文章编号：1006-9941(2008)05-0599-04

Extinction Performance of Nano-Ni Powder to 1.06 μm and 10.6 μm Laser

LIU Xiang-cui, ZHENG Wei-ping

(*Research Institute of Chemical Defense*, *Beijing* 102205, *China*)

Abstract: The extinction performance of 30 g nano-Ni powder smoke to 1.06 μm and 10.6 μm laser were tested in 20 m^3 smoke chamber. Its mass extinction coefficient is 1.542 and 1.078 $m^2 \cdot g^{-1}$ respectively, and the sedimentation rate is 1.035×10^{-3} $m \cdot s^{-1}$. Compared with the smoke performance of conventional materials such as HC, RP, oil, graphite, carbon black, nano-Ni powder smoke has better extinction capability to 1.06 μm and 10.6 μm laser and possesses the better suspending characteristic in the air.

Key words: military chemistry and pyrotechnics technology; nano-Ni powder; laser; smoke; extinction coefficient; sedimentation rate

CLC number: TJ53; TQ567.5 **Document code**: A

1 Introduction

In recent years, the laser-guided weapon has been widely used in modern warfare because of its high precision. Since smoke can weaken the energy of incident laser and reduce its efficiency by scattering and absorbability, it becomes a reliable and effective passive interference means to the laser-guided system[1-2]. At the same time, exploiting and using new obscurant materials is one of the important factors which develop smoke technology.

Although the conventional metal powder has satisfactory wave-absorbing property[3-4], it is not suitable for smoke composition, because it has great sedimentation rate in the air due to its big particle size and specific gravity. Compared with those conventional materials, nanostructured materials, often characterized by a physical dimension of 1 - 100 nm (such as grain size) and a significant amount of surfaces and interfaces, have been attracting much interest around the world because of their demonstrated or anticipated unique properties[5]. For example, many nanostructured materials exhibit excellent wave-absorbing ability in broad band and have been widely used in camouflage paints[6]. Furthermore, As obscurant materials, they may improve the extinction and suspending characteristics of smoke.

Received Date: 2008-07-23; **Revised Date**: 2008-09-09

Corresponding Author: LIU Xiang-cui, e-mail: liuxiangcui2001@yahoo.com.cn

In this paper, nano-Ni powder, as a new smoke material, was tested in 20 m^3 smoke chamber for its extinction performance to 1.06 μm and 10.6 μm laser.

2 Experiments

2.1 Materials

The nano-Ni powder sample[7-8], as the smoke material, is sphericity. Its particle size is 20 ~ 70nm with average diameter of 47nm and specific surface area of 14.23 nm. Its purity is 98.24%. The transmission electron microscope (TEM) photo of sample, magnified to 100 thousand times, is shown in Fig. 1.

Fig. 1 TEM of nano-Ni powder

2.2 Experimental apparatuses

The smoke chamber is 6.1 m × 2.0 m × 1.8 m, and the effective volume is 20 m^3, including weighing, spraying, stirring and sampling equipments (see Fig. 2).

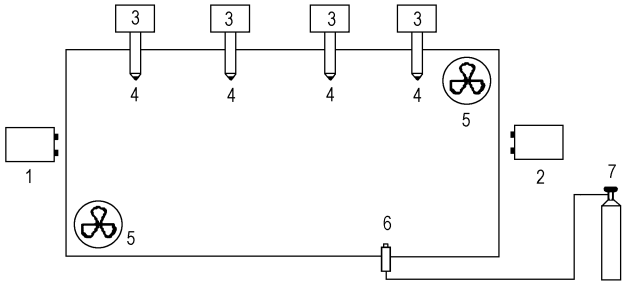


Fig. 2 Sketch of smoke chamber

1,2—dual laser testing system, 3—air pump,

4—sampling head of mass concentration,

5—mixing fan, 6—spray nozzle, 7—air compressor

Output wavelengths of dual laser testing system is 1.06 μm with over 50 mW average power export and 10.6 μm with over 10 W average power export. Transmittance rate is directly collected and displayed per second by the signal control system.

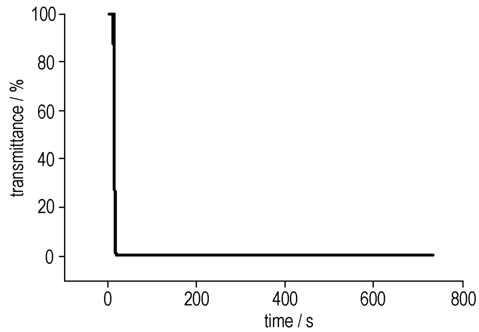
2.3 Experimental methods

All the experiments were finished in 20 m^3 smoke chamber. After the emitter and the receiver of laser were adjusted, the transmittance rate of background was collected. 30 g nano-Ni powder was sprayed into the smoke chamber by the spray nozzle with high-pressure air. At the same time, two mixing fans were operated continuously 20 s at a low speed to maintain uniform concentration. After the laser signal passed the smoke, its power data were collected. The sampling device was worked to make smoke concentration measurements at a flow rate of 40 $L \cdot min^{-1}$. In the end, opened the door of smoke chamber and started up the exhaust set to exhaust the remainder smoke particles.

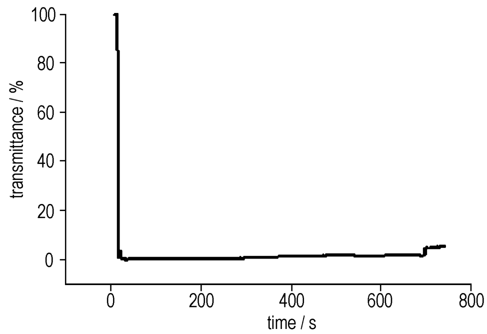
3 Results and discussion

3.1 Transmittance rate

Fig. 3 shows the transmittance rates of nano-Ni powder smoke to 1.06 μm and 10.6 μm laser. From that, the transmittance rates drop sharply and rapidly reach the minimum of less than 1% with the spraying of nano-Ni powder. It indicates that, as the time goes by, the transmittance rates of nano-Ni powder smoke to dual laser increase slowly and smoothly. Generally speaking, attenuation of nano-Ni powder to 1.06 μm laser is better than that to 10.6 μm laser. Because the particle size of nano-Ni powder is much smaller than the wavelength of laser, and the incident laser radiation obeys Rayleigh scattering law[9], that is, scattering light intensity I_s is inversely proportional to the biquadrate of incident light wavelength λ: $I_s \propto 1/\lambda^4$. And the shorter λ is, the more intensive the scattering effect is. Then the extinction effect of nano-Ni powder to 1.06 μm laser is better than that to 10.6 μm laser.



a. 1.06 μm laser



b. 10.6 μm laser

Fig. 3 Curves of the transmittance rate of nano-Ni powder to 1.06 μm and 10.6 μm laser

3.2 Mass extinction coefficient

The bigger mass extinction coefficient α ($m^2 \cdot g^{-1}$) is, the better the attenuation effect is. The line-of-sight attenuation of incident laser radiation, I_0, as a function of α, mass concentration C_m, and pathlength L (L = 6.1 m), is given by

$$I_s = I_0 \exp(-\alpha C_m L) \quad (1)$$

Where I_s is the transmitted intensity, equivalently expressed in the terms of the transmittance rate T as Lambert-Beer law

$$T = I_s / I_0 = \exp(-\alpha C_m L) \quad (2)$$

Formula (2) shows that T is depended on α if the mass concentration and thickness of smoke are fixed values. Therefore, α is one of the most important performance parameters that are used to judge smoke performance of a material. By means of formula (2), α is given by

$$\alpha = \frac{1}{C_m L} \ln \frac{1}{T} \tag{3}$$

3.3 Mass concentration

Pumping a certain volume of smoke, smoke particles are collected onto glass fiber filters that have been weighed beforehand. In formula (3), the mass concentration C_m is calculated by means of expression (4)

$$C_m = \frac{w - w_1}{v} = \frac{w - w_1}{Q \cdot t} \tag{4}$$

Where w_1 is the pure filter mass, w is the filter mass after catching smoke particles, v is pumped smoke volume, Q is the flow rate of rotometer (40 L · min^{-1}), t is the sampling time (1 min).

Drawing on expression (4), the average C_m of smoke in different time was computed, and the transmittance rate of sampling intervals was averaged, which was used in formula (3) to obtain the mass extinction coefficient of different intervals, as shown in Table 1.

Table 1　Mass extinction coefficients of nano-Ni powder to 1.06 μm and 10.6 μm laser

time /min	C_m /g · m^{-3}	1.06 μm			10.6 μm		
		T/%	α /m^2 · g^{-1}	$\bar{\alpha}$ /m^2 · g^{-1}	T/%	α /m^2 · g^{-1}	$\bar{\alpha}$ /m^2 · g^{-1}
1 ~ 2	0.870	0.0370	1.489	1.542	0.209	1.163	1.078
4 ~ 5	0.812	0.0370	1.595		0.728	0.994	

Note: $\bar{\alpha}$ is the average of α.

From Table 1, the mass extinction coefficients of nano-Ni powder smoke to 1.06 μm and 10.6 μm laser are above 1 m^2 · g^{-1}, and remarkably higher than that of conventional halogenated organic compound (HC), red phosphorus (RP), oil, graphite, carbon black in References [10 – 15] (as shown in Table 2). This is because nano-Ni powder has a smaller particle size and larger specific surface area which is over a thousand times greater than powders commercially available. Excessive atoms activity, consequently, nano-Ni powder exhibits remarkable wave-absorbing ability and excellent extinction performance.

3.4 Sedimentation rate

The suspending characteristic of smoke is directly related to the sedimentation rate, which is obtained from

Table 2　Mass extinction coefficients of the conventional smoke compositions on electromagnetic wave

	1.06 μm	10.6 μm	8 ~ 14 μm
HC[10]	–	–	≈0.1
oil[11]	–	0.1664	–
RP[12 – 13]	–	<0.7	–
graphite[14]	0.67	–	0.70
carbon black[15]	–	–	0.62

sedimentation rate. And the better the suspending characteristic of smoke is, the longer the valid interference time of smoke is. The sedimentation rate V_d is calculated by the formula (5)[16]:

$$V_d = \frac{H}{t_2 - t_1} \cdot \ln \frac{C_1(t_1)}{C_2(t_2)} \tag{5}$$

Where H is the height of smoke (H = 1.8 m), $C_1(t_1)$ is the mass concentration at t_1, $C_2(t_2)$ is the mass concentration at t_2. By formula (5), the V_d of nano-Ni powder smoke was obtained as 1.035×10^{-3} m · s^{-1}, lower than that of the materials in References [17 – 19] (as shown in Table 3). It indicats nano-Ni powder smoke has good suspending characteristic in the air. This is mainly because the bigger aerosol size is, the more rapidly it descends. If the particle radius is under 1 μm, the sedimentation rate is reduced by 2 orders of magnitude when the radius is reduced by 1 order of magnitude[9]. Consequently, as smoke composition, nano-Ni powder increases the suspended time of smoke.

Table 3　Sedimentation rate of some materials

materials	copper powder 800 mesh[17]	sample 1[18]	sample E[19]
V_d/m · s^{-1}	3.44×10^{-3}	2.68×10^{-3}	2.33×10^{-3}

Notes: V_d of sample 1 in reference 18 or sample E in reference 19 is minimum among all samples. The particle size of sample E in reference 18 is about 1 μm. The properties of sample 1 in reference 19 are unknown.

4 Conclusions

The experimental results show that, nano-Ni powder, as a new obscurant material, effectively interferes with 1.06 μm and 10.6 μm laser, and has excellent extinction capability. The mass extinction coefficients to 1.06 μm and 10.6 μm laser are above 1 m^2 · g^{-1}, furthermore, it possesses the outstanding suspending characteristic in the air.

References:

[1] CHEN Li, LI Tao, LI Qing. Influence of smoke curtain on laser guidance weapon[J]. *Tactical Missile Technology*, 2004(4): 66-67.

[2] ZHANG Hong-bin, SU Wu-xing, ZHANG Xiang-jun, et al. Passive laser interference and its present development[J]. *Infrared*, 2005(7): 13-17.

[3] WANG Hai. Studying status and developing trend of radar wave-absorbing materials[J]. *Aerospace Shanghai*, 1999, 1: 55-59.

[4] LIU Xiang-xuan, WANG Xuan-jun. Status and development of radar wave absorber[J]. *Modern Defence Technology*, 2003, 31(3): 55-58, 64.

[5] Carl C. Koch. Nanostructured Materials: Processing, Properties and Potential Applications[M]. Norwich, New York, USA: Noyes Publications/William Andrew Publishing, 2002: 3.

[6] ZHANG Li-de, MU Ji-mei. Nanostructured Materials[M]. Beijing: Science Press, 2001: 516-519.

[7] WEI Zhi-qiang, QIAO Hong-xia, DAI Jian-feng, et al. Characterization of Ni Nanopowders by Anodic Arc Plasma[J]. *Rare Metal Materials and Engineering*, 2005, 34(9): 1415-1418.

[8] WEI Zhi-qiang, XIA Tian-dong, DAI Jian-feng, et al. Particle Size Characterization of Ni Nanopowders Grown by Anodic Arc Plasma[J]. *Journal of Vacuum Science and Technology*, 2005, 25(6): 418-421, 443.

[9] PAN Gong-pei, YANG Shuo. Principles of Pyrotechnics[M]. Beijing: Beijing Institute of Technology Press, 1997.

[10] WANG Xuan-yu, PAN Gong-pei. New type of anti-infrared smoke agent based upon halogenated organic compound[J]. *Chinese Journal of Energetic Materials* (*Hanneng Cailiao*), 2005, 13(3): 173-178.

[11] AN Gang, WANG Xuan-yu, YU Shi-kui, et al. Study of oil smoke-screen in anti-10.6 μm laser Performance[J]. *Laser & Infrared*, 2007, 37(3): 266-267.

[12] WANG Xuan-yu, PAN Gong-pei. Study of the extinction ability of several kinds of smoke to CO_2 laser emission[J]. *Laser & Infrared*, 2006, 36(2): 144-146.

[13] WANG Xuan-yu, PAN Gong-pei. Study and test of extinction coefficient of red phosphorus smoke to 10.6 μm laser emission[J]. *Infrared and Laser Engineering*, 2005, 34(6): 636-640.

[14] REN Hui, JIAO Qing-jie, CUI Qing-zhong. Research on $CuCl_2$-$FeCl_3$-GIC used as aerosol material to interfere military apparatus in the range of infrared and MWM[J]. *Ordnance Material Science and Engineering*, 2005, 28(5): 7-10.

[15] J C Owrutsky, D A Steinhurst, H D Ladouceur, et al. Obscurants for infrared countermeasures Ⅲ[R]. ADA387724, March 9, 2001.

[16] ZHOU Zun-ning. Composition design and application research on pyrotechnic anti-infrareds moke agent[D]. Nanjing: Nanjing University of Science & Technology, 2003.

[17] YIN Xi-feng, CHEN Yu-zhong, CHEN Hong-da, et al. Study on the affecting factors on the performance of smoke agent based on copper powder[J]. *Initiators & Pyrotechnics*, 2003(4): 5-8, 44.

[18] ZHOU Zun-ning, PAN Gong-pei, LI Yi. Testing and calculating methods of instantaneous mass concentration of IR smoke in smoke chamber. The 11th Initiator & Pyrotechnics Academic Annual Meeting of COS[C]// Initiator & Pyrotechnics Academic Committee of COS, Beihai, China, 2001(5): 349-353.

[19] ZHOU Zun-ning, PAN Gong-pei, LI Yi, et al. Experimental research of the influence of adding RP on smoke characteristic of modified HC[J]. *Chinese Journal of Energetic Materials* (*Hanneng Cailiao*), 2002, 10(3): 128-131.

纳米镍粉对1.06 μm和10.6 μm激光的消光性能研究

刘香翠, 郑卫平

(防化研究院, 北京 102205)

摘要: 在容积为20 m^3 的烟幕箱中测试了30 g纳米镍粉形成的烟幕对1.06 μm和10.6 μm激光的消光性能。其质量消光系数分别为1.542 $m^2 \cdot g^{-1}$、1.078 $m^2 \cdot g^{-1}$,沉降速度为 1.035×10^{-3} $m \cdot s^{-1}$,与常规材料的烟幕性能比较表明,纳米镍粉形成的烟幕消光性能好,悬浮时间长,是一种能有效干扰1.06 μm和10.6 μm激光的新型烟幕材料。

关键词: 烟火技术; 纳米镍粉; 激光; 烟幕; 消光系数; 沉降速度

中图分类号: TJ53; TQ567.5 **文献标识码:** A