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A STUDY ON TUNABLE BROADBAND FILTER OF TERNARY PC CONTAINING PLASMA AND SUPERCONDUCTING MATERIAL

Jyoti* & Dr. Fazlay Ahmed**

* Research Scholar, School of Applied Sciences, Om Sterling Global University, Hisar, Haryana

** Assistant Professor, School of Applied Sciences, Om Sterling Global University, Hisar, Haryana

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Abstract:

In this study, we introduce a tunable broadband filter using a ternary photonic crystal (PC) structure that contains both plasma and superconducting materials. The structure is designed to enable control over a broad spectrum of frequencies and offers considerable flexibility in filtering capabilities. The proposed design combines the unique dispersion characteristics of photonic crystals with the tunable response of plasma and superconductive materials. By strategically arranging these materials in a ternary structure, we are able to manipulate the photonic bandgap and thereby control the transmission properties of the filter. We employ rigorous simulation and theoretical analysis to investigate the behavior of the proposed filter under various conditions. The results indicate that the filter's frequency response can be actively controlled by altering the external stimuli, such as magnetic fields and temperature. This active control allows for precise tuning of the filter's passband and stopband characteristics over a broad range of frequencies. Moreover, the incorporation of superconducting material contributes to a decrease in signal loss, enhancing the efficiency and performance of the filter. The utilization of plasma adds to the flexibility of the design, enabling real-time control and a broad range of operational capabilities. The proposed ternary PC filter demonstrates potential applications in various fields, such as telecommunications, signal processing, and optical computing. Its ability to adapt to different frequency requirements and environmental conditions makes it an attractive solution for next-generation photonic devices.

Key Words: Spectrum, Frequencies, Superconducting, Material

Introduction:

Plasma is a hot ionised plasma made up of charged ions and electrons in which the number of each is about equal. This was discussed in detail before. Plasma is not like other neutral gases; it has its own unique properties. Non-thermal or cold plasma is plasma that is not in thermodynamic equilibrium. This is because electrons have a far greater temperature than more massive atomic types, such as ions and neutrals. When plasma is introduced into PC s, the adjustable PBG in the microwave area is created [1]. After then, the PPC develops into a bustling research hub within the larger field of optics and photonics. A multilayer periodic structure consisting of thin plasma and other dielectric materials, the PPC is organised in a single dimension. Basically, superconducting materials exist at very low temperature since Dutch physicist Onnes [2] discovered this theory in 1911. In a simple language, superconducting materials are those materials where electric resistance of the material becomes zero, also at which temperature the resistance becomes zero, that temperature is known as critical temperature of that material. In 1986, it was discovered that the critical temperature of some cuprate-perovskite type ceramic materials is more than 90 K. Since a superconductor with such a high transition temperature doesn't exist in theory [3, 4], this material is known as a high temperature superconductor. Since, the discovery certain ceramic materials exist high temperature superconductivity for the applications. These materials studied extensively for the design of practical devices. Though there has been much research done, but a lot of left is to be done in optics. Additionally, a large amount of research accomplished in the use of pulse laser to break quasi-particle bonds in High Temperature Superconductor (HTS), lowering the transition temperature and including super conducting-to-non super conducting phase transition. The superconductor material exhibits markedly different optical properties in the superconducting state to the ordinary state. The infrared-pulsed laser (1.06μm wavelengths) is incident to illuminate a Yttrium Barium Copper Oxide (YBCO) thin films with an intensity above critical value, caused the thin film to switch from the superconductor to the normal state recover on the order of 1μs. Thus, when an HTS switches from superconducting to normal or ordinary its optical properties change, the degree to which they change depends on the frequency of incident light. If an HTS thin film was incorporated into a periodic structure (PBG materials), the transmittance characteristics of the resulting structure should reflect the optical properties of the HTS [5-9].

Methodology:

TMM [50] is used to study the transmission properties of a triple photonic crystal (PC), taking into account the properties of the insulator, magnetised cold plasma, and high-temperature superconductor (YBa2Cu2O7). The 1-D ternary PC is written as (ABC)N, where A, B, and C stand for the insulator, the magnetised cold plasma, and the high-temperature superconducting material, respectively. The amount N shows how many times the ternary arrangement repeats itself. Before "getting into the optical features of ternary PCs, which include dielectric, magnetised cold plasma, and high-temperature superconducting materials, we give a short review of the optics of magnetised cold plasma and high-temperature superconducting materials.

Results and Discussion:

In this theoretical study, we look at the optical features of a 1-D ternary photonic crystal (PC) made of alternating dielectric, magnetised cold plasma, and superconducting material. We use the basic Transfer Matrix Method (TMM) to look at both right-handed and left-handed polarisations [39]. Depending on the external magnetic field, which can be switched between positive and negative values, the behaviour of right-handed and left-handed polarisations of magnetised cold plasma is different. The TM field affects both the superconductor and the magnetised cold plasma in the way they let electricity through. To make it easier to make the 1-D PC, we show a picture of how the right-handed and left-handed polarisations of the 1-D ternary PC transfer light as a function of frequency (GHz). This graph shows how transparency changes when important factors like the angle of contact, magnetic field, electron density of the magnetised cold plasma, temperature of the superconductor, and widths of the magnetised cold plasma and superconducting materials are changed. The study of transparency gives us important information about how optical filters might be used in the future. This helps us learn more about the performance and properties of the 1-D ternary PC. The ternary PC as (ABC)N, where A, B, and C stand for air, magnetised cold plasma, and (YBa2Cu 2O7), respectively, at critical temperature Tc=92K and operational temperature T=4.2K. Material A is 18mm thick, material B is also 18mm thick, and material C is also 80nm thick. are $nA=1$, $nB=\sqrt{\varepsilon B\mu B}$, $nC=\sqrt{\varepsilon C\mu C}$ are the refractive indices for layers A, B, and C, respectively [15]. The lattice's periodicity (N) is set to three periods, or" N=3.

By changing the impact angle, magnetic field, plasma electron density, temperature, and thickness of the magnetised cold plasma and superconducting material, the transparency of the 1-D ternary photonic crystal (PC) can be changed. We can successfully control how light moves through the building by changing these factors. To figure out how well a structure lets light through, we look at how it responds as a function of the contact angle for both right-hand and left-hand polarisations. This study helps us figure out how the transmission changes for both polarisation states based on how the light hits the surface. By looking at the transparency as a function of the angle of contact, we can learn how light moves through the 1-D ternary PC structure depending on the angle, which is important for improving its optical performance. The ECF of magnetised cold plasma is calculated to ne=12x1017/m3, the transition temperature of high temperature superconductor (YBa2Cu2O7) TC=92K, and the operating temperature T=4.2K, with incident angles = 00, = 300, and = 400 studied. Figure4.2 depicts the relationship between frequency (GHz) and incidence angle θ= 00, θ=300 and θ=400 for a ternary PC made from right-hand polarisation material. Superconducting behaviour inside the structure explains why there is no transmission between 0 and 1 GHz. The influence of the dielectric behaviour of air and magnetised cold plasma material manifests as transmittance in the higher frequency range (2.3-10.0 GHz). At lower frequencies (θ= 00, 300 and 400), we observed a very little variation in transmittance regardless of incident angle. Since the superconductor's RI is constant regardless of the angle of incidence, this demonstrates that incident angle has no effect at low frequencies. In this part, we look at how the ternary photonic crystal (PC) behaves at low cutoff frequencies, which shows how it works as a low-pass filter. The building might also be able to work as a low-band deflector for microwave waves. But at higher frequencies, the transmission for impact angles of 0°, 30°, and 40° has moved towards the higher frequencies. By changing the angle of contact, you can change the passband of this frequency band and use it as a filter for more than one channel. As shown in Figure 1(a), the band gap gets bigger at higher frequencies as the angle of contact gets bigger because the material is insulating.

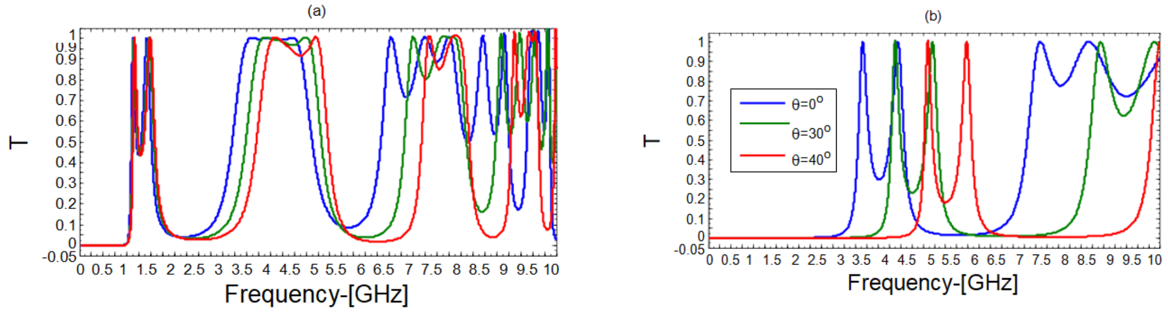

Figure 1: Shows the transmittance versus frequency with varying angle of incidence for (a) right hand polarization structure and (b) left hand polarization structure

Similarly, for left-hand polarisation, the transmittance of the proposed ternary PC is shown versus frequency (GHz) over a range of incidence angles (= 00, 300, 400). As a result of the superconducting layer, the cutoff frequency for the normal incidence, i.e. =00, is attained at 3.2GHz. Due to the effective property of the dielectric material, the cutoff frequency edge moves upwards as incidence angle rises. When the maximum angle of incidence, =400, is reached, a cutoff frequency of 4.5GHz is shown in the transmittance characteristics graph. As can be seen in Figure 1(b), there is a sizable transmission gap between the frequencies where the structure under consideration transmits and those where it does not. Broadband reflector or high pass filter applications are possible with the left-hand polarisation ternary PC due to its huge band gap at the low frequency.

We have investigated the differences between the ternary PC's transmittance in right- and left-hand polarisation. The findings of the left-hand polarisation ternary PC are superior than those of the right-hand polarisation PC. The ternary PC with left-hand polarisation has a higher cutoff frequency than the ternary PC with right-hand polarisation. These researches implemented a useful concept for designing a tunable filter that can be adjusted by varying the angle of incidence. Both the MCP layer and the superconducting layer (YBa2Cu2O7) are sensitive to changes in operating temperature and external magnetic fields. Thus, by altering the magnetic field strength, we have investigated the ternary PC's transmissivity in both the right- and left-hand polarisations. Where the wave falls naturally, i.e. =00, the transmittance of the proposed ternary periodic structure is explored as a function of frequency (GHz) for different values of the magnetic field of the MCP. When the angle of incidence is changed, the transmittance behaviour for B=0.4T, B=0.6T, and B=0.8T is identical to the first example, but the cutoff band edge is deformed because of the change in the gyro-effective frequency. As the refractive index changes, the transmittance also shifts. The gyro effective frequency determines the MCP's RI. Therefore, the RI of the ternary PC with right- and left-hand polarisation is altered when an external magnetic field of MCP is introduced. By adjusting the magnetic field strength, we may control the degree to which the ternary PC containing the material with right-hand polarisation transmits light. This indicates that the MCP's permittivity changes exclusively in response to an external magnetic field. As the magnetic fields in Figure 2(a) are increased, so does the cutoff frequency of the right-hand polarisation structure.

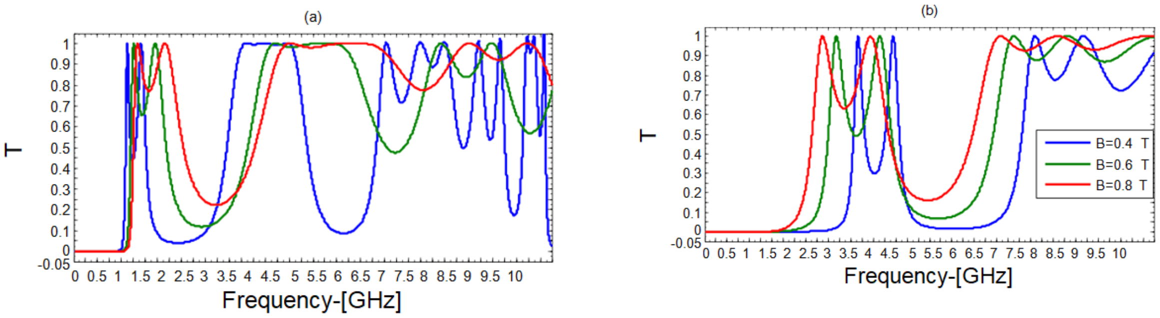

Figure 2: Shows the transmittance versus frequency with varying magnetic field for (a) right hand polarization structure and (b) left hand polartization structure

We have also calculated the transmittance of the same ternary PC at different frequencies (GHz) by adjusting the magnetic field of the MCP for the left-hand polarisation, using the same θ=00, ne=12x1017/m3, and other parameters as before. There is an effect on wave propagation from the altered RI of the left-hand polarisation material. Since the permittivity of the MCP is abnormally altered when the magnetic field applies in the reverse direction, the transmittance behaviour for the left-hand polarisation ternary PC follows a different pattern. As shown in Figure 2(b), when the magnetic field is at its lowest (B=-0.8T), the transmittance is zero, but it increases to 3.2GHz as the field strength diminishes. By adjusting the magnetic field, the ternary PC's transmittance may be tuned for left-hand polarisation. Band gaps are achieved both in the low-frequency and high-frequency ranges. Bandpass filter applications might benefit from the ternary PC's transmittance behaviour. As can be seen from Eq. (1), the electron density is the second most important parameter of the MCP, and the plasma frequency determines the RI of the MCP. By altering the electron density, we examine how the ternary PC's transmittance changes for both the right- and left-hand polarisations. Now, we've zeroed in on the transmittance of the right-handed polarisation ternary PC material under consideration as a function of frequency (GHz) for three different electron density values: ne=12x1017/m3, 16x1017/m3 and 20x1017/m3. All of the structure's parameters are the same as those in the preceding section. As can be shown in Figure 3(a), the electron density of the MCP, i.e. ne=12x1017/m3, 16x1017/m3, 20x1017/m3 with the positive magnetic field, i.e. B=+0.4T, affects the transmittance of the right-hand polarisation ternary PC at lower to higher frequency ranges. The low cutoff frequency is found to be between 0 and 1 GHz, where there is no transmittance due to the existence of the superconductor layer. This ternary PC operates as a low pass filter. Since the plasma frequency of the MCP reduces the permittivity of the MCP, the cutoff frequency drops as the electron density of the MCP grows.

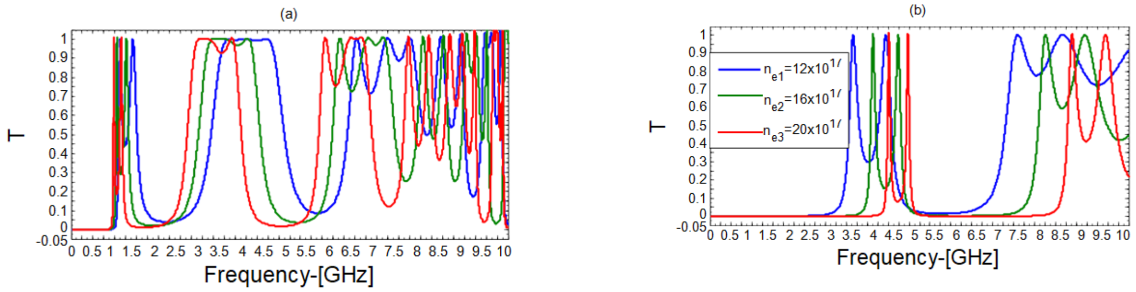

Figure 3: Shows the transmittance versus frequency with varying electron density of MCP for (a) right hand polarization structure and (b) left hand polarization structure

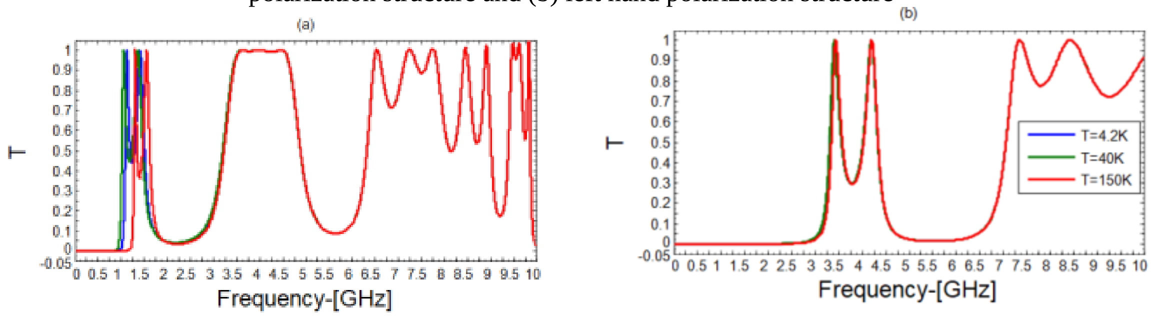

Figure 4: Shows the transmittance versus frequency with varying temperatue of superconductor for (a) right hand polarization structure and (b) left hand polarization structure

Again, we investigated the effect of changing the electron density of the MCP (ne=20x1017/m3, 16x1017/m3, 12x1017/m3) under a negative magnetic field (B=-0.4T) on the ternary PC's transmittance. Changes in electron density in the MCP cause shifts in transmittance between the low and high frequency ranges. As indicated in Figure 3(b), increasing the electron density of MCP from 12x1017/m3, 16x1017/m3, 20x1017/m3 enhances the zero transmittance at the lower frequency range up to 4.2GHz. At a maximum value of the electron density of MCP, i.e ne=20x1017/m3, the highest possible cutoff frequency is reached for the left-hand polarisation structure. According to Eq. (1), the plasma frequency rises with increasing electron density, and the denominator of permittivity becomes positive when the left-hand polarisation material has the negative magnetic field. As the value of the MCP's electron density rises, the material's permittivity falls. The band gap in the left-handed polarisation ternary PC area functions as a high pass filter or broadband reflector.

The superconducting material in the suggested ternary PC reacts differently to changes in operating temperature and applied magnetic field. Here, we examine the relationship between right- and left-hand polarisation transmittance and frequency (GHz) for three different superconducting material operating temperatures (T1=4.2K, 40K, and 150K). We have used YBa2Cu2O7 with the same Tc=92K, B=0.4T, and other parameters as those used in the aforementioned computations. As a result of the action of superconducting material, the transmittance of the right-hand polarizationternary PC varies in the lower frequency range but remains constant in the higher frequency range. Therefore, the dielectric behaviour of air and MCP materials is the sole cause of the effective transmittance at high frequencies. The ternary PC has a cutoff frequency that is very temperature dependent. For temperatures below the critical temperature, i.e. T=4.2K, 40K, the cutoff frequency is seen to drop. However, at operating temperatures above the critical temperature, T=150K, the action of the magnetic field in the superconducting material increases the transmittance (Figure 4(a)).

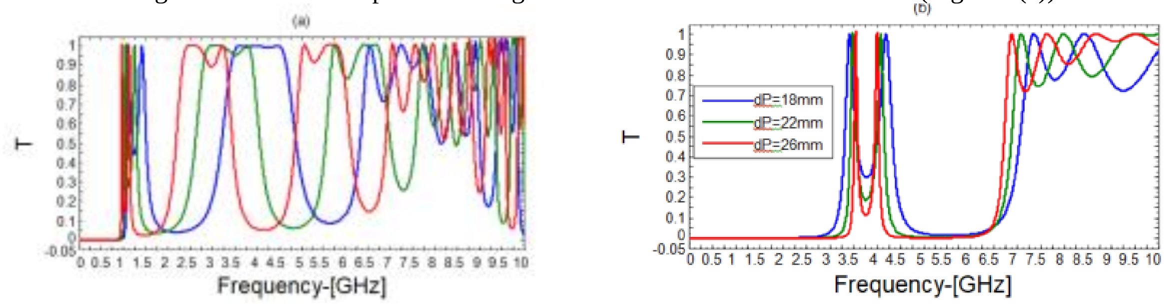

Figure 5: Shows the transmittance versus frequency with varying thickness of MCP for (a) right hand polarization structure and (b) left hand polarization structure.

Using the same conditions (operation temperature T=4.2K, 40K, 150K, magnetic field B=-0.4T), we examine the transmittance of a ternary PC with left-hand polarisation as a function of frequency (GHz). As can be seen in Figure 5(b), the transmittance behaviour of the left-hand polarisation ternary PC does not differ from that of the right-hand polarisation ternary PC, although it does exhibit zero transmittance in the lower frequency range, namely at 3.2 GHz. This indicates that the left-handed polarisation ternary PC's transmittance is temperature independent. The 3.2 GHz cutoff frequency suggests that the ternary PC with left-hand polarisation might serve as a broadband reflector.

Transmittance against frequency (GHz) for both right- and left-hand polarisations was examined by altering the thickness of the MCP in this region. Figure 5 shows the transmittance against frequency (GHz) for right-hand polarisation and left-hand polarisation when the thickness of the superconducting material is varied. Figure4.6(a) depicts a study of the transmittance against frequency (GHz) for the right-hand polarisation, with the thickness of the MCP being varied from 18 mm to 22 mm to 26 mm with B=0.4T and ne=12x1017/m3. The thickness of the MCP material, i.e. 0.0-1.0GHz, determines the cutoff frequency for the right-hand polarisation ternary PC with the superconducting material. Due to the influence of the thickness of the MCP layer, the transmittance at the higher frequency area has developed substantial variance.

By altering the thickness of the MCP with the same parameters as prior studies, we examine the transmittance of the proposed ternary periodic the left-hand polarizationternary PC vs frequency (GHz). Transmittance increases with increasing MCP thickness in the lower frequency range (0-3.4GHz), but decreases in the higher frequency range (>3.4GHz), as shown in Figure 5(b). This is because the cutoff frequency of the considered left-hand polarisation ternary PC follows an opposite trend for the lower frequency region compared to the higher frequency region. Between these frequencies, a low transmittance value is attained that is insensitive to the MCP material's thicknesses. A specific use case for this is a narrow band filter.

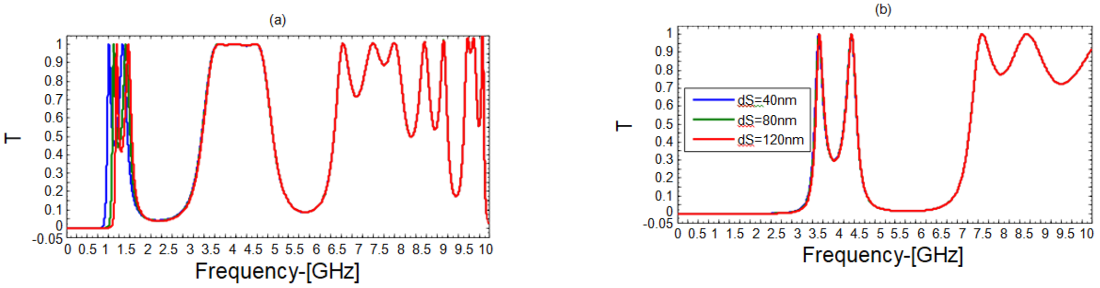

Figure 6: Shows the transmittance versus frequency with varying thickness of superconductor for (a) right hand polarization structure and (b) left hand polarization structure

We recalculated the transmittance versus frequency (GHz) for three different widths of the superconducting material: 40 nm, 80 nm, and 120 nm. We used the same values as before. Figure 6(a) shows how the thickness of a superconducting material affects how well it lets low-frequency signals through. At higher frequencies, though, all sizes have the same transparency. The ternary photonic crystal (PC) with right-hand polarisation has a different cutoff frequency. When the superconducting material is 120 nm thick, a large cutoff frequency can be seen. As the width of the superconducting material goes up, so does the frequency at which it stops conducting electricity. Figure 6(b) shows the results of a similar study, in which the thickness of the superconducting material was changed from 40 nm to 80 nm and then to 120 nm to see how it affected the transmittance at a chosen cutoff frequency for left-hand polarisation. In this case, there is no link between the width of the superconducting material and how well the ternary PC with left-hand polarisation lets light through. Figure 6(b) shows that when the magnetic field is applied in the opposite direction (B=-4T), the left-hand polarisation ternary PC behaves like a dielectric, which is the same as the right-hand polarisation ternary PC at the same temperature.

Conclusion:

The theoretical transmittance of a ternary PC changes as a function of frequency (GHz). We have looked at the effects of different factors, such as the angle of contact, magnetic field, electron density of the MCP, temperature, and thickness of the MCP, for both RHP and LHP. Depending on how the MCP and superconductor are set up, the RHP and LHP ternary PCs have different visual properties. As an optical feature, the transmission is affected by the working temperature and the external magnetic field. The superconductor layer in LHP ternary PCs has led to better performance than in RHP ternary PCs. Because the superconducting layer makes a large band gap, the LHP ternary PC can be used for things like broadband mirrors or high-pass filters. But it's important to note that the transmission of the RHP ternary PC can also be changed by changing how the MCP works. Based on what we found, we suggest a new way to build broadband mirrors, high-pass filters, and narrow adjustable filters using ternary PCs made of MCPs and superconductors. This can be done by carefully controlling the temperature of the gadget and the magnetic field perpendicular to the PC's axis.

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