1.2 TYPES OF THIN FILMS	1.2 CÁC LOẠI MÀNG MỎNG
1.2.1 Classification of Thin Films Coatings	1.2.1 Phân loại màng mỏng Checked 15/4
Thin films are classified in many ways, mainly, according to the materials used for the coatings, the damage threshold, the strength, and the characteristics, etc. There are metallic coatings, and dielectric coatings. The metallic coatings always have lot of absorption	Màng mỏng được phân loại theo nhiều cách, chủ yếu theo vật liệu phủ, ngưỡng hủy hoại, độ bền, và đặc tính, v.v…Có thể có các lớp phủ kim loại và điện môi. Các lớp phủ kim loại luôn luôn có độ hấp thụ mạnh và chỉ có ứng dụng giới hạn. Các lớp phủ

and have only limited applications. The dielectric coatings have practically negligible level of absorption, and hence, are very useful for various applications in optics, e.g., laser systems and imaging instruments. Higher laser damage threshold coatings are useful for high power lasers. The coatings with higher mechanical strength and higher abrasion resistance are used for mechanical tools for increasing their life.	điện môi có mức hấp thụ thực tế không đáng kể, và do đó, rất hữu dụng cho các ứng dụng khác nhau trong quang học, chẳng hạn như các hệ laser và các công cụ ghi ảnh. Các lớp phủ có ngưỡng hủy hoại laser cao hữu dụng cho các laser công suất cao. Các lớp phủ có độ bền cơ học cao và khả năng chống mài mòn cao được sử dụng cho các công cụ cơ để kéo dài tuổi thọ của chúng.
1.3 THINFILMSDESIGN	1.3 THIẾT KẾ MÀNG MỎNG
1.3.1 Designing of Dielectric Coatings The designing of dielectric mirrors is a very interesting and specialised topic, and some important work is done by Willy1, Dobrowolski2,3,et al. and Tikhonravov4. A dielectric coating consists of two or more thin layers of different transparent optical materials. The design is done by considering the Fresnel reflection coefficient from a single interface between two materials and is carried out by keeping in mind the function to be performed by the coated component, e.g., high reflection, anti-reflection (AR), polarisation, chromatic dispersion, beam splitting or filtering, etc. Other parameters to be considered are the operational wavelength range and the desired angle of incidence.	1[redacted]
It is interesting to note that even if the value of the reflection coefficient is small for a particular interface because of small difference of refractive indices of the materials of the layers	[redacted]

surrounding it, it is still possible to obtain a very high overall reflectivity of the component because of the contributions of the reflection from other interfaces, based on constructive interference in a certain wavelength range.

The well known laser mirrors have all the optical layer thicknesses equal to a quarter of thickness of the desired wavelength. The design becomes more complicated if the desired effect is to be obtained in a broader region of wavelengths. For AR coatings, design is based on the destructive interference. It is also possible to design coatings for other specific functions like beam splitting, polarisation, a combination of beam splitting and polarisation, edge filters (like short wave pass filters, long wave pass filters, and band pass filters), a combination of desired reflection properties in different wavelength ranges (like AR at certain wavelengths and high reflection at other wavelengths or vice versa), and chromatic dispersion, i.e., dichroic mirrors.

The design of dielectric coatings is a complete topic in itself, and has to be learnt by the optical design engineer. Here the subject is being introduced and its physics is discussed. It is to be understood that the complexity of the design depends upon the nature and the number of functions to be performed by the coated component. The more complicated the functions, and more the number of functions, the more

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complex is the design. In some cases, the number of layers is small (3 to ~21), and in some cases, it can be very high indeed (in the vicinity of 100). The design also depends on the difference of the values of refractive indices of the materials of the layers. Resonator mirrors in lasers are mostly dielectric-coated mirrors, as these are free from absorption associated with the metallic coatings, and leading to very high reflection (99.99 per cent or higher). However, these do not give shining lustre like appearance as is the case for metallic mirrors. Instead, they appear transparent, since they have high reflection at a particular wavelength, and also because the materials have negligible absorption.	[redacted]
The reflection properties of a multilayer (ML) mirror can be calculated by matrix method, in which each layer is associated with 2 × 2 matrix, and the matrix of the design is obtained by multiplying together the matrices of all the layers. The resultant matrix can be used to calculate the complex amplitudes of the reflected and the transmitted waves, along with the field distribution in the multilayer structure. The frequency dependence of these coefficients results in achieving chromatic dispersion, i.e., designing of dichroic mirrors. It is to be noted that nowadays, many numerical optimisation software based on the matrix method are commercially available. Some refined softwares like Monte Carlo method are also available	[redacted]

for efficient optimisation of the designs. (a) Anti-reflection Coatings The AR coatings (optical thin film coatings for reducing reflections from surfaces) are one of the most important coated components. These AR coatings are dielectric thin film coatings applied to an optical surface to reduce the optical reflectivity of that surface at a certain wavelength or in a certain wavelength range. The AR coatings are used for reducing reflection and contrast degradation in the images due to multiple reflections. The AR coatings, designed by optimisation, can reduce the reflection to ~ 0.1 per cent per surface for a given wavelength and a given angle of incidence. In case of the requirement of such coatings for a wide wavelength range and a wide range of incidence angles, the achievable reduction is much less. The AR coatings are employed for laser crystals and nonlinear crystals, e.g., lithium triborate crystals. These are also usefully employed on the open ends of the optical fibres. While designing the AR coatings, damage threshold of the coatings has to be considered for certain applications like Q-switched lasers, which depends on the refractive indices of the material combination wrt that of the substrate, and also the fabrication technique. For achieving very high damage thresholds, dual ion-beam sputtering technique is used. Generally, these are based on the principle that the reflected waves from different optical interfaces largely	[redacted]

cancel each other by destructive interference. A single-layer AR coating designed for normal incidence consists of a single quarter wave layer of a material with the value of refractive index (n) equal or close to the geometric mean of the refractive indices of the two adjacent media. Such an arrangement results in two reflections of equal magnitude arising at the two interfaces, and these cancel each other by destructive interference, as these are out of phase.

However, the problem in designing such coatings is that it is not always possible to find a coating material with suitable refractive index, especially in cases where the bulk medium has a relatively low refractive index, e.g., in case of glass with n = 1.5, the material required should have n ~ 1.24, if the coated component is to be used in air (n = 1). Such a dielectric material suitable for coating is not available, and so generally MgF2 with n = 1.38 is used which reduces the value of reflection from a single surface from ~ 4 per cent to ~ 1.33 per cent. Another limitation of this coating is that it works only at a single wavelength or in a limited wavelength range around it. The wideband AR coatings can be obtained from gradient index coatings, in which case the composition of a layer material is gradually varied. Theoretically, it is possible to suppress the reflection over a wide spectral and angular ~~ring~~ range by a smooth index transition between two optical materials over a range of a few wavelengths. However, the

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difficulty arises because for the surfaces next to air, all materials have value of refractive index quite different from that of air (n = 1). Still good broadband AR coatings in a wide angular range without using materials with a very small refractive index, can be obtained by integrating gradient index layers into a ML coating.

(b) Designing of Anti-reflection Coatings for Photonic Crystals

The field of designing the AR coatings for photonic crystals (PhCs) is emerging, and because of its great importance, an introduction of the topic is given here. The PhCs are materials with periodic variation in dielectric constant. These are man-made materials, and have many interesting properties like negative refraction, with a period of the wavelength of the electromagnetic radiation for which these are to be used. These are designed with a particular band gap, which means that it does not allow that band of frequencies to propagate through these. The PhCs are attractive optical materials capable of controlling and manipulating flow of photons, i.e., flow of light. The PhCs are periodic dielectric or metal-dielectric structures that can modify the propagation of electromagnetic waves in the same way the periodic potential in a semiconductor crystal modifies the electron motion by defining allowed and forbidden electronic energy bands.

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Thus, PhCs can be considered as the artificial structures with the optical equivalent of the energy gap in a semiconductor. Using high speed photons in place of relatively slow electrons as the carriers of information, the speed and bandwidth of advanced communication systems is expected to increase dramatically, and thus, revolutionising the telecommunications industry. During the data movement on silicon chips, electrons pass through electronic gates, and being charged interact with each other, thus generating excessive heat and limiting their movement.	[redacted]
The PhCs use uncharged photons for data flow and are thus free from this problem. It is to be noted that negative refraction has been observed in periodically inhomogeneous substances. This has been demonstrated in photonic crystals, both theoretically as well as experimentally. Negative refraction of acoustic waves has also drawn the attention of the researchers. The experimental confirmation of negative refraction has helped the electromagnetic research community to identify many observable and exploitable effects. When photons pass through a block of transparent dielectric material, these encounter regions of high refractive index (dielectric)– separated by regions of low refractive index (the air holes).	[redacted]
This contrast in refractive index acts like a periodic potential experienced by electrons traveling through a silicon crystal. In case of a large contrast in	[redacted]

refractive index between the two regions, most of the light is confined in either of the two regions, thus resulting in the formation of allowed energy regions separated by a forbidden region, i.e., photon band gap. The effect can be more pronounced in the presence of defects which are nothing but irregularities introduced by changing the size of a hollow ball or the chemical microstructure of the PhC. This is because the defects act like efficient guides routing light through desired paths at a speed much higher than that of electrons in a chip.

The PhCs have applications in waveguides, Bragg reflectors, supercollimators, and superprisms. Choi5, et al. have studied improved transmittance in one-dimensional metallic PhCs5. They have theoretically considered the effect of absorption losses in metal layers, and have shown that the transmittance of a one-dimensional metallic PhC can be increased up to 67 per cent. The starting structure for their study consisted of a stack of five alternate layers of Ag (layer thickness 30 nm) and four layers of GaN (layer thickness 64 nm), and also one layer each of GaN of 32 nm (i.e., half thick) on top and bottom of the stack. The total thickness of Ag layers chosen in this PhC was 150 nm, so that it is several times longer than the skin depth of Ag.

An interesting observation made by them is that the stack without the two GaN layers produces strong oscillations in the transmittance spectrum, with the

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peak value of only 30 per cent. The addition of one GaN layer to the structure results in smoothening of the overall increase of transmittance, but with the same peak value. It is only in the case of having the two additional layers, that one can achieve the smoother transmittance spectrum with more than twice the transmittance.	[redacted]
Recently, Alejo-Molina6, et al. have studied the metallo-dielectric photonic crystal (MDPhC) in relation to the substratum DPhC, by carrying out the analytical and numerical analysis of metallic insets embedded in a DPhC. The complex MDPhC dispersion relation curves and the transmission coefficient at different propagation regimens through the finite stack have been described. It has been observed that in a DPhC6, the band gap argument corresponds to undefined complex solutions of a real dispersion relation, but in a MDPhC, it corresponds to a definite complex solution which is a function of the metal thickness; and analytic continuation of the dispersion curve on the imaginary K plane.	[redacted]
As it is clear that in these applications, light has to be coupled into the PhC, and so insertion losses take place, especially at the frequencies near band gaps, and this provides noise. The coupling losses can be controlled by long mode matching structures or by short AR coatings. This concept is comparatively new, and not much is known about the coupling losses, and so designing of efficient PhC AR	[redacted]

coatings is done by trial and error method, which involves a lot of numerical simulation. However, in case, the impedances of the PhCs used in the design are known, these trials become simple and can be calculated easily.	[redacted]
Impedance is an intrinsic property of the substance, and if its value for two adjacent materials is known, the reflection and transmission coefficients at their interfaces can be easily calculated. It is difficult to extend the concept of impedance to PhCs, as the bulk PhCs scatter light in multiple directions, and it is difficult to distinguish the interface reflections from the internal scattering. So, various ad hoc impedance definitions have been proposed in the literature, but they are all scalar and not very useful for efficient design of AR coatings for PhCs.	[redacted]
For a good AR coating design, the impedance should satisfy two criteria, viz., it should be uniquely defined for each PhC at any wavelength, incident angle, and polarisation, and also should be sufficient to find the reflection and transmission between the two PhCs. Lawrence7, et al. have designed and discussed AR coatings for two-dimensional PhCs using a rigorous impedance definition. In the latest treatment of this type of design, at each wavelength, the field inside each PhC is considered as a superposition of	[redacted]

propagating and evanescent Bloch modes and their quasiperiodic eigenmodes, since PhC's Bloch mode travels through the PhC's interior without reflection. Each PhC is considered as a stack of gratings, and its Bloch modes are represented as a superposition of propagating and evanescent plane wave solutions to the grating equation.	[redacted]
Since the Bloch modes are infinite in number, the calculations are made manageable by projecting the field onto a truncated but sufficiently complete set of propagating and slowly evanescent Bloch modes by a least square approximation that satisfies the two criteria in a balanced manner and is economical. The set is divided into N forward travelling/decaying modes and N backward modes, and thus the interface reflection and transmission coefficients become M × M matrices mapping between the truncated Bloch sets. It should be noted that a larger value of N leads to better accuracy, but the accuracy is good for M approximately equal to the number of propagating plane wave solutions to the grating equation.	[redacted]
The impedance is defined by calculating the reflection at an interface between uniform dielectrics, and is generalised to work with Bloch modes. The Bloch modes are mapped in each PhC to plane-wave field amplitudes and are used to compare fields across the interface and to find the reflection. The matrix that maps forward Bloch	[redacted]

modes to plane-wave field strength coefficients, are found numerically via the transfer matrix, for the E and M field components. The columns of E and M are taken from the sums and differences of forward and backward plane-wave expansions of Bloch modes. It should be noted here that the accuracy of the AR coating design depends upon the accuracy of finding the impedances. The AR coating consists of one or more thin layers coated on the substrate, i.e., bulk medium. The refractive indices and the thicknesses of the layer materials have to be so chosen that all the interface reflections cancel. Since a PhC's width cannot be varied continuously, two layers are required in general for designing a perfect AR coating. The net reflection is easily derived from the interface reflections and the phase changes across the layers, and is made to approach zero.	[redacted]