Electrically Active Defects and Dielectric Loss in Silicon Carbide

J. M. Dutta[1], C. R. Jones[1], V.V. Parshin[2], B. Garin[3], and V.I. Polyakov[3], A. Rukovishnikov[3]

[1]Department of Physics, North Carolina Central University, Durham, NC 27707 U.S.A.
[2]Applied Physics Institute, RAS, Nizhny Novgorod, Russia
[3]Institute of Radio Engineering & Electronics, RAS, Moscow, Russia

Abstract—**Data are presented on SiC of various grades for their dielectric loss values at millimeter wavelengths to explore their potential as an alternate material for gyrotron window application. In order to identify the impurities or defects that give rise to the excess loss, temperature-dependent conductivity and DLTS measurements are being undertaken on SiC. Dielectric loss measurements over a wide range of temperatures are in progress to verify the results obtained from electrical methods and help to determine the primary loss mechanisms for SiC in the millimeter wave length range. Experimental results and their implications to loss properties will be discussed.**

I. INTRODUCTION AND BACKGROUND

The response of materials to electromagnetic waves in the millimeter (mm) and sub-millimeter (smm) wavelength range (from approximately 50 to 500 GHz) has received relatively little study. As an understanding of the nature and origin of absorption in materials at these wavelengths has basic significance for solid state physics as well as importance for RF technology. In an ideal crystalline material, theory predicts that the intrinsic lattice loss (ILL) in this frequency region arises from two-phonon processes and is expected to be quite small [1]. In practice, a higher level of loss is observed, due to lattice disorder, defects, impurities, and free charges. The role of these various mechanisms has not been established. It is one of the key problems that determine perspectives for the development of the technology of advanced devices and systems operating in this range. These developing applications include, for example, imaging for security screening, high bandwidth communications, and the fusion energy program. The latter application has become pressing because the design of the International Tokamak Experimental Reactor (ITER) hinges upon the use of megawatt level vacuum tube sources (gyrotrons) operating at the plasma's cyclotron resonance frequency of 170 GHz. Failure of the vacuum window on these tubes has proven to be a limiting factor in the high power performance [2]. Currently only the very expensive CVD diamond has shown satisfactory performance and even its losses are still far in excess of the theoretical limit [1]. Recently high-purity, semi-insulating silicon carbide (HPSI-SiC) has also been shown to have relatively low loss and is a promising alternative material [3, 4].

The evaluation of very low loss materials in the millimeter-wave region requires precision measurement of the change in the linewidth of a resonant cavity when a sample is inserted. The precision required is on the order of a few kHz change in a 300 kHz linewidth. For a number of years this laboratory (NCCU) has utilized the combination of a backward wave oscillator (BWO) source and a microwave spectrum analyzer to obtain such measurements. We have achieved this precision by installing a simple and relatively inexpensive, phase-locked loop (PLL) to stabilize the BWO frequency and synchronize it with the analyzer's local oscillator (LO). This newly developed system and details of the dielectric measurement method will be presented.

II. RESULTS

Samples of high purity ("vanadium free"), semi-insulating (HPSI) SiC have become available from the commercial firm CREE and the first measurements of loss for this material in the mm-wave region were performed at this laboratory (NCCU). Some of the recent results are tabulated below. The data in Table1 suggest a trend toward higher loss as the frequency is increased. If confirmed, this would indicate that free charge carriers are not the predominant cause of loss.

Initial measurements [3] of the loss tangent in Silicon Carbide at millimeter wavelengths yielded a value of 5.5×10^{-5} at room temperature. While low, this value is still well above that expected for the ideal material, hence studies have been undertaken to identify the impurities or

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defects that give rise to the excess loss. Previous studies of resistivity versus temperature by CREE researchers [5] revealed the presence of several deep level states with excitation energies in the range of 0.9 to 1.5 eV. In charge-based deep level transient spectroscopy (Q-DLTS) measurements we observed several discrete deep levels in HPSI-SiC substrates related to intrinsic point defects (Fig.1). The donor defect centers – A with activation energies E_a ~ 1.5 eV and capture cross section $\sigma_A \sim 10^{-14}$ are associated with the carbon vacancy - Vc. Deep centers - B and D with activation energies E_a ~ 0.6 eV and E_a ~ 0.75 eV most probably are related to (Vc – Vsi) complex and silicon vacancy - Vsi, respectively. The capture cross sections of these defects are approximately $\sigma_B = 2x10^{-17}$ cm^2, $\sigma_D = 3x10^{-15}$ cm^2. The deep defect centers – C with E_a ~ 0.25 eV and $\sigma_C \sim 3x10^{-16}$ cm^2 are attributed to with atom displacement on the carbon sublattice in SiC and have a microstructure containing carbon vacancy or carbon interstitial. The acceptor defect centers E_n with activation energies ~ 0.6 eV and $\sigma_D = 3x10^{-15}$ cm^2 was found also and its possible identification is discussed.

We are currently measuring the loss tangent for SiC at millimeter wavelengths over the temperature range, 295 K to 800 K and these results and their implications for identifying the mechanisms that cause excess loss in Silicon Carbide will be discussed.

Sample Type	Dielectric Constant	Tanδ	Frequency (GHz)
CH0532-05	9.99	6.4×10^{-5}	131.6
CH0532-12	9.99	7.4×10^{-5}	131.4
FF0147-10	9.74	6.6×10^{-5} 4.8×10^{-5}	170 90
FF019606 FB0762-07	9.95 9,48	4.3×10^{-5} 5.1×10^{-5}	145.5 132.1

Table1. Dielectric properties of HPSI-SiC

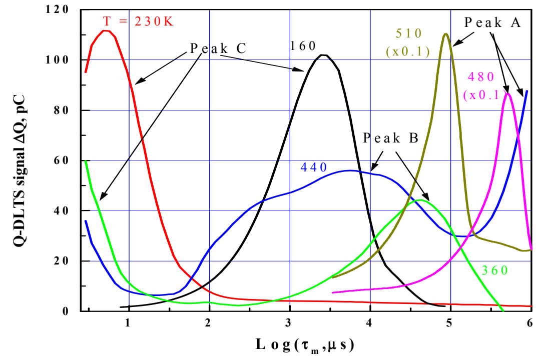

Fig.1. Q-DLTS spectra one of the sample HPSI SiC (second) at different temperatures T.

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