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In this Issue...

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Message from Editor

Dear Valued ECTI Members,

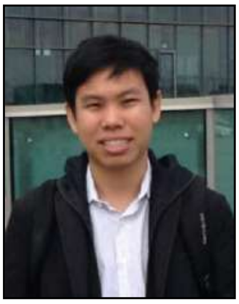
During the passing September 2017, the world witnessed two major disastrous events caused by the mother nature, Hurricane Maria which swept through the Carribean areas, and the 6.1-earthquake in Oaxaca, Mexico, both of which caused human losses and called for major reconstructions in the regions. The ECTI Association would like to pass condolence to these major losses and affected families. Science and Engineering will play even greater role in disaster management resulting from increasingly volatile climate and earth conditions. Researchers need to work together with the private sector and government body in initiating new ideas, fostering public-private collaboration for these efforts both at the national and international scales.

Coming back to this issue of ECTI E-Magazine, we are pleased to publish a review article titled "Applications of Gradient Metasurfaces: A Review" by Dr. Sarawuth Chaimool and Assoc. Prof. Yan Zhao (Chulongkorn University). It describes recent research trends on metasurfaces (MTSs), planar and thin metamaterials, as well as potential applications.

The ECTI-CON 2017 conference, our flagship conference, held in Phuket during June 2017, as well as the ECTI-CARD 2017 conference, with emphasis on projects and practical research, held in Chiang-kan, Loei province, were successfully organized with record number of participants. The summary of these two events as well as other seminars from each academic area are listed in the conference section.

In addition to the activities/Workshops of each Technical Area as well as the ECTI Association, list of articles in the ECTI Journals, upcoming sponsored conferences and seminars, we welcome the articles related to the activities, collaboration projects at your research group, laboratories or research centers. In the near future, we will publish the articles or updates related to industry, graduate students and new researchers. Should you have any comments or suggestions to improve the ECTI E-Magazine so that it serves our members better, please do not hesitate to contact us via E-mail or Facebook.

Pornchai Supnithi
ECTI E-Magazine Editor



Watid Phakphisut
ECTI E-Magazine Assistant Editor

Applications of Gradient Metasurfaces: A Review

Sarawuth Chaimool and Yan Zhao

ABSTRACT

In this paper, we attempt to review briefly the recent trends and development in gradient metasurface research, focusing on ways to design these metasurfaces for various applications from acoustics to optical regimes. We place emphasis on the physical mechanisms and designs required for phase gradient metasurfaces. The performance advantages and disadvantages of various schemes will be emphasized. The novel metasurface structures discussed here offer intriguing properties and have potential applications in design and development.

Keywords

Metamaterials; Gradient Refractive Index (GRIN); wavefront control; antenna

I. INTRODUCTION

Engineered electromagnetic (EM) metamaterials have given prominence due to their attractive unprecedented properties such as negative refractive index. Nowadays, researchers have achieved great development to planar and thin metamaterials, also called metasurfaces (MTSs), which are ultra-thin two-dimensional metamaterials composed of subwavelength unit cells (scatterers). Especially, MTSs have shown dynamic abilities in manipulating and controlling the transmissions, reflections, and polarizations of EM waves, independently. Therefore, MTSs have enabled a myriad of novel physics and phenomena including beam focusing, polarizers, anomalous refraction, and reflection, light bending, flat lenses, cloak and antennas [1]-[6].

Recently, according to Fermat's principle, wavefront and phase-control engineering have been widely studied. The nature of wave matter interactions at the metasurface interface is distinct from the bulk metamaterials, as a metasurface enforces artificial boundary conditions on the EM fields. More recently, the gradient metasurface (G-MTS) is a special case of metasurface with distributed phase response, proposed by Yu *et. al.* to demonstrate the generalized Snell's law and provide a powerful solution to break the mentioned limitations [7]. It is a special nanoantenna array MTS, which can create abrupt phase discontinuities through the interface and drastically change its reflected and refracted flow. Subsequently, much research interest has been concentrated in this field due to the ultra-thin thickness and low-loss of the MTSs. Actually, the G-MTS is a class of planar gradient metamaterials, which can be classified into three categories: gradient index metamaterials, gradient metasurfaces and gradient metallic gratings as shown in Fig. 1 [8]. Compared with the phase accumulation in gradient refractive index (GRIN) bulk metamaterials [9]-[10], the G-MTS is able to alter EM wavefront due to their strong abilities to control the refractions or reflections of incidence waves by locally controlling the phase and amplitude of the designed scatterers within a subwavelength scale. In contrast to the phase accumulation in typically GRIN metamaterials, the G-MTS presents a strong control over the phase by properly tailoring phase discontinuities on a metasurface, which provides a promising way to construct thin planar devices. Although this is a relatively new area of research in the optics and photonics community, similar concepts have been employed in the acoustics to terahertz regime communities since the early twentieth century, notably in the context of steering beam antennas and MIMO (Multi-input multi-output) applications. As the following, G-MTSs have been discovered for a wide range of applications over the entire EM spectrum, including focusing lenses [11], high resolution imaging [12], holography [13], radar cross section [14], polarization conversion and beam splitter [15], waveguide mode converters [16], and antenna performance improvement [17].

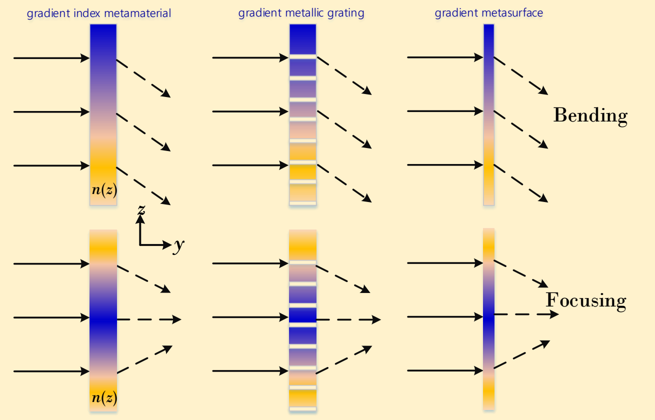


Figure 1: Different bulk gradient metamaterials and planar gradient metasurfaces for the manipulation of electromagnetic waves in free space [8].

In this paper, we review the recent progress of G-MTSs from the fundamental theoretical background, physical realization and their potential practical applications. Moreover, we have discussed the merits and fascinating characteristics of G-MTS in general. We believe that G-MTSs have great potential applications in wavefront engineering.

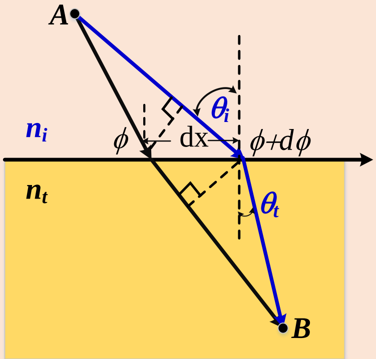


Figure 2: Schematics used to derive the generalized Snell's law. An incident EM wave propagates from the top (n_i) into the bottom one (n_t), and θ_i is the incidence angle.

II. FUNDAMETALS OF GRADIENT METASURFACES

Gradient metasurfaces refract and reflect EM waves in accordance with the generalized Snell's law of refraction and refraction, which can be obtained from an application of Fermat's principle [7]. Figure 2 shows the schematic used with this principle in order to derive a generalized law of reflection and refraction:

$$n_t \sin\theta_t - n_i \sin\theta_i = \frac{\lambda_0}{2\pi}\frac{\partial\phi}{\partial x} \tag{1}$$

$$\sin\theta_r - \sin\theta_i = \frac{\lambda_0}{2\pi n_i}\frac{\partial\phi}{\partial x} \tag{2}$$

where n_i and n_t are the refractive indices of the two sides where wave is incident and transmitted, respectively, θ_i is the incident angle of the EM wave, θ_t is the angle of refraction, λ_0 is the vacuum wavelength and $\partial\phi / \partial x$ indicates the gradient of the phase discontinuity along the interface. As the phase can only reach values between 0 and 2π the required phase gradient for back reflection of wave with the wavelength λ_0 is periodic:

$$\frac{\partial\phi}{\partial x} = \frac{2\pi}{\Lambda} \text{with the period } \Lambda = \frac{\lambda_0}{2\sin(\theta_i)} \tag{3}$$

Especially, one of the most applications of G-MTSs is beam steering. Traditional way to steer EM waves is using reflector and lenses antennas due to their low cost, easy for fabrication, and their ability to provide high gain. However, beam steering is only available using mechanical scanning, and beam shaping can only be achieved if more sophisticated feeding systems are used. Moreover, antenna arrays are able to overcome the drawbacks of aperture antennas by utilizing electronic circuits to control each element excitation which provides beam steering in real time. However, the main drawbacks of antenna arrays are the complex and relatively large hardware size. Figure 3 portrays a schematic diagram of a simplified model architecture and operation principle of a conventional phased array antenna. It consists of an array of radiating elements and a feeding network. Each radiator is connected to the feeding network and fed by an excitation to radiate a wave with specific magnitude and phase. By controlling the phase delay value ($\Delta\phi$) of each phase shifter in each channel electronically, the direction of the main beam (θ) can be controlled in the far field.

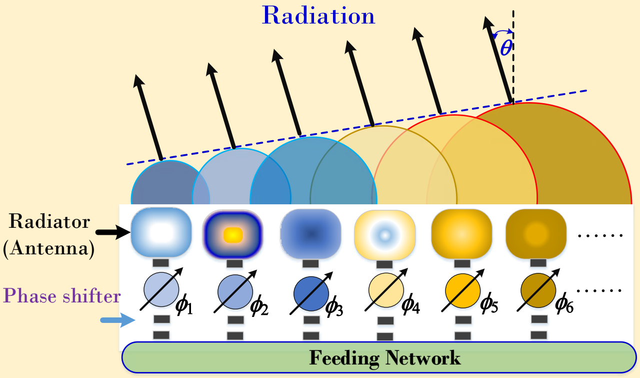


Figure 3: Configuration indicating the architecture and operation principle of a conventional phase array.

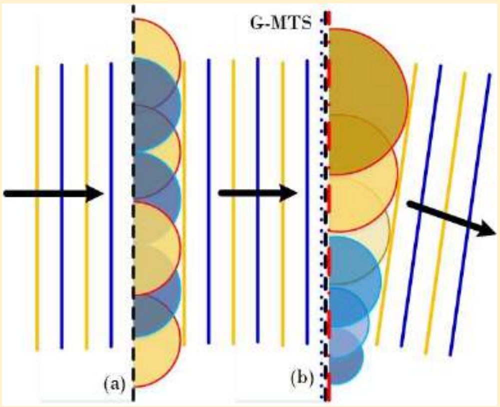


Figure 4: (a) Basic Huygens' construction of the plane wave and (b) Through the introduction of the phase G-MTS [18].

On the other hand, one possible way to steer a beam utilizing phase gradient surfaces is by designing a suitable resonator array on top of a dielectric substrate. This array of resonators can work well as a reconfigurable phase gradient due to the locally introduced phase shifts between the emitted and incident radiation at resonance and the subwavelength nature of each unit cell. When the array of the resonators can provide a constant gradient of the phase discontinuity, such a metasurface is called phase gradient metasurface [7],[19]-[20]. By tailoring the geometry of the resonator array, one can build an arbitrary phase profile along the air/substrate interface. Phase shifts from the individual resonators need to cover a difference from 0 to 2π to provide full control of the electromagnetic wave propagation. Figure 4 shows the concept of the phase G-MTS for steering beam, which plane-wave refraction can be

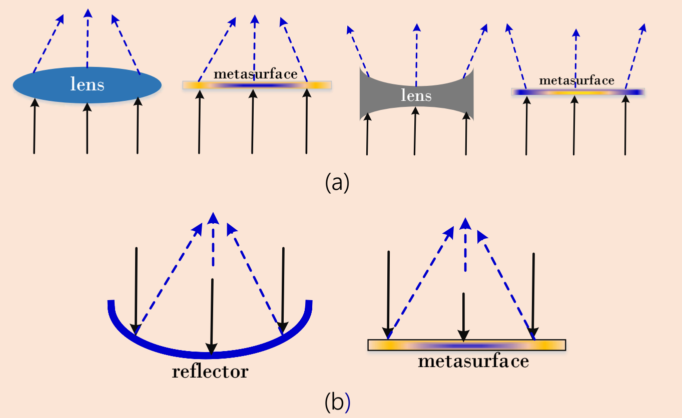


Figure 5: Diagrams of the operation of traditional lenses and metasurfaces (a) Transmissive type and (b) Reflective type.

explained in terms of Huygens' principle. In Figure 4 (b) for phase G-MTS, the phase of each point of the radiation wavefront from the bottom is advanced at a spatial point. Variations in phase or amplitude of the aforementioned metasurfaces are based on varying resonator geometry; another terminology, known as Pancharatnam–Berry phase (PB phase) metasurfaces, achieves a full phase control by adjusting the orientation angle of antennas with identical geometry [21]-[22].

III. IMPLEMENTATIONS OF GRADIENT METASURFACES

In order to simply classify G-MTSs, two categories according to the format of the G-MTSs: transmissive and reflective types are arranged. For the design of reflective G-MTSs, the scattering waves are almost totally reflected owing to the existence of the layer so that only the reflection phase should be taken into consideration. It achieves the same as the mirror surface topography._However, the transmissive type must be built on the base of high transmission efficiency which makes the design more challenging. In millimeter-wave to optic regimes, it usually takes changing the thickness of a transparent dielectric medium. The phase delay of passing rays matches the difference between the desired input and output beams. For microwave region, however, dielectric host inclusion metallic has been created. The representations of the operation for traditional transmissive and reflective surfaces compared with metasurfaces are shown in Figure 5.

In this section, therefore, the G-MTS applications and the recent progress will be discussed. In the following two sections, we select two main metasurfaces, working in transmission and reflection properties, respectively.

A. Transmissive Phase Gradient Metasurfaces

Most of the phase G-MTSs are reflective types since the transmissive metasurfaces have the low transmission efficiency which limits further applications. Nevertheless, the first and well-known transmissive phase G-MTS is the V-shaped nanoantennas proposed by Yu [7] and Ni [23].

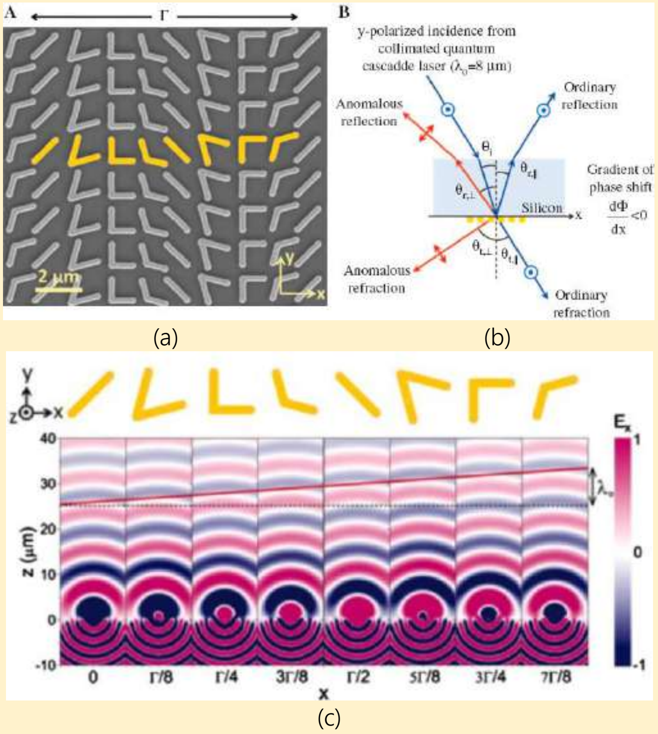


Figure 6: (a) SEM image of the V-shaped antennas for transmissive G-MTS (b) diagram of reflection and refraction showing the coexistence of both co-polarized ordinary beams and cross-polarized anomalous beams (c) a reflection phase gradient realized enabled by 8 resonators [7].

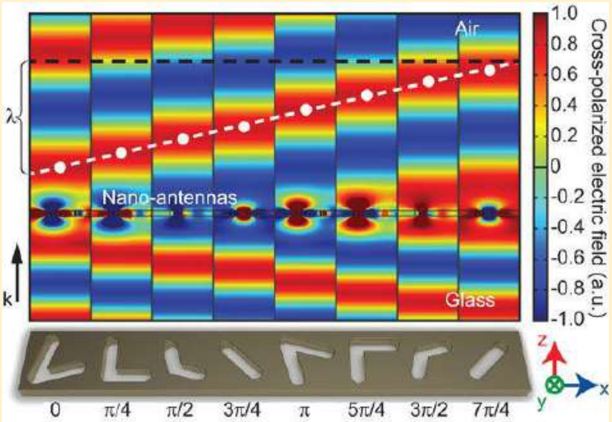
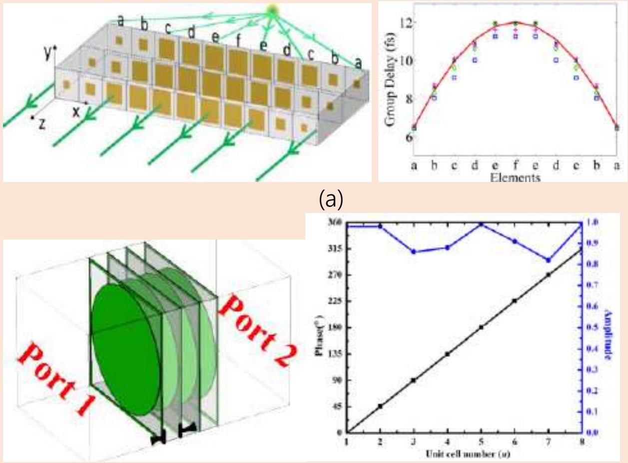


Figure 7: A set of similarly shaped nano-voids milled in a thin metallic film and the individual phase responses [24].

Figure 6 illustrates schematic of the V-shaped nanoantennas metasurface and phase responses. It can be observed that in order to obtain a full range 2π phase modulation, it is essential to reconfigure the orientation of the V-shaped resonators and change to I-shaped resonators as shown in Figure 6 (c). According to Babinet's principle, instead of metallic nanoantennas as Yu, nanoslots or nanovoids with the similar V-shaped set were proposed [24]-[25] as shown in Figure 7. Furthermore, in order to improve overall efficiency, some efforts have been devoted using several approaches such as multi-layer [26]-[27], combined unit cell shapes [28], material technology [29]-[31] and so on.



(a)

(b)

Figure 8: Multilayer techniques (a) Layout of the collimating metasurface lens (left) and group delay profile for the lens composed of 11 elements (right) [26] (b) Structure and transmission phase difference (black square dots) and amplitude (blue circle dots) of the unit cell with different radius of the solid circle [27].

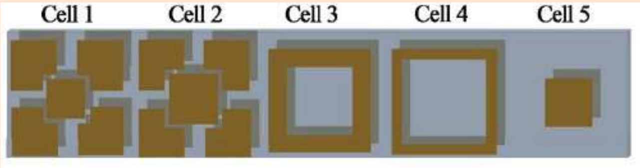


Figure 9: A method of combined unit cell shapes composed of five different unit cells [28].

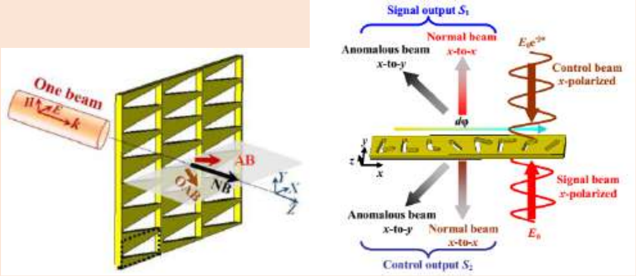
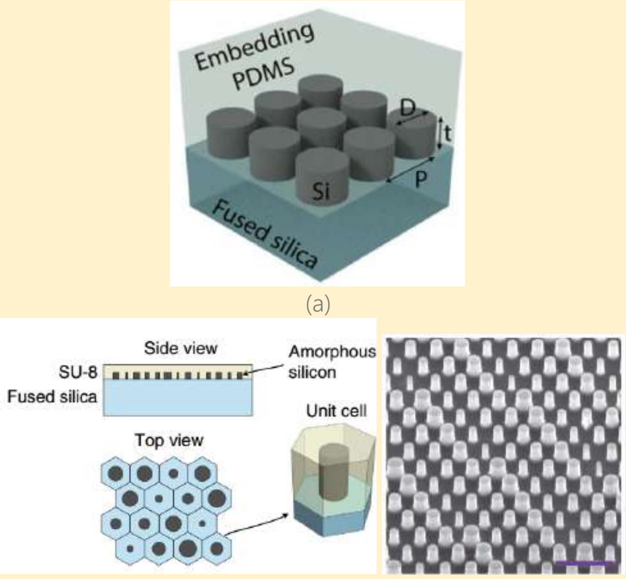


Figure 10: Schematics of coherent control of the G-MTSs. (a) the trapezoid-shaped slit metasurface [32] (b) the V-shaped slot antennas [33].

Since cross polarizations of several single layer G-MTSs do not depend on the dispersion of the V-shaped dipole antennas but depends on the orientation of the dipoles. Hence, the overall efficiency is restricted owing to the cross-polarization mechanism. For a sake of increasing efficiency, bandwidth and reduce size, usually multi-layer technique has been applied [26]-[27]. Cheng and Mosallaei [26] showed truly achromatic metasurfaces at midinfrared and visible ranges. The proposed phase G-MTS consists of the metallic patch layers as displayed in Figure 8(a). The results show that this allows successful broadband operation with almost linear phase response over the designed spectra. Li *et. al.* designed a high-gain antenna by employing layered phase G-MTS at 10 GHz [27]. The phase G-MTS is performed like a lens antenna using four metallic circle patch layers and three dielectric layers (Figure 8(b)).



(a)

(b)

Figure 11: Configuration of dielectric resonator MTSs (a) an array of silicon nanodisks on top of a fused silica substrate with high refractive index [29] (b) an array of amorphous silicon nanoposts covered with a layer of SU-8 polymer and arranged in a hexagonal lattice and a SEM image [30].

Furthermore, a method of combined unit cell shaped was proposed with large phase coverage and high transmission efficiency [28]. The proposed G-MTS is based on both the electric and magnetic responses, called *Huygens' metasurface*, which is composed of a number of closely capacitive patches and rings etched on a single dielectric substrate as shown in Figure 9.

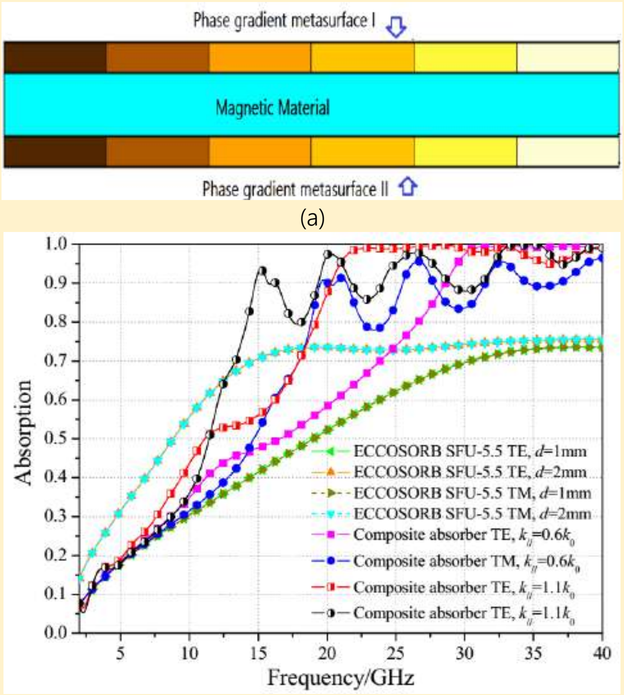
The coherent controls of the G-MTSs with arrays of trapezoid slot antennas [32] and V-shaped apertures [33] were investigated to modulate intensity, polarization and propagation direction of light as shown in Figures 10 (a) and 10 (b), respectively. Two deflected outgoing beams and one normal beam can be coherently controlled by changing the phase difference between two coherent beams.

One of the limitations using metallic at shorter wavelengths, particularly in the visible frequency range, is their large inherent ohmic losses. Therefore, all-dielectric resonator metasurfaces with high refractive index provide another way for full range phase control by the simultaneous excitation of electric and magnetic dipoles [29]-[31]. Yu *et. al.* demonstrated a high-index metasurfaces using amorphous silicon and embedded in a poly-dimethyl-siloxane (PDMS) layer from the top [29]. Figure 11 shows a schematic of the dielectric metasurface consisting of an array of silicon nanodisks on top of a fused silica substrate and embedded into a PDMS layer from the top to realize refractive index matching. In addition, Arbabi *et. al.* proposed a doublet lens formed by cascading two metasurfaces which act as polarization insensitive phase plates that are patterned on two sides of a single transparent substrate [30]. The proposed metasurfaces are implemented using the dielectric nanopost metasurface platform shown in Figure 11 (b). Most of dielectric metasurfaces were designed for in the visible spectrum (500-800 nm wavelength).

Conversely, magnetic materials were presented for a composite absorber and a phase G-MTS to improve the absorption without increasing the thickness [31]. The composite absorber is designed by a composition of the magnetic material ECCOSORB SFU-5.5. The phase G-MTS using magnetic material is used to increase the propagation path by controlling directions of incident wave. Figure 12 depicts a performance of the composite absorbers compared with the conventional magnetic materials. It can be observed that the absorption of the magnetic material increases with the increase of its thickness and meanwhile the absorption shifts to the lower frequencies. However, the absorptions of the composite absorber are greatly increased compared with the magnetic material and they possess different absorptions for TE and TM incident waves.

As discussed above, the transmissive G-MTSs usually have fixed gradient of the phase discontinuity ($\partial\phi / \partial x$), so the beam directions are pointed out in only one specific direction. Thus, an electronically controllable fashion has been used to reconfigure metasurfaces for steering beams and deflecting electromagnetic waves [34]-[37]. There are various approaches to design reconfiguration unit cells especially using the discreate elements including PIN diodes [34], varactor diodes [35], and MIC and MEMS switches [36]. Li *et. al.* presented a tunable phase G-MTS using PIN diodes for beam-steering application [34] as shown in Figure 13. In addition, the vanadium dioxide (VO_2) as the substrate with electronically-tunable dielectric constant is used [37]. The phase front of the transmitted electromagnetic wave through the metasurface is varied and the transmitted beam is deflected to the specified direction by controlling the applied current to each individual metasurface unit-cell. Figure 14 displays the schematic diagram and scanning electron microscope (SEM) image of a fabricated beam-steering metasurface.

Moreover, transmission MTS may use transmitarrays for phase and wavefront control [34],[38]. The other unit cell configurations and applications of transmissive phase G-MTS are listed in Table 1.



(a)

(b)

Figure 12: (a) The super unit of the designed composite absorber and (b) comparisons of absorptions between the traditional magnetic materials and the composite absorbers [31].

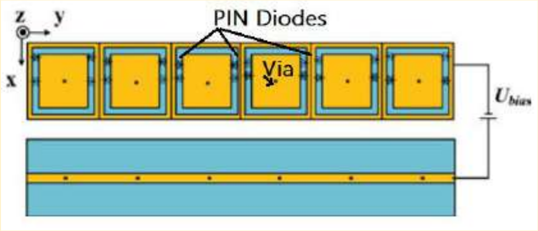


Figure 13: Geometry of the super cell and the DC circuit [34].

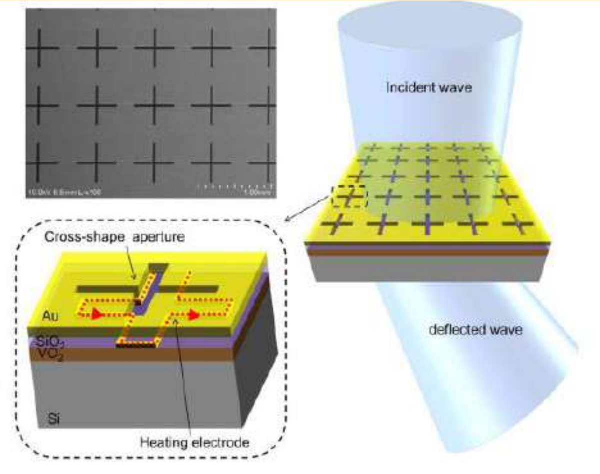


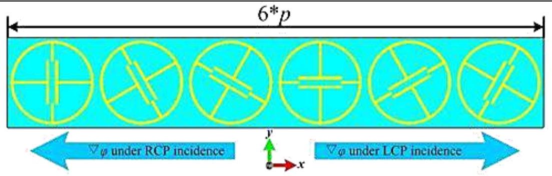
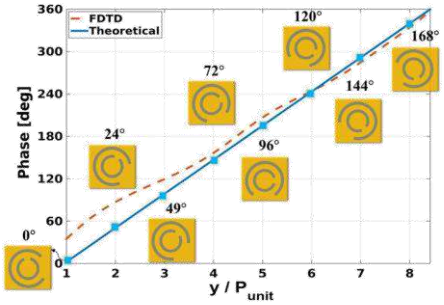
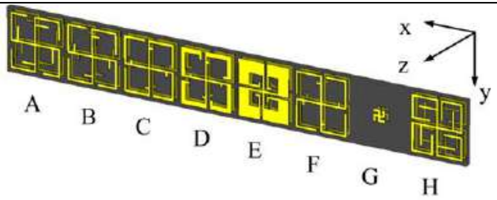
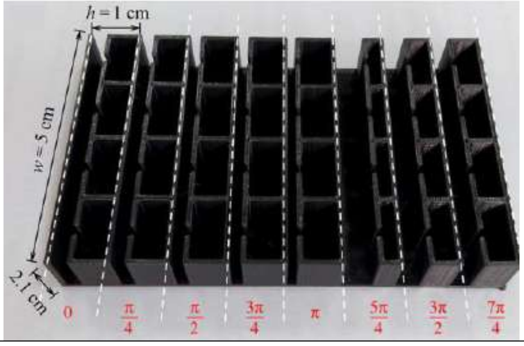
Figure 14: An SEM image of the fabricated prototype and operation principles of the electronically-controlled beam-steering metasurface [37].

B. Reflective Phase Gradient Metasurfaces

Compared with transmissive G-MTSs, the reflective type is easier since only phase profile design is considered. Usually, reflective G-MTSs have higher efficiency than transmissive types. So, several variations of phase G-MTSs based on reflective type, mainly arrays of metallic resonators on a dielectric substrate above a ground plane have been proposed [11], [46]-[51]. As with the previous transmissive type, many kinds of reflective G-MTSs are similar such as C-shaped [49], patch shaped [46], split ring shaped [50] and H-shaped [51]. The reflection phase of the plane wave reflected by a metasurface can be adjusted by varying the dimensions of the metal patch [46]-[47]. Hwang and Tsai investigated the reflection characteristics of multiple orthogonal G-MTS [46]. The reflection phase on a surface containing various sizes of metal patches should vary with respect to the observation position. Figure 15 shows the far-field reflection pattern on the *x-z* plane for the structure consisting of one period along the *x*-axis. It can be seen that the reflection main beam is steered away from the normal incident direction. Kuse *et. al.* combined the frequency selective surface and ground plane formed a reflective G-MTS using double layer of scaling patches [Fig. 16 (a)] and loop incorporating with patch as shown Fig. 16 (b) [47]. To enable both focusing and anomalous reflection under different polarizations, a bifunctional G-MTS was designed using a pair of orthogonal meander-line resonators as shown in Fig. 17 (a) [11]. As seen in Fig. 17 (b) and (c), a reflective bifunctional MTS achieves both functionality of a focusing lens and a beam deflector under two orthogonal polarizations, respectively.

Very recently, a new concept of the coding phase gradient metasurface was performed [48]-[52]. The proposed G-MTS has wide-band, wide-angle with zero and non-zero phase gradient based on Pancharatnam-Berry phase using the co-polarization reflection unit cells under circularly polarized (CP) wave incidence [48]. Figure 18 depicts the structure of coding unit cells and the design of

Table 1: Various phase gradient metasurfaces of transmissive type and their applications.

No.	Configuration of Metasurface	Ranges	Remarks/Applications	Ref.
1		15 GHz	• Normal incident LP wave split into two transmitted CP waves	[39]
2		1.55 um wavelength	• Anomalous wavefront bending • Bifunctional wavefront manipulation for divergence and convergence	[40]
3		9.6-10.4 GHz	• Metasurface based on chiral branched gammadion structure • Compact lenses and antennas at THz or higher frequencies	[41]
4		10 GHz	• Huygens' metasurface • Single-surface lenses, polarization controlling devices, stealth, and perfect absorbers.	[42]
5		Acoustic wave	• transmits sound energy from a single source and steers the transmitted wave front to form the desired fields. • Diverse wave-shaping such as non-diffracting beams, vortex beams, acoustic focusing, acoustic holography.	[43]-[44]
6		8.9-9.5 GHz	• couple the wave from the feed into spatial radiated wave • a similar electromagnetic field to that of spoof surface plasmon polariton rather than excite the spoof surface plasmon polariton.	[45]

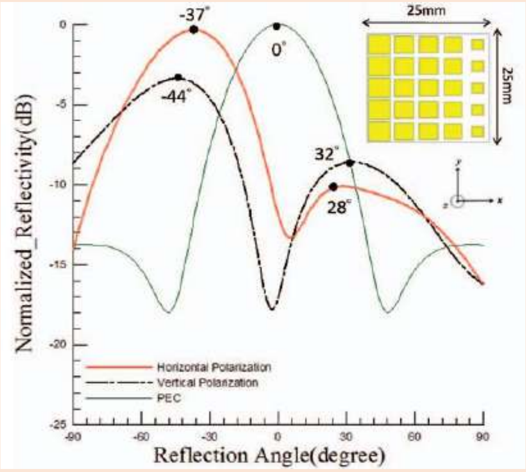
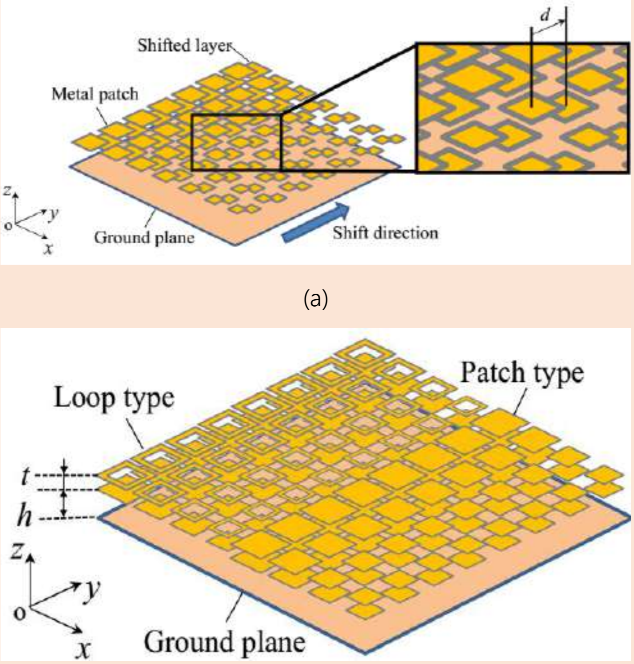


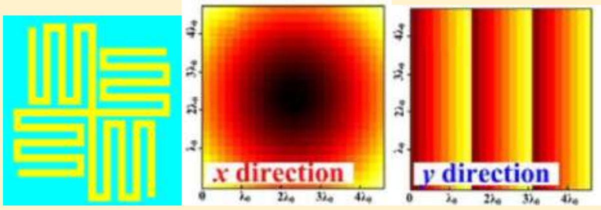
Figure 15: Far-field reflection pattern for a periodic gradient metasurface consisting of one period [46].



(a)

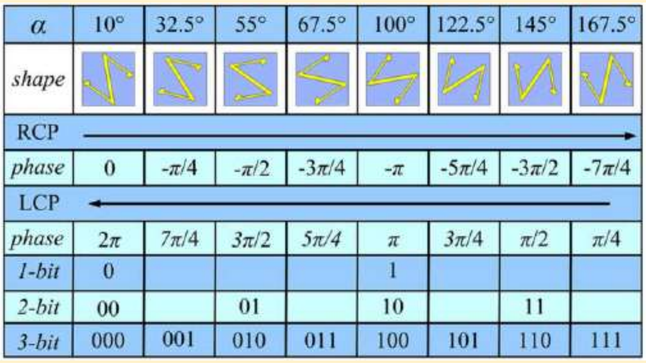
(b)

Figure 16: Configuration of double layer reflective G-MTSs (a) patch only (b) loop and patch [47].



(a) (b) (c)

Figure 17: (a) Topology of the three-turn meander-line resonator and the phase distributions of (b) focusing for Ex (c) anomalous reflection for *Ey* polarizations [11].



α	10°	32.5°	55°	67.5°	100°	122.5°	145°	167.5°
shape								
RCP	→							
phase	0	-*π*/4	-*π*/2	-3*π*/4	-*π*	-5*π*/4	-3*π*/2	-7*π*/4
LCP	←							
phase	2*π*	7*π*/4	3*π*/2	5*π*/4	*π*	3*π*/4	*π*/2	*π*/4
1-bit	0				1			
2-bit	00		01		10		11	
3-bit	000	001	010	011	100	101	110	111

Figure 18: structure of unit cells and phase responses of coding elements (LCP: Left-handed and RCP: Right-handed) [48].

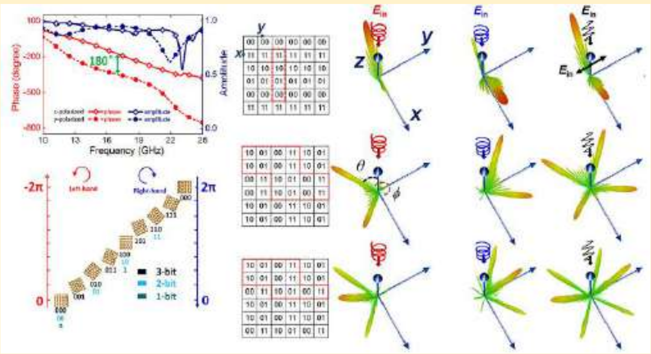
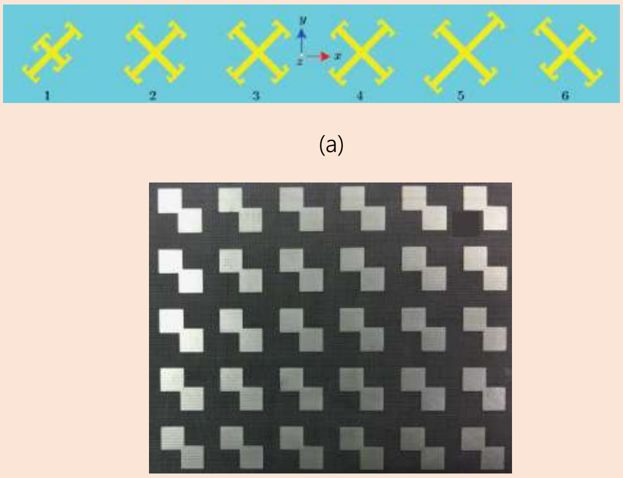


Figure 19: Reflection spectra of the unit cell, the definition of the bit elements and the 3D far-field radiation pattern of the digital metasurface [52].

the coding element. In the other shape, the corrugated meander line structured unit cell was designed for the digital metasurface [52]. Figure 19 shows performances of basic meta-particle and the definition of geometric phase coded bits. Moreover, the 3D far-field radiation pattern of the digital metasurface at 17 GHz with regular coding sequences is also mentioned.

In order to convert polarization and anomalous reflection simultaneously, reflective phase gradient metasurfaces with different unit cells were proposed [53]-[54]. Six modified cross-shaped structures were designed cautiously to serve as quarter wave-plates, and achieve 60° phase difference between adjacent structures as shown in Fig. 20 [53]. From results, the mirror reflectivity is lower than −10 dB; the axial ration is lower than 2 dB within the frequency band of 13.8-14.7 GHz which can achieve the linear-to-circular polarization. Moreover, Wu *et. al.* reported an ultra-wideband reflective linear cross-polarization converter based on anisotropic metasurface. Its unit cell is composed of a square-shaped resonator with intersecting diagonal and metallic ground sheet separated by dielectric substrate (Fig. 20(b)). In addition, a concept of multifunctional metasurfaces that possess different predetermined functionalities at different frequencies have been introduced. Huang *et. al.* explored a multispectral metasurface that can achieve beam deflection and broadband diffusion simultaneously at two different frequency bands [55]. Two-layered metallic patterns backed by a metallic ground plane was modeled a reflective



(a)

(b)

Figure 20: Reflective G-MTSs for polarized conversion (a) the modified cross shape [53] (b) photograph of the square-shaped particles with intersecting diagonal [54].

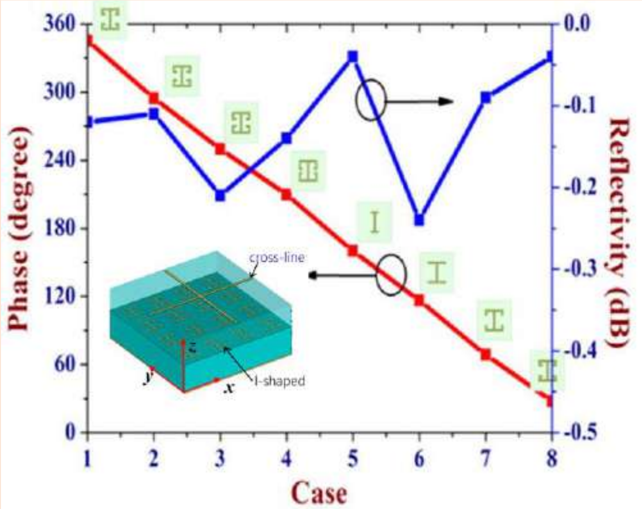
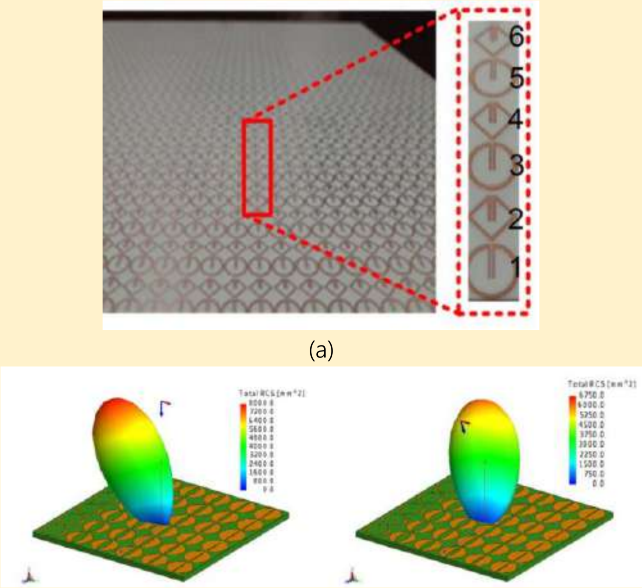


Figure 21: The reflection phase and magnitude for a series of I-shape patterns and structure of unit cell (inset) [55].

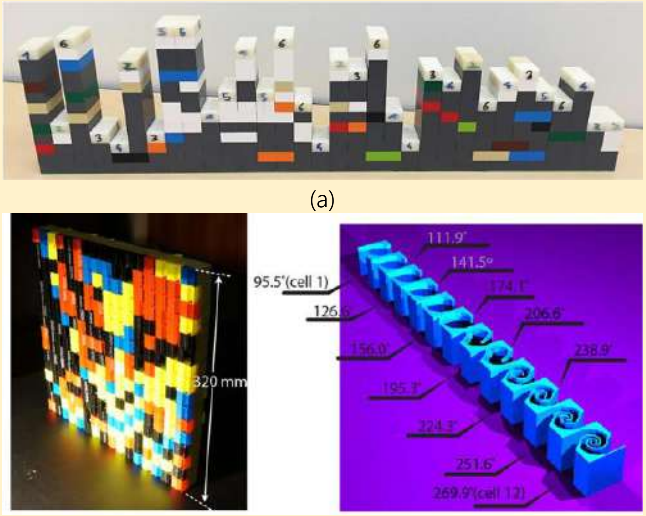
metasurface. The top-layer MTS utilizes the cross-line structures with two different dimensions for producing 0 and π reflection phase response, while the bottom-layer metasurface is realized by a topological morphing of the I-shaped patterns for creating the gradient phase distribution as show inset in Fig. 21. The reflection phase and magnitude with different I-shaped dimensions were designed to produce the gradient phase distribution with very high reflectivity (larger than -0.3 dB).



(a)

(b)

Figure 22: (a) A photo of fabricated phase G-MTS sample for RCS reduction [56] (b) The 3D bistatic RCS patterns at 10 GHz under normal incidence (left) and 30° incident angle (right) [57].



(a)

(b)

Figure 23: Acoustic cloaking with the metasurface (a) The complex random structure is constructed from LEGO bricks [58] (b) The photograph of a fabricated hologram and constituting unit cells used to achieve gradient phase delays [13].

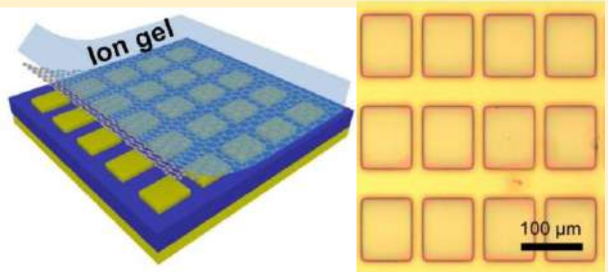


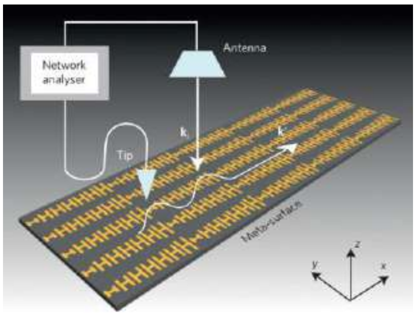
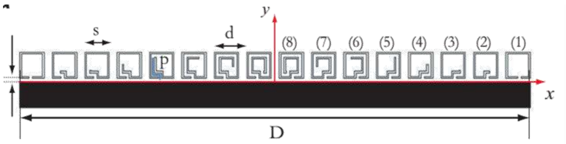
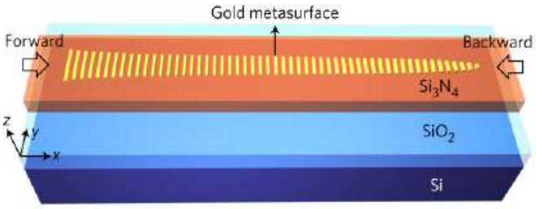
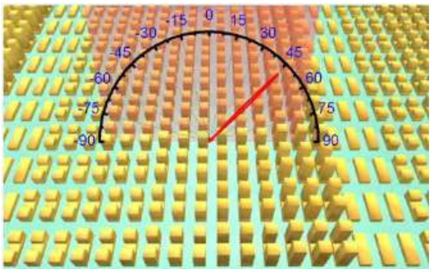
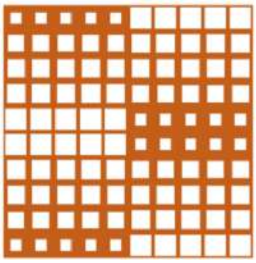
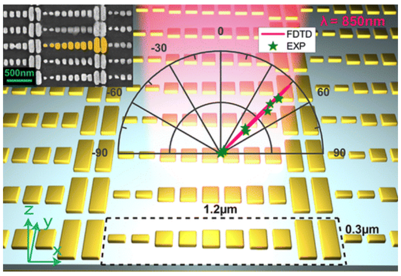
Figure 24: Structure of graphene metasurface [59].

Another important application of the MTS is to reduce radar cross section (RCS) due to the rapid development of the stealth technology. The conventional methods of RCS reduction include shaping and coating with radar absorbing materials. Compared with the RCS-reduction method based on absorption, this new approach of the MTS does not rely on the resistance and environment. Cheng *et. al.* experimentally and theoretically studied a dual-band phase G-MTS to accurately facilitate dual-band beams defection for electromagnetic waves [56]. The designed PGM is composed of two kinds of split-ring resonators as the basic element of a super cell. Figure 22 shows a photo of the fabricated phase G-MTS for RCS reduction. With the same concept, a stack of 2D gradually-varied subwavelength elliptical rings arrays was proposed as shown in Fig. 22 (b) [57].

In acoustic and very low frequency, phase G-MTSs have been also developed. Due to it is very low frequency (a few kHz), the unit cell should be particularly designed. Dubois *et. al.* proposed the metasurface carpet cloak, which has the random height profile (Figure 23). From the result, it exhibits a reflective surface with a large in-plane phase gradient.

Besides, graphene ribbons have exotic features such as low resistivity, high optical transparent, tunable conductivity, so they can be instead of metal-based

Table 2: Selected reflective gradient metasurfaces and their applications.

No.	Configuration of Metasurface	Ranges	Remarks/Applications	Ref.
1		15 GHz	• Convert a propagating to a surface wave with nearly 100% efficiency. • Trapped rainbows, lensing, beam bending, deflection, and even anomalous reflection/refraction.	[51]
2		Acoustic wave	• To manipulate sound energy to an extraordinary extent. • Acoustic imaging, sonic weaponry, and underwater communication.	[60]
3		1,480–1,580 nm	• To control guided waves via strong optical scattering at subwavelength intervals. • waveguide mode converters, polarization rotators and waveguide devices supporting asymmetric optical power transmission.	[16]
4		1548 nm	• 3D nanostructures, namely vertical split-ring resonators • beam steering with phase modulation by tuning only the vertical dimension of the VSRRs	[61]
5		7 GHz	• 2D hybrid electromagnetic gradient metasurface with non-uniformly distributed reflection phase. • To reduce radar cross section at boresight.	[62]
6		750–900 nm	• High-efficiency anomalous reflections (~80%) for near-infrared light • antireflection coating, polarization and spectral beam splitters, high-efficiency light absorbers, and surface plasmon couplers.	[63]

structure. Miao *et. al.* investigated full-range active phase modulations in the terahertz regime, realized by gate-tuned ultra-thin reflective metasurfaces based on graphene as shown in Figure 24 [59]. The selected reflective G-MTSs are listed in Table 2.

IV. CONCLUSIONS

In conclusion, we have reviewed some of the recent advances in the gradient metasurfaces. We believe that gradient metasurface holds great promises for future development of novel compact and muti-functional electromagnetic devices. We also hope that this paper will provide some insights to researchers interested in gradient metasurface and help them to develop gradient metasurface with better performance and different functionalities.

ACKNOWLEDGEMENT

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BIOGRAPHY

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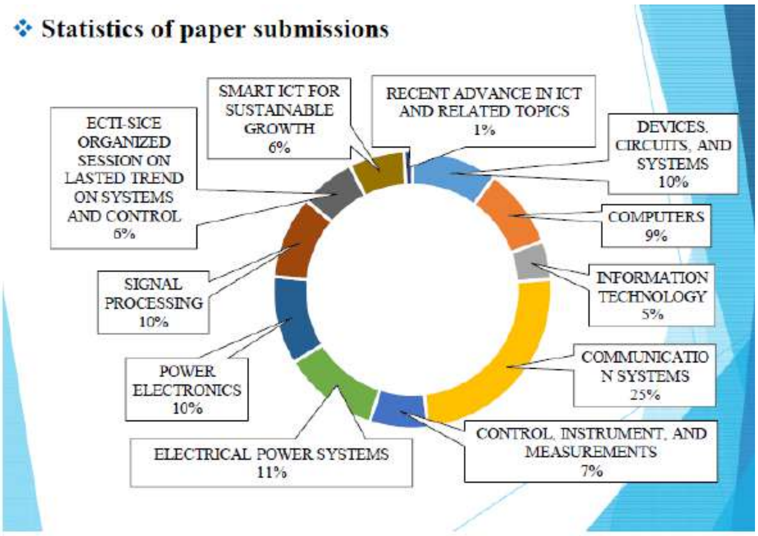

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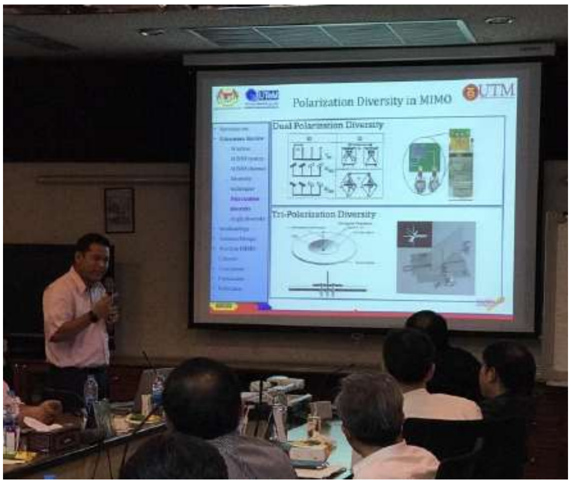

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Special issues in ECTI-CIT Journal
(For Extended Version)

Hosted By:

Department of Computer Engineering
Faculty of Engineering
King Mongkut's Institute of Technology Ladkrabang

Preliminary call-for-papers

ITC-CSCC 2018

The 33rd International Technical Conference on Circuits/Systems, Computers and Communications

Theme: Fostering Innovation towards Digital Transformation

July 4 – 7
2018
Bangkok , Thailand

With the great success of the International Technical Conference on Circuits/Systems, Computers and Communications (ITC-CSCC) as the world leading conference devoted to the advancement of high technologies in Circuits/Systems, Computers and Communications, we would like to invite all the scholars and experts around the world to attend the 33rd ITC-CSCC 2018 to be hosted in Bangkok, the City of Angels, Thailand.

Topics

The conference is open to researchers from all regions of the world. Participation from Asia Pacific region is particularly encouraged. Proposals for special sessions are welcome. Papers with original work in all aspects of Circuits/Systems, Computers and Communications are invited. Topics include, but not limited to, the followings

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Circuits & Systems

- Computer Aided Design
- Power Electronics & Circuits
- Analog Circuits
- RF Circuits
- Modern Control Systems
- Medical Electronics & Circuits
- Semiconductor Devices & Technology
- VLSI Design
- Sensors & Related Circuits

Computers

- Artificial Intelligence
- Image/Speech Processing
- Internet Technology & Applications
- Computer Systems & Applications
- Multimedia Service & Technology
- Computer Vision
- Face Detection & Recognition
- Security
- Watermarking
- Data Mining and Big Data Analytics
- Cloud computing
- Engineering Education

Communications

- Antenna & Wave Propagation
- Network Management & Design
- Optical Communications & Components
- Circuits & Components for Communications
- IP Networks & QoS
- Communication Signal Processing
- Ubiquitous Networks
- Multimedia Communications
- Visual Communications
- Future Internet Architectures
- IoT
- 5G and beyond
- Satellite Navigation
- Vehicular Communication

Submission of Papers

Prospective authors are invited to submit original paper(s) of either MS Word or PDF format written in English. Abstract is limited to two pages of text and figures. Abstract can be submitted on the official website. If you have any trouble in preparing papers and online submission, please contact the conference secretariat.

Proceedings and Publications

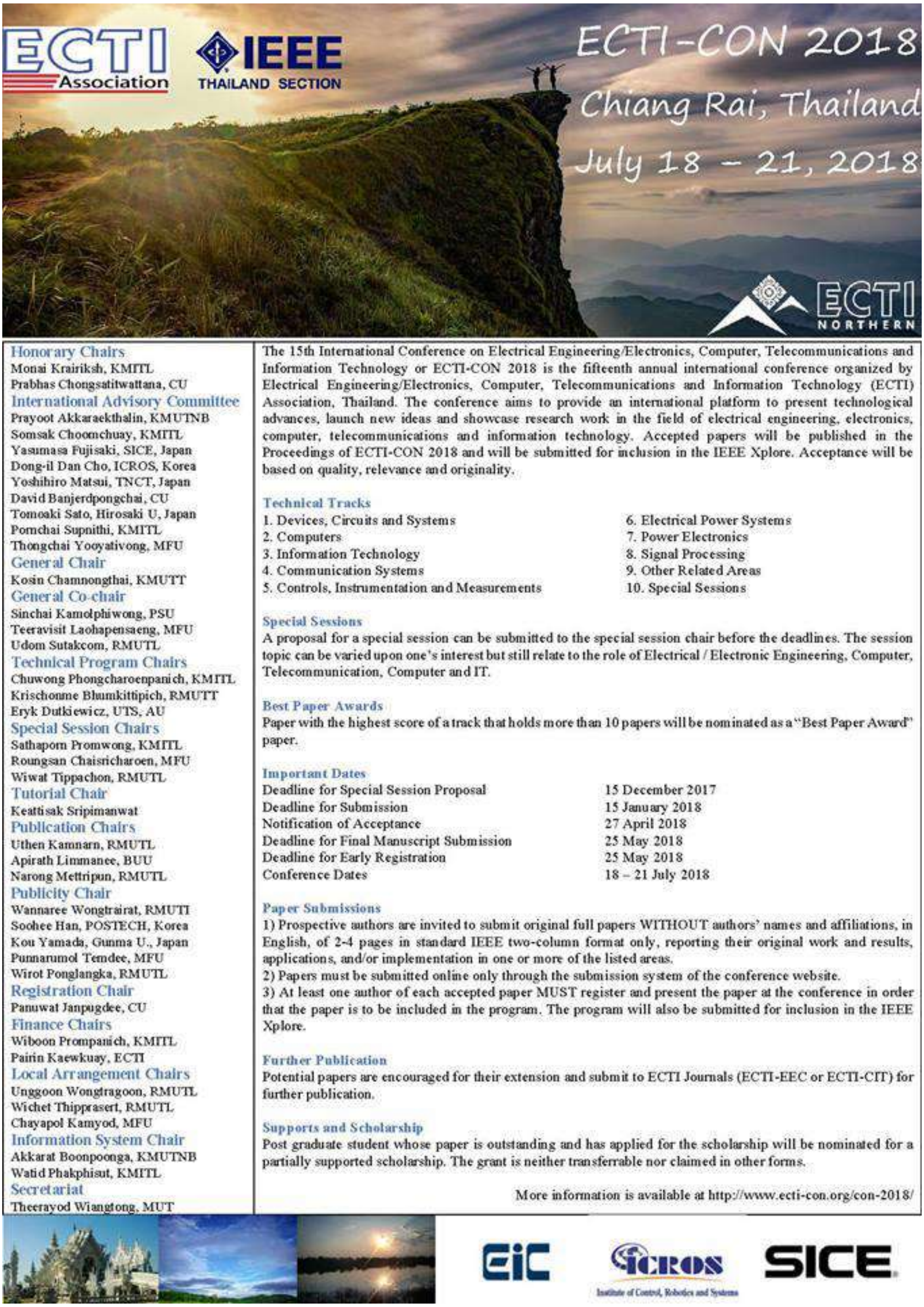
All registered participants are provided with conference proceedings. Moreover, authors of the accepted papers are encouraged to submit full-length manuscripts to IEIE JSTS (Korea), IEICE Transactions (Japan), or ECTI Transaction (Thailand). Papers passed through the standard review procedures of the IEIE JSTS and IEICE Transactions will be published in regular issues while ECTI Transactions and Engineering Journal will be published in special issues. The authors (or their institute) are requested to pay the publication charge for the IEIE JSTS or IEICE Transactions when their paper is accepted.

Important Dates

Submission of Two-Page Extended Abstract:
April 1, 2018
Notification of Acceptance:
May 7, 2018
Submission of Camera Ready Paper:
June 4, 2018

Contact: secretary@itc-cscc2018.org
http://www.itc-cscc2018.org

ITC-CSCC 2018 July 4 – 7, 2018 Bangkok, Thailand



ECTI-CON 2018

Chiang Rai, Thailand

July 18 – 21, 2018

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The 15th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology or ECTI-CON 2018 is the fifteenth annual international conference organized by Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI) Association, Thailand. The conference aims to provide an international platform to present technological advances, launch new ideas and showcase research work in the field of electrical engineering, electronics, computer, telecommunications and information technology. Accepted papers will be published in the Proceedings of ECTI-CON 2018 and will be submitted for inclusion in the IEEE Xplore. Acceptance will be based on quality, relevance and originality.

Technical Tracks

1. Devices, Circuits and Systems
2. Computers
3. Information Technology
4. Communication Systems
5. Controls, Instrumentation and Measurements
6. Electrical Power Systems
7. Power Electronics
8. Signal Processing
9. Other Related Areas
10. Special Sessions

Special Sessions

A proposal for a special session can be submitted to the special session chair before the deadlines. The session topic can be varied upon one's interest but still relate to the role of Electrical / Electronic Engineering, Computer, Telecommunication, Computer and IT.

Best Paper Awards

Paper with the highest score of a track that holds more than 10 papers will be nominated as a "Best Paper Award" paper.

Important Dates

Deadline for Special Session Proposal	15 December 2017
Deadline for Submission	15 January 2018
Notification of Acceptance	27 April 2018
Deadline for Final Manuscript Submission	25 May 2018
Deadline for Early Registration	25 May 2018
Conference Dates	18 – 21 July 2018

Paper Submissions

1) Prospective authors are invited to submit original full papers WITHOUT authors' names and affiliations, in English, of 2-4 pages in standard IEEE two-column format only, reporting their original work and results, applications, and/or implementation in one or more of the listed areas.
2) Papers must be submitted online only through the submission system of the conference website.
3) At least one author of each accepted paper MUST register and present the paper at the conference in order that the paper is to be included in the program. The program will also be submitted for inclusion in the IEEE Xplore.

Further Publication

Potential papers are encouraged for their extension and submit to ECTI Journals (ECTI-EEC or ECTI-CIT) for further publication.

Supports and Scholarship

Post graduate student whose paper is outstanding and has applied for the scholarship will be nominated for a partially supported scholarship. The grant is neither transferrable nor claimed in other forms.

More information is available at http://www.ecti-con.org/con-2018/

The 18th ISCIT 2018, Bangkok Thailand "Communication and IT for Smart City"

30 September - 2 October 2018

The 18th International Symposium on Communications and Information Technologies (ISCIT 2018) will be held in Bangkok, city of angles, ISCIT 2018, under the technical sponsorship of IEEE, will provide a forum for researchers, engineers and industry experts to exchange and discuss new ideas, recent development, and breakthroughs in IoT, communications and information technologies. ISCIT2018 will also offer an exciting social program. Accepted and presented papers will be published in the conference proceedings and submitted to IEEE Xplore as well as other Abstracting and Indexing databases.

Important Date

Date	Details
May 27, 2018	Paper submission deadline
April 29, 2018	Proposals for workshops, Tutorials and Special Sessions
July 1, 2018	Paper acceptance notification
July 29, 2018	Author registration Camera-ready paper submission

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