is dissolved in toluene. This absorption in the UV region has been used for the first experiments with an ArF and a KrF excimer laser emitting at λ = 193 nm and λ = 248 nm, respectively.

EXCIMERLASER

ArF

With the ArF excimer laser (Lambda Physik LPX300) interaction between pulsed laser light with an energy density up to 650 mJ/mm^2 and a 10 mg solid TNT sample is investigated. The energy is measured with a pyroelectrical joule meter (gentec ED-200). The laser beam is focussed by a lens with a focal length of 150 mm to a spot size of 1.24 x 0.53 mm^2. The focal length and spot size are varied with a second lens with f = 75 mm. The pulse frequency is varied from 1 to 15 Hz and the average pulse duration (FWHM) is 20 ns. The TNT sample is placed behind a protection shield in case of detonation during irradiation.

Already with a relatively small energy density of 6 mJ/mm^2 per pulse and a frequency of 5 Hz ablation is achieved. Ablation increases with the frequency and the number of interacting pulses even if the energy density decreases. Rising the frequency to 10 Hz reduces the ablation threshold to an energy density of 4.3 mJ/mm^2. Fig. 3 shows a sample, which has been irradiated during 1 minute at a pulse frequency of 10 Hz.

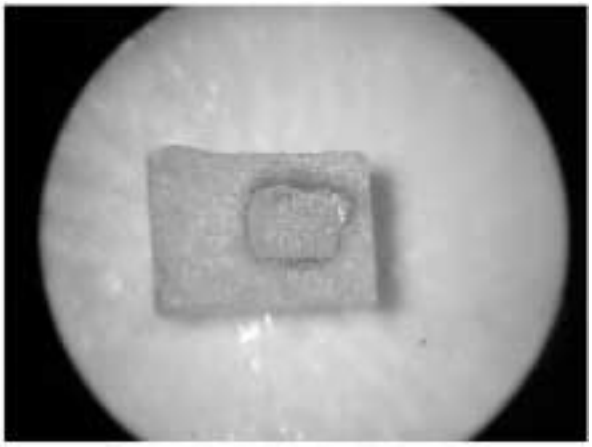

Figure 3. Ablation of TNT (sample surface dimensions are 3 x 2 mm^2) after ArF excimer laser irradiation during 1 minute at 10 Hz.

The spot size and the interacting zone are clearly visible. At the surrounding of the ablation zone the sample is burnt. Although a plasma is created at the sample surface, neither detonation nor deflagration occurs. As shown in Fig. 4 with 17 mJ pulses (37.3 mJ/mm^2) during approximately 1 minute it is possible to drill a hole into the TNT sample. Further increasing of the pulse energy leads to cracking of the TNT sample.

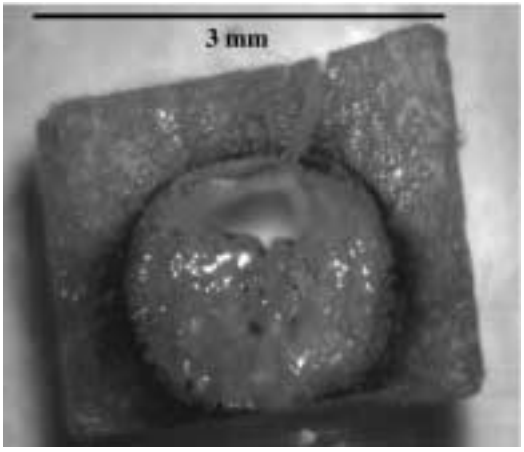

Figure 4. With ArF excimer laser irradiation (17 mJ pulses during 1 minute) drilled hole in TNT.

KrF

For the experiments with the KrF excimer laser emitting at λ = 248 nm the same equipment and experimental setup as for the ArF experiments is used. The frequency is varied from 1 to 10 Hz; the average pulse duration is 30 ns. If the sample is placed in the beam spot, the energy density is around 1 J/mm^2. Under this irradiation the sample cracks after 2 shots. With energy of 207 mJ (7.4 mJ/mm^2) per pulse and a repetition rate of 1 Hz no variation in the sample surface is visible. Increasing the rate to 5 Hz leads to a completely different result. The sample begins to melt and burn after an exposure time of approximately 10 s. Interrupting the irradiation stops melting and burning.

Nd:YAG SOLID-STATE LASER

Despite of the weak absorption at 1060 nm but encouraged by the results with higher repetition rate of the excimer lasers experiments with a cw Nd:YAG and a 25 mg sample of solid TNT is performed. The beam is focused by a lens with a focal length of 308 mm to a spot size of about 0.8 x 1 mm^2 and the incident power on the sample is varied up to 32 W. To investigate the behaviour of different case materials, the TNT sample is placed on different material layers, namely, mica, glass, perspex, dyed polyvinyl and steel plate. In first experiments the TNT sample is placed on an approximately 1 mm layer of mica to reduce heat conductivity out of the irradiated sample. After approximately 3 seconds of irradiation by an incident power of approximately 15 W the bare sample begins to melt and a burning process occurs. It is clearly visible, that the burning process starts in the molten TNT. Even after stopping the exposure the sample completely burns up. Is the TNT placed on a glass or perspex layer, the sample melts but does not begin to burn during irradiation up to 32 W. The molten TNT forms a thin layer. The absorption of this thin layer seems not to be high enough to deposit the necessary energy for reaching the flash point. In contrast to this behaviour the reaction of the explosive is completely different, if it is placed on the dyed polyvinyl or 0.5 mm thick steel plate. On the polyvinyl the TNT sample melts and burns after an irradiation time of approximately 0.5 seconds (see Fig 5 a–d). Also on the steel plate a fast melting of the sample followed by a burning process is achieved. If a TNT sample on a glass layer is covered with a dyed polyvinyl sheet (3 x 3 x 2.5 mm^3) and exposed to the 32 W irradiation a burning process occurs and the TNT burns up completely.

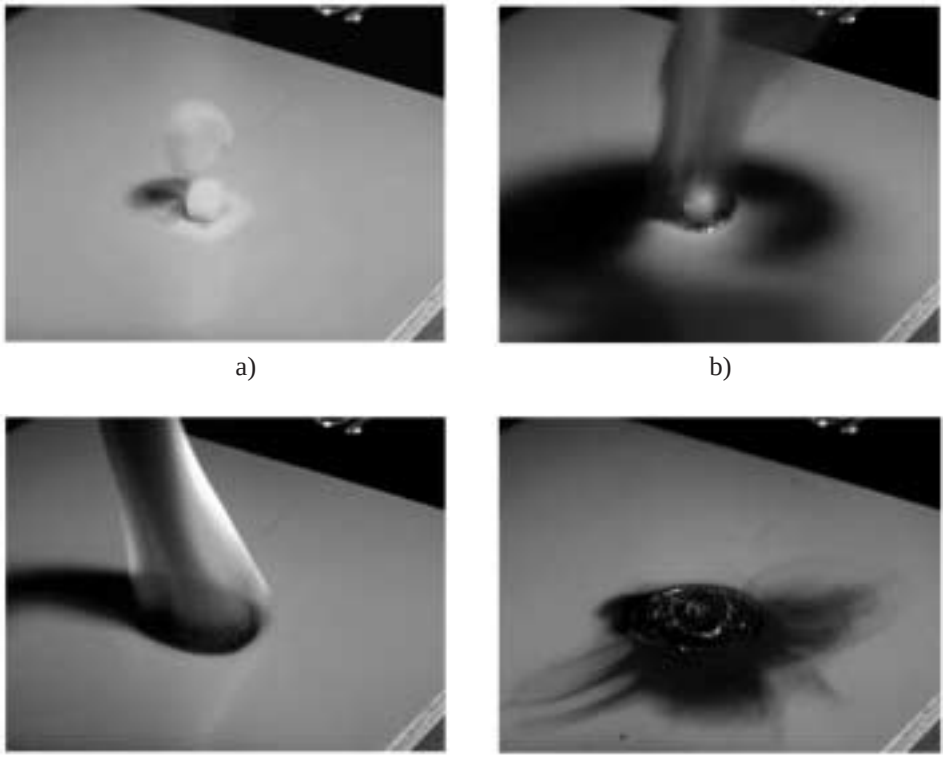

Figure 5 a-d: Deflagration of TNT on dyed polyvinyl.

DISCUSSION

With the aim of low order neutralisation of AP-mines in view, laser treatment of TNT samples at λ = 248 nm with a KrF excimer laser shows more desirable results than treatment at λ = 193 nm with an ArF excimer laser in the same setup. With the same repetition rate of 5 Hz and approximately the same energy density on the surface of the TNT sample, the reaction of the TNT is different. Under ArF pulses ablation occurs while under KrF irradiation the heat deposited in the TNT is high enough to start melting and burning the sample. After each pulse, the visible flame disappears. The duration of the KrF pulses of 30 ns is approximately 1.5 times longer than the duration of the ArF pulses. This longer interaction time could be a reason for different behaviour under equal conditions. The irradiation with a cw Nd:YAG laser shows, that the interaction time of the laser beam with a TNT sample and the larger heated volume is more important than the exact spectroscopic match of TNT absorption and laser emission. The experiments with different layers show, that the case of the TNT is important to obtain the desired burning process. If the case does not absorb Nd:YAG radiation and is therefore not sufficiently heated up. So, in

our setup the small sample of TNT does not burn. Normally the AP-mine case is made out of some synthetic material that is difficult to detect by available detectors. For laser neutralisation of such mines this case is an advantage due to its higher absorption of 1060 nm laser radiation than the pure TNT.

CONCLUSION

In conclusion, we have investigated three of the most promising lasers for mine neutralisation based on spectroscopic measurement of TNT. TNT is the most common used explosive in mines. The interaction between pulsed excimer laser at two different wavelengths of λ = 192 nm (ArF) and λ = 248 nm (KrF), a cw solid-state laser (Nd:YAG) at λ = 1064 nm and a bare sample of TNT has been studied. We have varied the repetition rate of the pulsed excimer lasers in a range from 1 to 15 Hz, the energy density up to approximately 1 J/mm^2 as well as the exposure time. Under ArF laser irradiation with relatively low energy densities of several millijoules it has already been possible to drill a hole into the explosive by ablation of TNT. The repetition rate was 10 Hz and the measured pulse duration 20 ns. The ablation increased with number of interacting pluses and the repetition rate. With radiation of a wavelength of λ = 248 nm a melting process of the TNT sample but no detonation has been observed. We have further shown, that with a cw emission of a Nd:YAG laser at λ = 1064 nm, despite of a relatively low absorption of the TNT in that range, the sample completely burnt up even after stopping the laser treatment.

Acknowledgements

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