Long-wave infrared variable emissivity combat identification panel

Robert E Peale
Dept. of Physics
University of Central Florida
Truventic LLC
Orlando, USA
Robert.Peale@ucf.edu

Pedro N Figueiredo
Truventic, LLC
Orlando, USA
p.figueiredo@truventic.com

Francisco J. González
Truventic, LLC
Orlando, USA
javier.iico@gmail.com

Masahiro Ishigami
Dept. of Physics
University of Central Florida
Orlando, USA
masaishigami@gmail.com

***Abstract*— A structured thin film with widely variable long-wave emissivity and insignificant change to its visible reflectance is proposed and demonstrated theoretically. An application is dynamic Identification Friend or Foe (IFF) panel viewable at LWIR but optically invisible.**

Keywords—Salisbury Screen, Identification of Friend or Foe, Long Wave Infrared, Combat Identification Panel, variable emissivity

I. INTRODUCTION

Long wave infrared (LWIR)-viewable passive IFF panels (or Combat Identification Panels, CIP) were first widely used during the Iraq war. They distinguish friendly-force vehicles to reduce friendly fire incidents by means of spatial emissivity contrast. However, with the proliferation of low cost uncooled micro-bolometer cameras, there is increased likelihood an enemy can distinguish an otherwise-camouflaged IFF-equipped vehicle from background.

The opportunity presented is a dynamic IFF that allows emissivity contrast to be blanked. Problems with known variable emissivity devices [1] include slow switching, unsuitable materials, and unscalable structures. In contrast, the design proposed here comprises a simple multi-layer thin film made from materials, which are robust under UV and a wide range of temperature and moisture conditions.

Fig. 1 presents the considered design, a Salisbury screen [2] comprising a metal ground plane, a dielectric layer, and a semi-transparent top layer. Strong absorption occurs when infrared standing waves in the dielectric cause high field amplitude at the lossy top-layer. The center wavelength and width of the resonant absorption band may be engineered to span the LWIR (8-12 μm wavelength) band.

Switching in our design is achieved by electrical tuning of the graphene permittivity by electrical gating. The gate electrode must be insulated from the graphene, but it also must be as close as possible to the graphene to achieve the highest electric field for a given applied voltage. The semiconductor Si acts as the gate electrode and simultaneously as quarter-wave dielectric. This dual function is possible because silicon's plasma frequency at ordinary doping levels falls well below LWIR frequencies [3]. Thus, at infrared frequencies (30 THz), the Si layer behaves as a low-loss dielectric, but at the low frequencies (< kHz) used to modulate the graphene conductivity, the Si behaves as a conductor. A very thin layer of high-strength dielectric isolates the Si from the graphene, which may be mechanically protected by another thin dielectric without affecting the gating properties.

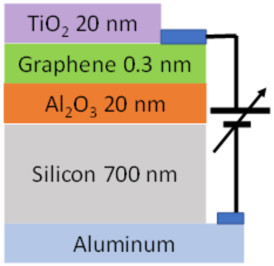

Figure 1. (left) Schematic of Salisbury screen with dynamically-tuned LWIR emissivity

II. METHODS

Reflectivity spectra were calculated as function of layer thicknesses, graphene chemical doping, and gate voltages using Fresnel equations to seek tunable absorption resonances with suitable center wavelength, spectral width, and strength. Reflectance minima correspond to absorption and emissivity maxima. Graphene conductivity (and permittivity) range is centered around a zero-bias value determined by chemical doping and extending to values limited by achievable gate voltages. The calculation input was a 5-layer structure comprising metal, Si infrared dielectric, Al_2O_3 gate dielectric, graphene, and TiO_2 protection layer. The Al_2O_3 gate dielectric needs to be as thin as possible to allow maximum range of gating, e.g. 20 nm. The total thickness of the Si layer and gate dielectric is taken to give quarter-wave optical thickness at 10 μm wavelength, which indicates for the Si layer (index = 3.42) a thickness of 700 nm.

The resonant absorption strength depends strongly on the complex permittivity of the top layer [4]. Graphene's permittivity is well-described by the Drude model, which in the

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long-wave limit is given by $\varepsilon = 1 + i\,\sigma/(\varepsilon_0\,\omega)$, where σ is the DC conductivity and ε_0 the vacuum permittivity. This formula holds in the LWIR where $\omega\tau \ll 1$ (ω = frequency, τ = relaxation time).

Chemical doping of graphene is chosen to achieve the widest range of emissivity. Conservatively, the Al_2O_3 static permittivity is 6, and its break down voltage is 5 MV/cm. Including a safety factor of two, this allows us to apply gate voltages of ± 5 V across a 20 nm gate. This enables fast switching with low-voltage and low-power electronic control.

III. RESULTS

Figure 2 presents Fresnel calculations for reflectance R in the LWIR spectral region. There are two sets of three curves corresponding to two different chemical doping levels. The black curves have a zero-bias sheet resistance of 1222 Ω/sq. For the red curves, it is 481 Ω/sq. The other pair of curves in each set correspond to gate biases of ± 5 V. An absorption resonance is observed with a full-width at half maximum (FWHM) that spans the LWIR. The sample with lower chemical doping has the larger achievable range of reflectance values. The emissivity can be varied by a factor of 3.

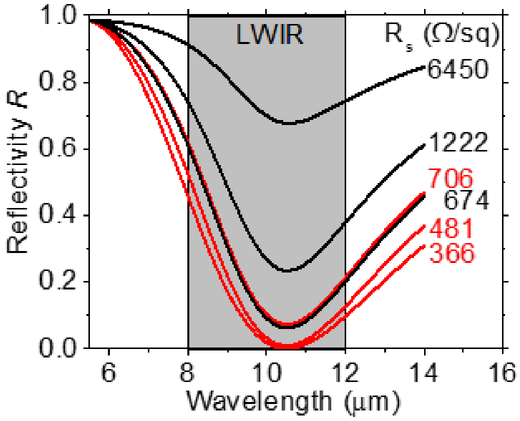

Figure 2: Calculated LWIR reflectivity spectra for two different chemical doping levels and gate voltages of -5, 0, and 5 V.

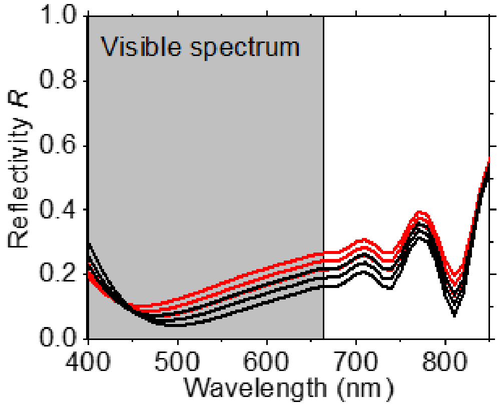

Figure 3: Corresponding visible to near-IR spectra

The visible reflectance spectrum should not change when the LWIR emissivity is changed. This is satisfied automatically with a Si-based Salisbury screen, because the strong fundamental absorption of Si below 1 μm wavelength, kills the Q of the resonance, as demonstrated in Fig. 3. The higher resonance harmonics weaken as wavelength decreases below the fundamental absorption edge. In the visible no resonances occur at all, reflectance is low, and the change in reflectance with gate bias is less than 10% within each group of curves.

IV. DISCUSSION AND SUMMARY

Mirror-finish metal substrates may be produced by aluminum deposition on smooth ceramic substrates. Si may be deposited on this metal surface by electron-beam evaporation, sputtering, or plasma-enhanced chemical vapor deposition. Ohmic contact between silicon and aluminum may be achieved by annealing at 475°C in reducing forming gas (20:1 N_2/H_2), which avoids oxidation and reduces the existing interface oxide between Al and Si. Al_2O_3 may be deposited by electron-beam evaporation. Growth of graphene over large areas can be achieved by chemical vapor deposition (CVD). Chemical doping may be achieved by depositing MoO_x.

Our recent work on Salisbury screens [4] shows that Fresnel calculations and experiment are in excellent agreement, and strong changes in absorption occur when top-layer permittivity is modified. Graphene-based Salisbury screens have been described recently by others [5-7]. These screens are either unsuited for dynamic, repetitive switching, showed weak gating, require electron-beam lithography, or operated outside the LWIR wave band.

In summary, structured thin film with widely variable long-wave emissivity and insignificant change to its visible reflectance is proposed and demonstrated theoretically, with application to dynamic Identification Friend or Foe (IFF) panel viewable at LWIR imagers, but optically invisible.

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