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High Frequency Applications of Polycrystalline Diamond Field-Effect Transistors

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In recent years, wide bandgap semiconductors have attracted attention as high-power, high-frequency device materials. In particular, diamond has exceptionally high figure of merits in the above field of application, because of excellent material properties such as high breakdown field (2 x 10^7 V/cm), the highest thermal conductivity in materials (22 W/cm·K), low dielectric constant (5.7). In order to make the best use of merits of diamond, hydrogen terminated surface conductive layer which has suitable properties for channel of FETs such as high density of carriers (10^{13} cm^{-2}), low surface states ($< 10^{11}$ cm^{-2}) and shallow carrier profiles (< 10 nm) has been utilized for high transconductance and high frequency homoepitaxial diamond FETs [1,2].

From the industrial point of view and for the purpose of realization of MMICs on diamond, attainment of high performance transistors on polycrystalline diamond (poly-diamond) films is highly desired. In this study, poly-diamond MISFETs with CaF_2 gate insulator are fabricated on undoped hydrogen-terminated poly-diamond film by self-aligned gate process. High transconductance and high RF performance poly-diamond FETs are realized for the first time.

Figure 1 shows the I_{DS}-V_{DS} characteristics of 0.75 μm gate poly-diamond MISFET measured by source measure unit system. The maximum extrinsic transconductance g_m is 50 mS/mm (@V_{GS}=-1.0V). This is the maximum performance in poly-diamond FETs ever reported. Improvement of g_m by gate refining is shown in fig. 2. Slight increase of g_m by gate refining is shown in this figure. Because of the scattering at grain boundaries, some FETs show low g_m. Consequently, the dispersion of g_m becomes larger than that of homoepitaxial FETs. Small-signal on-wafer S-parameter measurements are carried out on poly-diamond MISFETs. Figure 3 shows the gain characteristics calculated from S-parameters. The cut off frequency (f_T) of 2.1 GHz and maximum oscillation frequency (f_{max}) of 3.5 GHz are obtained. The power gain at 1 GHz reaches 12 dB, which is comparable to homoepitaxial diamond MISFETs. The stability factor k is lower than 1 in the frequency range of 0.5 – 1.1 GHz. f_{max} of 4.2 GHz is obtained by insertion of extrapolation straight line of –6dB/oct. on MSG at 1.1 GHz. Improvement of f_T by gate refining is shown in fig. 4. The maximum f_T of 2.5 GHz are obtained at 0.65 μm gate MISFET. f_T is improved by gate length refining. However, this performance is lower than those of homoepitaxial films. Due to the grain boundaries around channel-drain area, the large gate-drain capacitance is formed. This gate-drain capacitance limit the improvement of RF performance by g_m and source-gate capacitance improvement. Poly-diamond FETs with high RF performance comparable to homoepitaxial diamond FETs are expected by fabricating larger grain size diamond substrates.

References

[1] H. Umezawa, et. al. Jpn. J. Appl. Phys. 38 (1999) L908.

[2] H. Taniuchi et. al. IEEE EDL (2001) (in print)

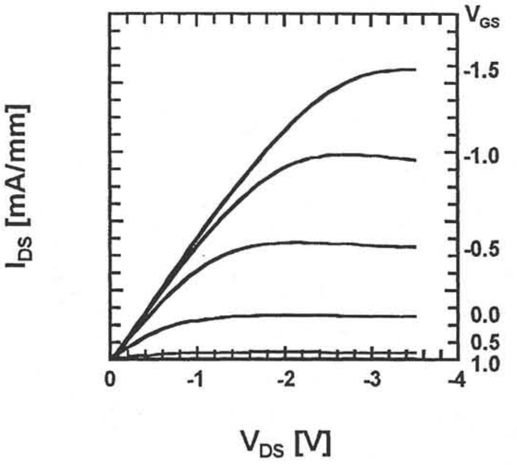

Fig. 1. I_{DS}-V_{DS} characteristics of poly-diamond MISFET with 0.75 μm gate length. gm = 50 mS/mm @ VGS = -1V.

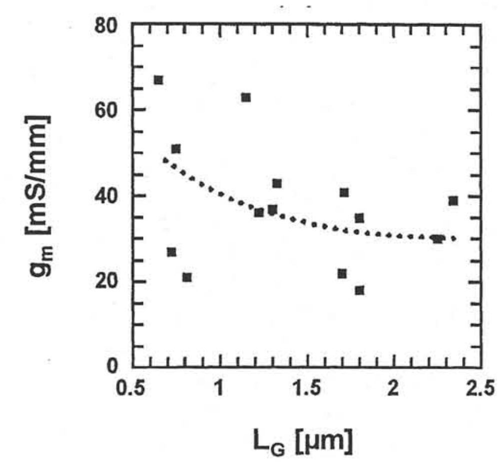

Fig. 2. Extrinsic transconductance versus gate length of poly-diamond MISFETs.

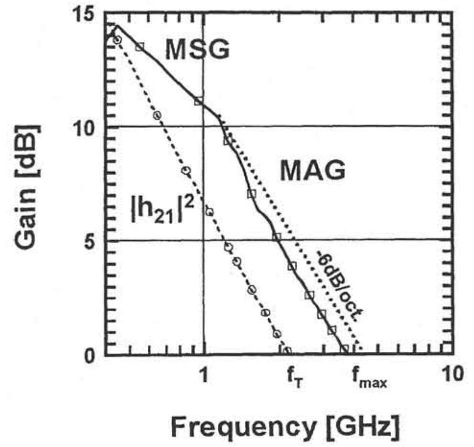

Fig. 3. Current and power gain versus measurement frequency. f_T and f_{max} reaches 2.1 and 4.2 GHz.

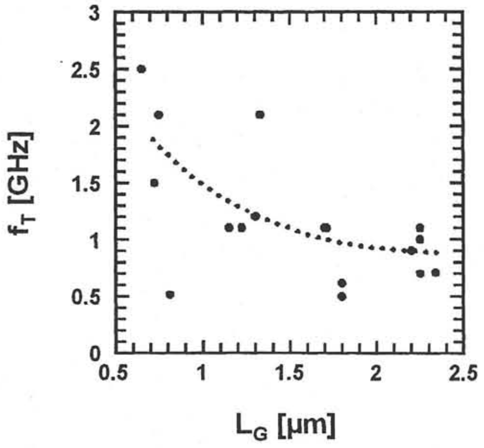

Fig. 4. f_T versus gate length of poly-diamond MISFETs.