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- Experimental Method
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**Introduction**

- Security screening
- Remote sensing
- Bio-Medical Imaging

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2. Figure copied from: Coherent Infrared Center Advance Light Source: http://circe.lbl.gov/THzGap.html
Basic Design

Schematic cross section of metal and dielectric coated Hollow-core THz waveguide
Theory

\[ \alpha_{\text{tot}} = \alpha_{\text{propagation}} + \alpha_{\text{bending}} \]

\[ \alpha(\text{TM}_{pq}) = 10 \times \frac{1}{r} \left( \frac{n}{n^2 + k^2} \right) \quad \text{and} \quad \alpha(\text{TE}_{pq}) = 10 \times \frac{u^4}{(u^2 - p^2)} \frac{n}{n^2 + k^2} \left( \frac{1}{k_0^2 r^3} + \frac{p^2}{u^4 r} \right) \]

Theoretical Loss as a function of Wavelength for lower order TE & TM modes

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Selection of Metal

Skin Depth:

\[ \delta = \frac{2\rho}{\sqrt{2\pi f \mu R \mu_0}} \]

- \( \rho \) - Resistivity (\( \Omega \)m)
- \( f \) - Frequency = 1.4THz
- \( \mu_0 \) - 4\( \pi \)x10\(^{-7} \) (Henries/meter)

\( \delta_{Ag} = 0.05 \mu m \) at 1.4 THz and 0.08 \( \mu m \) at 584 GHz;

\( \delta_{Au} = 0.07 \mu m \) at 1.4 THz and 0.1 \( \mu m \) at 584 GHz.

\[ F_{Metal} = \frac{n}{n^2 + k^2} \propto \frac{1}{\text{Reflectivity}} \]

When \( \lambda = 215 \mu m \)

\( F_{Ag} = 0.684, F_{Au} = 0.878, F_{Al} = 0.994, F_{Cu} = 1.159, F_{W} = 1.965, F_{Pb} = 2.945 \)

Selection of Dielectric

\[ \alpha(\text{HE}_{pq}) = 10 \frac{u_{pq}^2}{(n_0 k_0)^2 r^3 n^2 + k^2} F_{\text{diel}}; \quad F_{\text{diel}} = \frac{1}{2} \left( \frac{n_d^2}{n_d^2 - 1} \right)^2 \]

\[ t_{\text{diel}} = \frac{\lambda}{2\pi \sqrt{n_d^2 - 1}} \tan^{-1} \left[ \frac{n_d}{\sqrt{4 \frac{n_d^2}{n_d^2 - 1}}} \right] \]

Attenuation coefficient of as a function of bore diameter for lower order HE modes, for TE_{11} and HE_{11} modes of Silver coated waveguide

Base Material: Polycarbonate  Metal: Silver, Gold  Dielectric Material: Polystyrene

Fabrication: Liquid Flow Coating Process
Fabrication: dynamic liquid phase coating process ........

Experimental Setup

Experimental setup for the measurement of attenuation coefficient for metal, metal/dielectric coated Terahertz waveguides.
Mode Cleaning

The attenuation constant for $E_{Hnm}$ modes in dB/m is given by,

$$\alpha_{nm} = 8.686 \left( \frac{u_{nm}}{2\pi} \right)^2 \left( \frac{\lambda^2}{r^3} \right) \text{Re}(v_n) \quad \& \quad v_n = \frac{N^2 + 1}{2\sqrt{N^2 - 1}}$$

A polycarbonate tube with CIR 1.64 – ix0.05, 5 cm length: 1.25 dB, 6.6 dB, 16.2 dB and 15 cm length: 3.76 dB, 19.79 dB, 48.7 dB for EH11, EH12, and EH13 modes.

Two-dimensional mode profiles of the propagated terahertz beam acquired using silicon bolometer a) 20 cm after OAP, b) after 5 cm, and c) 15 cm Polycarbonate tube.

Theoretical and Experimental attenuation coefficients as a function of inner bore diameter for silver and gold coated waveguides at 1.4 THz and 584 GHz freq.
Bending Loss

\[ \alpha_{\text{tot}} / r^3 = (\alpha_{pq} L + \alpha_{\theta} L_R) / r^3 = \left( \frac{C_1}{r^3} \right) L + \left( \frac{C \cdot r^3}{R} \right) R \theta / r^3 = C_1 \left( \frac{L}{r^6} \right) + C(\theta) \]

Total attenuation coefficient per bore diameter cube as a function of bending angle and bore diameters for Ag coated waveguides at 584 GHz (inset: 1.4 THz) with 6.5 cm bend radius.
According to Beer-Lambert’s Law,

$$\alpha = \frac{10}{2L} \log \left( \frac{P_{in}}{P_{out}} \right)$$

Spatial output profile from Ag coated waveguides at (I) 1.4 THz, (II) 584 GHz as a function of bore diameter (rows) (2) 2 mm, (3) 3 mm, (4) 4mm; and bending angle (columns) (1) 0°, (2) 60°, (3) 120°.
Summary

- Attenuation Characteristics of flexible Terahertz waveguides were studied at both 1.4 THz and 584 GHz frequencies.

- Propagation loss as small as 1.7 dB/m was achieved in silver coated waveguides by coupling the lowest loss $TE_{11}$ mode.

- The 2 mm ID metal coated waveguide showed least variation in transmission loss (<1 dB/m) with $0^\circ$ – $150^\circ$ bending angle.

- The 1 µm thick silver coated 2 mm inner diameter waveguides can be used at both the frequencies, to obtain low transmission losses and mode preservation.
THANK YOU