# An effective design method for trapezoidal pulse compression metal multilayer dielectric gratings

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***Abstract* - Metal multilayer dielectric gratings (MMDGs) for pulse compressors used in high-energy laser systems should enable high efficiency, as well as provide broad bandwidths and high laser-induced damage thresholds. The effects of duty cycle and the ridge slope angle on the MMDG bandwidth is investigated. Keeping all other parameters constant, the bandwidth remains nearly the same with increasing duty cycle and decreasing slope angle. Importantly, the results show a linear relationship between the duty cycle and slope angle of the large bandwidth MMDG. The trapezoidal MMDG designs can be obtained base on the linear relationship and a optimize rectangle grating result. A 200 nm bandwidth (from 700 nm to 900nm) MMDG with efficiency exceeding 90% is obtained using the method. This method can be effectively used in the design of pulse compression grating.**

***Index Terms* - *Diffraction and gratings, Rigorous coupled-waves analysis, Pulse compression, Thin films.***

## I. INTRODUCTION

In high-energy pulse laser systems, chirped pulse amplification (CPA) [1] is an important method for improving the short pulse output intensity. The grating compressor is one of the most critical components of a high power CPA laser system. To improve the output coefficient of laser energy, the pulse compression grating should satisfy the requirements of high diffraction efficiency, high laser-induced damage threshold, and wide bandwidth. The metal multi-layer dielectric grating (MMDG) [2,3] exhibits high diffraction efficiency and wide bandwidth. Thus, the MMDG is an ideal candidate for the realization of a broadband pulse compression grating. And most broad bandwidth design is rectangle ridge grating. But perfect rectangle grating ridge fabrication is difficult, most of the time the grating ridge is trapezoid. Different from rectangle gratings , in the calculation the trapezoidal grating ridge is divided into a stack of layers rectangular lamellar gratings with equal thickness. To ensure the precision of the calculated results, a sufficient number of layers required for the approximation of the trapezoidal grating ridge. The trapezoidal grating optimization is low efficient and time consuming. In this paper, we present a new method of the trapezoidal grating design. The trapezoidal MMDG designs can be obtained base on the linear relationship and a optimize rectangle grating result.

## II. NUMERICAL CALCULATIONS AND DISCUSSION

As shown in Fig. 1 (a) and (b), the 800nm broad bandwidth multilayer dielectric grating (MDG) [4,5] consists of the surface-relief grating, a matching layer, a multilayer dielectric HR mirror and the substrate. For convenient manufacturing, the most common form of the multilayer dielectric HR stack is chosen as $(HL)^9H$, where H and L denote the high-index ($Ta_2O_5$, $n_H$ :2.04) layer and the low-index ($SiO_2$, $n_L$ :1.46) layer, respectively. The diffraction efficiency is calculated by RCWA. The slope angle is defined as the corner between the sidewall of the gratings and its bottom margin. As shown in Fig. 1 (c), keeping all other parameters constant, the bandwidth remains nearly the same with increasing duty cycle and decreasing slope angle. The data are put together, and a linear relationship between the duty cycle and slope angle is shown in Fig. 1 (d). The duty cycle and slope angle determine the profile of the grating ridge. This means that broad bandwidth trapezoidal grating can be obtained based on a rectangle grating design and the linear relationship.

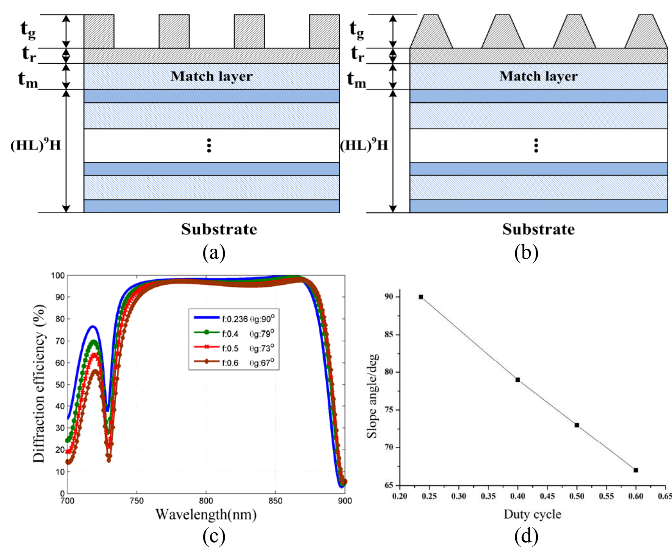


Fig. 1 (a)Structure of a rectangle MDG; (b) Structure of a trapezoidal MDG; (c)Bandwidth of the rectangle and trapezoidal MDGs; (d) A linear relationship between the duty cycle and slope angle

This is a new design method for broad bandwidth trapezoidal grating. The first step, a broad bandwidth rectangle grating optimization design is obtained by using a genetic algorithm . The second step, the linear relationship between the duty cycle and slope angle of the grating should be obtained by fitting calculation data. Base on the linear relationship, the duty cycle and the slope angle of the trapezoidal gratings can be obtained in the line.

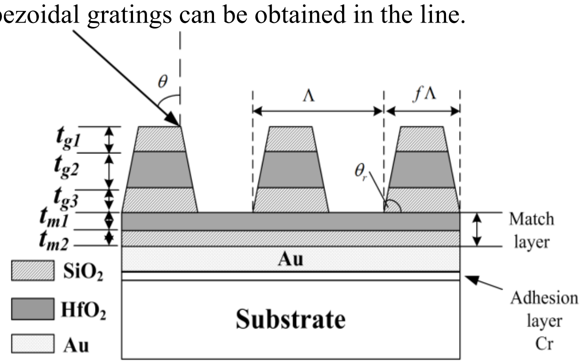


Fig. 2 Structure of a trapezoidal MMDG

The MMDG comprises a grating ridge, a match layer, a metal high-reflection mirror, an adhesion layer, and the substrate. The sandwich structure grating ridge is deposited in the order of L, H, and L with respective thicknesses of $t_{g1}$, $t_{g2}$, and $t_{g3}$. H and L are assumed to be $HfO_2$ (n =1.96) and $SiO_2$ (n=1.44). The match layer is used to connect the metal layer and the grating ridge. The thicknesses of the grating ridge and match layer are tm1 and tm2. Gold is used as the metal layer. MMDG has a broad bandwidth; thus Au dispersion is taken into account in this letter [6]. The Au layer thickness is set to 200 nm, which is sufficient to reflect most incident wave energy. Good adhesion of Au with the substrate over a large area is difficult to achieve. Thus, the substrate is covered by a thin Cr layer (10 nm) for better adhesion, as shown in Fig. 2. The substrate is fused silica. The MMDG period is $\Lambda$ , the duty cycle is f, the slope angle is , and the incident angle is $\theta_r$ . The grating is designed to have a line density of 1740 lines / mm. Thus, the period in this Letter is 574.7 nm, so that the zeroth order and the −1st order in reflection can be obtained, and all other orders are evanescent.

All parameters {*f, $t_{g1}$, $t_{g2}$, $t_{g3}$, $t_{m1}$, $t_{m2}$* } of the rectangle grating after optimization are {0.26, 100 nm, 150 nm, 57 nm, 119 nm, 81 nm}. When the slope angle duty cycle are 89° and 0.27, the bandwidth of the grating is the same as the rectangle grating. The linear relationship between the duty cycle and slope angle of the MMDG is shown in Fig. 3.

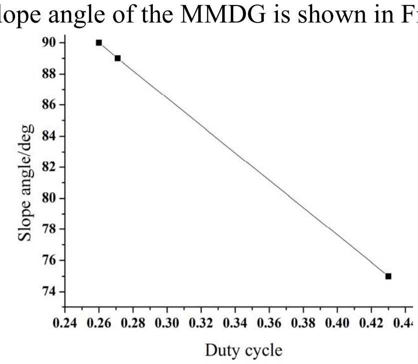


Fig. 3 Linear relationship between the duty cycle and slope angle of the MMDG

The slope angle is 75° based on the grating fabrication requirements. Base on Fig. 3, the corresponding duty cycle is 0.43. A trapezoidal ridge MMDG is designed by a new effective design method.

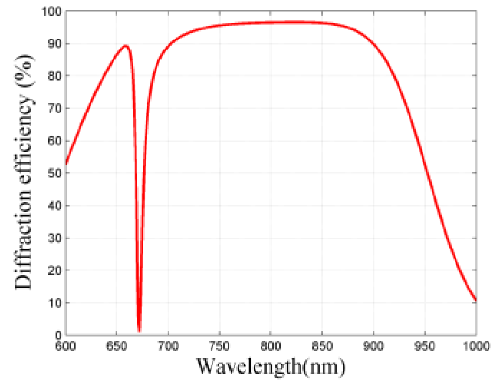


Fig. 4 The bandwidth of the MMDG operating at 800 nm and 53°

The bandwidth of the spectrum with the -1st-order diffraction efficiency greater than 90% is 200 nm-wide (from 700 nm to 900 nm). Up to 137 nm wavelength range (from 738 nm to 875 nm) is obtained with the -1st-order diffraction efficiency exceeding 95%.

## III. CONCLUSION

In conclusion, a trapezoidal ridge MMDG is designed by a new effective design method without low efficient and time consuming. Keeping all other parameters constant, the bandwidth remains nearly the same with increasing duty cycle and decreasing slope angle. Calculation results show a linear relationship between the duty cycle and slope angle of the large bandwidth MMDG. The bandwidth of the designed MMDG reaches 200 nm centered at 800 nm.

## ACKNOWLEDGMENT

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